Vol. 66 JANUARY 15, 1943 No. 2

JOURNAL OF AGRICULTURAL RESEARCH

CONTENTS

ISSUED BY AUTHORITY OF THE SECRETARY OF AGRICULTURE
WITH THE COOPERATION OF THE ASSOCIATION
OF LAND-GRANT COLLEGES AND
UNIVERSITIES

For Sale by the Superintendent of Documents, Washington, D. C. - See page 2 of cover for prices

Articles for publication in the Journal must bear the formal approval of the chief of the department bureau, or of the director of the experiment station from which the paper emanates. Each manuscript must be accompanied by a statement that it has been read and approved by one or more persons (named) familiar with the subject. The data as represented by tables, graphs, summaries, and conclusions must be approved from the statistical viewpoint by someone (named) competent to judge. All computations should be verified.

Station manuscripts and correspondence concerning them should be addressed to V. R. Gardner, Director, Michigan Agricultural Experiment Station, East Lansing, Mich., who is chairman of the Station subcommittee.

Published with the approval of the Director of the Budget. Issued on the 1st and 15th of each month. This volume will consist of 12 numbers and the contents and index.

Subscription price:

Entire Journal:	Domestic, $3.25 a year (2 volumes)
	Foreign, $4.75 a year (2 volumes)
Single numbers:	Domestic, 15 cents
	Foreign, 20 cents

Articles appearing in the Journal are printed separately and can be obtained by purchase at 5 cents a copy domestic; 8 cents foreign. When purchased in quantity of 100 or more, a reduction of 25 percent in the cost will be made. If separates are desired in quantity, they should be ordered at the time the manuscript is sent to the printer. Address all correspondence regarding subscriptions and purchase of numbers and separates to the Superintendent of Documents, Government Printing Office, Washington, D. C.

JOURNAL OF AGRICULTURAL RESEARCH

VOL. 66 WASHINGTON, D. C., JANUARY 15, 1943 No. 2

EFFECT OF SOIL AND PEAT ADMIXTURES ON THE GROWTH OF PLANTS IN QUARTZ SAND[1]

By PHILIP L. GILE, *senior chemist, Division of Soil and Fertilizer Investigations,* and IRVIN C. FEUSTEL, formerly *associate chemist,*[2] *Division of Soil Chemistry and Physics, Bureau of Plant Industry, Agricultural Research Administration, United States Department of Agriculture*

INTRODUCTION

In a previous publication (*3*)[3] it was shown that millet (*Setaria italica* (L.) Beauv.) does not grow so well in pure quartz sand as in quartz sand to which a little soil is added. Experiments indicated that the beneficial effect of the soil admixture is not due to supplying a trace element, to counteracting an injurious impurity in the sand, to modifying the texture of the sand, or to reducing a total salt injury.

It was suggested that the beneficial effect of the soil is due to its buffer capacity and also to its capacity for supplying available iron. It seemed that the soil admixture should tend to prevent an injurious degree of acidity from developing in the layer immediately contiguous to the roots when the nutrient salts are such that the plant absorbs more cation than anion equivalents. In case the nutrient salts are such that the plant absorbs more anion than cation equivalents, and an alkaline reaction develops, the soil material should reduce the alkalinity and supply available iron.

Since no attempt was made to determine the hydrogen-ion concentration in the water film immediately contiguous to the root, this explanation was not based on data directly determined. The idea was suggested by the results obtained when plants were grown in pure sand with mixtures of salts containing various proportions of nitrate and ammonium salts. As the proportion of ammonium in the fertilizer was increased, the acidity increased, and the yields declined in pure quartz sand but not in the sand-soil mixtures. When all the nitrogen was supplied as nitrate, an alkaline reaction developed in quartz sand, and the plants became chlorotic, owing to a reduced absorption of iron.

Hydrogen-ion determinations made at the end of the growth period on samples representative of all the material in the pot did not always support the conclusion that the soil addition acts beneficially by creating a more favorable hydrogen-ion concentration; since some sand-soil mixtures were more acid than the pure sand cultures. However, it was pointed out that determinations of this character probably do not show the hydrogen-ion concentrations of the absorption films. Since the acidity or alkalinity is developed in the films by the nonequivalent absorption of cations and anions, there should be periods when the hydrogen-ion concentration in the films should be much higher or lower than that obtaining in the medium as a whole.

[1] Received for publication August 6, 1942.

[2] Now senior chemist, Western Regional Research Laboratory, Bureau of Agricultural Chemistry and Engineering, Agricultural Research Administration, U. S. Department of Agriculture.

[3] Italic numbers in parentheses refer to Literature Cited, p. 64.

Since the foregoing explanation was suggested, additional sand-culture experiments have been conducted that throw some light on the beneficial effect of soil admixtures. These experiments are described here.

METHODS

Details regarding the pot experiments were as follows, except as otherwise noted. Glazed earthenware crocks without drainage holes were used as containers. They were of 1-gallon capacity and held approximately 5,000 gm. of quartz sand or sand-soil mixture. Ten millet, or six or seven wheat (*Triticum aestivum* L.), plants were grown per pot for periods that ranged from 25 to 50 days, according to the season. When the millet plants were cut they were in the joint stage or the heads were about to appear. The water content of the sand or sand-soil mixture, determined by weighing, was maintained at 15 percent by the addition of distilled water. The quantity of soil mixed with the sand varied with the colloid content of the soil. Unless specified otherwise, the soil addition was sufficient to supply 50 gm. of colloidal material per pot. The different mixtures of nutrient salts used in the following experiments are shown in table 1. Most data on the effect of soil admixtures were obtained with the standard mixture, No. 3. Nutrient salts, dissolved in 750 cc. of water to bring the sand to a 15-percent water content, were added just before planting. The quartz sand used in the experiments was made up chiefly of particles 1.0 to 0.5 mm. in diameter.

TABLE 1.—*Mixtures of nutrient salts used in sand cultures*

Salt used in nutrient mixture	Amount of salt applied per pot in mixture No.—				
	1	2	3	4	5
	Gram	*Gram*	*Gram*	*Gram*	*Gram*
Potassium nitrate, KNO_3			0.93	0.93	0.499
Ammonium sulfate, $(NH_4)_2SO_4$	0.938		.33		
Ammonium nitrate, NH_4NO_3		0.57		.20	
Calcium nitrate, $Ca(NO_3)_2.4H_2O$					1.103
Potassium sulfate, K_2SO_4		.82			
Potassium chloride, KCl	.685				
Magnesium sulfate, $MgSO_4.7H_2O$				.45	.45
Magnesium chloride, $MgCl_2.6H_2O$	.42	.42	.42		
Monocalcium phosphate, $Ca(H_2PO_4)_2.H_2O$	.36	.36	.36	.36	
Dipotassium phosphate, K_2HPO_4					.25
Monopotassium phosphate, KH_2PO_4					.19
Sodium chloride, NaCl	.05	.05	.05	.05	.05
Ferric tartrate, $Fe_2(C_4H_4O_6)_3.H_2O$	.0185	.0185	.0185	.0185	.0185
Manganese sulfate, $MnSO_4.2H_2O$	.0015	.0015	.0015	.0015	.0015
Boric acid, H_3BO_3	.003	.003	.003	.003	.003
Zinc chloride, $ZnCl_2$	.00013	.00013	.00013	.00013	.00013
Copper sulfate, $CuSO_4.5H_2O$	.00047	.00047	.00047	.00047	.00047

COMPARATIVE YIELDS OF MILLET IN QUARTZ SAND AND IN A SAND-PEAT MIXTURE, AS INFLUENCED BY THE HYDROGEN-ION CONCENTRATION OF THE PEAT

According to the ideas advanced, addition of soil to a quartz sand culture improves growth only through reducing the hydrogen-ion concentration where the nutrient salts are such that acidity is developed. If this is correct, sand-soil mixtures containing nearly neutral soils should exceed the yields of pure sand cultures by greater amounts than sand-soil mixtures containing acid soils of low buffer capacity.

This was true for the most part, although the correlation between the hydrogen-ion concentration of a soil and the magnitude of the increase it produced was by no means close. Probably there would have been a closer correlation if the data for different soils had been obtained in a single experiment instead of in many different experiments, since it was observed that the beneficial effect of a single soil varied considerably in different experiments, owing presumably to different conditions of light, temperature, and humidity.

The following experiment shows that the beneficial effect of the soil admixture may be influenced markedly by the hydrogen-ion concentration of the material. The experiment was conducted with peat, but previous work has shown that peat has the same growth-promoting effect as soil when added to sand cultures. In this experiment the effect of an unlimed moss peat of pH 3.5 was compared with the effects of three lots of the same peat limed some months previously to pH values of 5.0, 5.9, and 6.6. The quantities of calcium hydroxide required to produce these hydrogen-ion concentrations were, respectively, 2.9, 4.3, and 5.3 percent of the weight of peat. Before the peats were mixed with the sand they were ground to pass through a ½-mm. sieve. The nutrient salts applied to the pure sand and the sand-peat mixtures were the standard fertilizer mixture, No. 3 of table 1, used in previous experiments. Millet was grown from April 19 to May 13.

It is evident from the data in table 2 that the effect of peat on growth in sand cultures varied with the degree to which the culture had been neutralized, at least to a limit of about pH 6. If no determinations had been made of the hydrogen-ion concentrations of the cultures before and after growth, it would have seemed obvious that the effect of peat on growth in sand cultures lies in its effect on the hydrogen-ion concentration of the medium. However, the fact that the pure sand cultures before and after growth had the same pH values as the superior culture containing the peat of pH 5.9 seems to indicate that the beneficial effect of the peat does not lie in modifying the hydrogen-ion concentration of the medium.

TABLE 2.—*Effects of peats having different hydrogen-ion concentrations on the yield of millet in quartz sand*

Peat mixed with the sand: Amount (grams)	Peat mixed with the sand: pH	Air-dry yield of individual pots				Average air-dry yield per pot	Hydrogen-ion concentration of medium: At start of experiment	Hydrogen-ion concentration of medium: At end of experiment
		Grams	*Grams*	*Grams*	*Grams*	*Grams*	*pH*	*pH*
0	----------	5.12	4.06	4.42	4.07	4.42	6.3	5.6
5	3.5	2.50	2.80	4.44	3.70	3.36	5.3	4.4
10	3.5	2.28	3.27	1.58	1.80	2.23	4.6	----------
20	3.5	1.35	1.13	1.32	.96	1.19	4.4	----------
40	3.5	.46	.68	.48	.73	.59	4.2	4.4
5	5.0	5.78	5.62	5.15	6.23	5.70	5.9	5.0
10	5.0	5.43	5.82	6.15	5.76	5.79	5.7	----------
20	5.0	5.82	5.87	5.84	5.79	5.83	5.7	----------
40	5.0	5.79	5.56	5.29	5.47	5.53	5.7	5.0
5	5.9	6.50	6.58	6.73	6.65	6.62	6.3	5.4
10	5.9	6.98	6.52	6.60	7.02	6.78	6.0	----------
20	5.9	7.48	6.79	6.85	7.17	7.07	6.0	----------
40	5.9	6.73	6.32	6.92	7.23	6.80	6.0	5.7
5	6.6	6.00	6.10	6.88	5.70	6.17	6.3	5.4
10	6.6	6.34	6.83	5.88	5.99	6.26	6.6	----------
20	6.6	6.79	6.70	7.23	7.34	7.02	6.6	----------
40	6.6	6.93	7.00	6.98	6.21	6.78	6.6	6.1

Similarly contradictory evidence regarding the hydrogen-ion concentration as a factor in the increased growth produced by soil admixtures was obtained in previous work (*3*) with some of the 60 different soils used. This contradiction is disposed of in the explanation outlined in the introduction, on the grounds that the pH values determined at the end of an experiment indicate only the net acidity developed and do not show the acidity or alkalinity obtaining at different times in films contiguous to the roots.

Direct confirmation of the idea that the sand near the roots is different in reaction from the sand in the whole pot was obtained in the experiment with wheat. (See table 9.) After the sand in the whole pot had been sampled, the roots were removed and colorimetric determinations were made of the sand that adhered closely to the roots. This was done by dropping the indicator on a mass of roots and adhering sand. The results are shown in table 3.

TABLE 3.—*Hydrogen-ion concentration of all the sand in a pot and of sand adhering to wheat roots*

Nutrient salt mixture		Hydrogen-ion concentration of—	
No.	Form of nitrogen present	All the sand in a pot	Sand adhering to different lots of roots
		pH	*pH*
1	All as NH_4	4.4	4.2, 4.0
2	½ as NH_4	4.7	4.0, 5.0, 4.2, 4.7
3	⅓ as NH_4	5.2	6.4, 7.6, 8.4, 7.8
4	⅙ as NH_4	6.8	7.5, 8.8
5	All as NO_3	8.6	9.0, 9.2, 8.6

It will be seen that the sand near the roots was in most instances considerably more acid or alkaline than the average sample of the whole pot. Presumably, the microscopic film immediately contiguous to the roots differs from the average sample still more widely in reaction.

The hydrogen-ion determinations made on samples from pots receiving the No. 3 salt mixture are of especial interest. Evidently, here the plants had absorbed most of the ammonia and at the time of examination were drawing more heavily on the nitrates, so that the acidity previously developed was being reduced. Subsequent experiments with wheat and millet indicated that this was the case. A number of pots containing quartz sand and the No. 3 or No. 2 mixture of salts were planted at the same time and harvested at intervals for hydrogen-ion determinations of all the sand in the pot and of sand adhering to roots of the plants. Wheat was grown from December 16 to January 26 and millet from January 26 to March 2. The results are given in table 4.

Column 6 of table 4 gives the pH value for only the greater part of the sand adhering to the roots in a pot. Frequently the sand adhering to individual roots and to certain parts of the same root was ½ to 1 pH unit more acid or alkaline than this "majority" value. Unplanted pots had the same hydrogen-ion concentration at the end of the experiment as at the start.

TABLE 4.—*Hydrogen-ion concentrations developed by wheat and millet at different stages of growth*

Crop	Form of nitrogen present in salt mixtures	Age of plant	Air-dry weight of plants per pot	Hydrogen-ion concentration of—	
				All the sand in a pot	Most sand adhering to roots
		Days	*Grams*	*pH*	*pH*
Wheat	⅓ as NH_4; ⅔ as NO_3	6	----------	6.5	4.8
		21	0.84	6.5	6.3
		27	.87	6.8	7.5
		34	2.19	6.9	7.2
		41	3.35	7.0	7.6
Millet	⅓ as NH_4; ⅔ as NO_3	11	.04	6.9	4.2
		16	.12	6.7	3.9
		21	.47	6.4	4.6
		24	.67	6.2	5.9
		28	1.61	6.3	6.4
		32	3.13	6.5	6.2
		35	5.80	6.3	6.1
Do	½ as NH_4; ½ as NO_3	11	.03	6.9	4.2
		16	.10	6.7	3.9
		21	.36	6.4	4.6
		24	.59	6.2	4.8
		28	1.23	5.9	4.6
		32	2.25	4.8	4.8
		35	4.31	4.8	4.8

From the data in tables 3 and 4 it is concluded (1) that the sand close to the roots may have a hydrogen-ion concentration quite different from that of the whole mass of sand; (2) that the final hydrogen-ion concentration varies with the proportion of nitrate nitrogen to ammonium nitrogen; (3) that when certain proportions of ammonium and nitrate are supplied the hydrogen-ion concentration of the sand, especially that near the roots, varies with the growth of the plant, sometimes shifting from acid to alkaline.

These conclusions are supported by some previous work. Solberg (*8*) found that in quartz sand cultures the sand near the roots was about one-half of a pH unit more acid than sand between roots when nitrogen was supplied as ammonium and one-half of a pH unit more alkaline when nitrogen was supplied as nitrate. These differences are less than those recorded for millet in table 4, but the samples compared are not the same in the two cases. Nightingale (*7*) found that the hydrogen-ion concentration at the surface of apple roots sometimes differed from that of the culture solution by 1 to 2 pH units. The markedly different hydrogen-ion concentrations developed with different proportions of ammonium and nitrate nitrogen (table 3) are in general accord with the data obtained by Trelease and Trelease (*10*) on wheat grown in water cultures containing different proportions of potassium nitrate and ammonium sulfate. The hydrogen-ion concentrations did not vary so widely in the Treleases' culture solutions as in the sand cultures shown in tables 3 and 4, but this difference is probably due to the fact that the water cultures were renewed every 8 days.

Data in table 4, showing a change in reaction from acid to alkaline during the growth period, find only slight confirmation in the Treleases' water-culture data. In their work a reversal in the trend of hydrogen-ion development is shown only by the solution containing 5 parts of ammonium to 95 parts of nitrate, which was tested each day for the last 8-day period. Probably a similar reversal would have been shown by solutions containing a higher proportion of ammonium if the plants had been grown for a longer time in the same solution. With buckwheat grown in a culture solution containing equal proportions of ammonium and nitrate, Stahl and Shive (*9*) observed a pronounced shift from ammonium to nitrate absorption after blossoming. A change conditioned by maturity of the plant, however, would not account for the shift observed in the present studies, since it does not occur in the series grown with one-half of the nitrogen as ammonium and one-half as nitrate. Moreover, the oldest plants were cut when the heads were just starting to emerge.

EFFECT OF CALCIUM CARBONATE AND INCREASED IRON ON YIELD OF MILLET IN QUARTZ SAND

If the poor growth in pure sand with the standard salt mixture is due to acidity resulting from the absorption of more cation than anion equivalents, it might seem possible to correct the condition by an application of calcium carbonate. However, too much calcium carbonate reduces the availability of iron in the quartz sand cultures to such an extent that the plants become chlorotic. The chlorosis can be overcome to some extent by increasing the iron supply, but too much reactive iron reduces the availability of the phosphate until it becomes deficient. Increasing the phosphate in order to maintain an adequate supply tends to lower the availability of the iron. Because of these conditions it may not be possible to produce optimum conditions for growth merely by adding calcium carbonate to the sand cultures.

In the following experiment the standard mixture of nutrient salts, No. 3, was used. The quantity of precipitated calcium carbonate added to the sand cultures was only 0.5 gm. per pot, since previous work (*2*) had shown that 0.8 gm. induced chlorosis. Three quantities of ferric tartrate were tested in conjunction with this application. There were also several other treatments in this experiment. Additional increments of iron were tried with the all-nitrate mixture of salts, No. 5, since diminished growth with these salts in quartz sand was found to be due to a lack of available iron (*3*). In addition to the potassium in the standard salt mixture, potassium chloride was added to some pots, since it was thought possible that the injurious effect of the acidity developed from these salts might lie in diminishing potassium assimilation, as held by Wadleigh and Shive (*11*). If this were the case, increasing the potassium concentration might ameliorate the condition. The treatment with peat of pH 5.0 was installed as a check on the efficacy of the other treatments. In the previous experiment this peat increased the yield markedly. Millet was grown from May 12 to June 4. The results of the experiment are given in table 5.

The increase produced by calcium carbonate with the highest iron application is almost as large as the increase produced by the peat of pH 5.0, and this in turn is about equal to the average increase produced by 46 different soils in 66 comparisons (*3, p. 620*). The results, therefore, support the idea that the beneficial effect of a soil application lies in acting as a buffer and in supplying available iron.

TABLE 5.—*Effect of calcium carbonate, extra iron, and extra potassium on yield of millet in quartz sand*

Substance added to quartz sand			Air-dry yield of individual pots				Average air-dry yield per pot	Relative yield	pH at end of experiment
Nutrient salt mixture[1] No.	Additional compound: Name	Additional compound: Amount							
		Grams	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Percent*	
3	None	----------	3.82	3.40	4.78	4.04	4.38	100	5.9
3	do	----------	4.92	4.76	4.53	4.79			
3	Calcium carbonate	0.5	4.06	5.98	5.00	5.09	5.03	115	7.5
3	do Iron	.5 .037	3.51	5.21	6.78	6.07	5.39	123	7.5
3	Calcium carbonate Iron	.5 .148	6.80	5.35	6.68	6.10	6.23	142	7.5
3	Potassium chloride	.343	4.11	4.72	4.99	4.15	4.49	103	5.2
3	do	.686	3.52	4.05	4.14	3.87	3.90	89	6.5
3	do	1.029	3.94	3.68	4.10	3.58	3.83	87	6.5
3	Peat, pH 5.0	10	6.40	6.68	6.30	--------	6.46	147	4.7
3	Peat Potassium chloride	10 .343	6.00	5.82	5.45	5.62	5.72	131	4.7
5	None	----------	3.31	4.54	3.91	2.60	3.59	82	7.8
5	Iron	.037	5.18	5.15	4.25	4.25	4.71	108	7.5
5	do	.148	4.19	4.41	4.62	3.96	4.30	98	8.0

[1] Nitrogen present in nutrient salt mixtures: In No. 3, ⅓ N as NH_4, and ⅔ N as NO_3; in No. 5, all N as NO_3.

The failure of the extra potassium applications to increase growth indicated that a potassium deficiency is not the cause of reduced growth in the pure sand cultures.

In pots receiving the all-nitrate salt mixture, all plants were markedly chlorotic during early growth, but toward the end of the experiment the color improved considerably and at that time the plants receiving extra iron were an almost normal green. The improved color at the later period when the heads were forming may be connected with an increase in the plants' requirement for potassium as compared with nitrogen, since an increase of this kind, if sufficient, would develop an acid reaction instead of an alkaline one in the absorption zone. The appearance of the plants and the yields indicated that the extra iron applications increased iron assimilation slightly but not to an optimum degree when this mixture of nutrient salts was applied.

COMPARATIVE YIELDS OF MILLET IN QUARTZ SAND AND IN SAND-SOIL OR SAND-PEAT MIXTURES, AS INFLUENCED BY THE WATER CONTENT AND BY FLUSHING

According to the ideas outlined in the introduction, unfavorable conditions for growth in pure sand cultures are developed in the zone of root absorption and do not necessarily obtain throughout the whole medium. It was thought that if the absorption zone could be flushed at intervals with the salt solution draining from the whole pot, growth should be as good in quartz sand as in sand-soil mixtures. The first experiment in which the pots were drained and flushed at intervals is described in the following paragraphs. This experiment was also designed to test an idea that had been expressed that better growth would be obtained in pots provided with drainage holes than in the standard closed crocks.

The pots used in this experiment were especially designed for drainage and held approximately 8,000 gm. of sand. The drainage holes of some pots were stopped with cotton and rubber cement, while the holes of other pots were left open. Half the pots were filled with quartz sand and half with a sand-Marshall soil mixture containing 1 percent of colloidal material. Most pots were maintained at a water content of 15 percent, but water was added to other pots until approximately 500 cc. percolated through. The 500 cc. of percolated solution was added to the pots at the next watering along with sufficient water to again provide a percolate of about 500 cc. For the 15 percent water content, 1,175 cc. of water was required, and for the drained pots, 2,763 cc. of water was required to produce the percolate of 500 cc. The sand and sand-soil mixtures in the drained pots thus held approximately 27 percent of water after drainage. The drained pots were filtered 11 times during the 27 days the experiment lasted. The standard mixture of nutrient salts, No. 3 of table 1, was applied to all pots. The quantity of salts was increased to eight-fifths of the normal quantity, however, since the pots in this experiment held approximately 8,000 gm. of sand instead of the usual 5,000 gm. Millet was grown from September 29 to October 26. The results of the experiment are shown in table 6.

TABLE 6.—*Effect of water content and drainage on yield of millet in quartz sand and a sand-soil mixture*

Material in pots	Kind of pots	Water content	Air-dry yield of individual pots			Average air-dry yield per pot
		Percent	*Grams*	*Grams*	*Grams*	*Grams*
Quartz sand only	No holes	15	6.47	4.48	5.47	5.47
Do	Holes	15	5.74	5.80	5.27	5.60
Do	do	27+	5.76	6.86	7.52	6.71
Sand plus Marshall soil	No holes	15	9.86	10.78	10.01	10.22
Do	Holes	15	10.78	9.90	10.41	10.36
Do	do	27+	9.00	7.56	----------	8.28

It will be seen that the pure quartz sand and the sand-soil mixture, maintained at a water content of 15 percent, gave almost exactly the same yield in closed pots as in pots provided with holes in the bottom. Thus it is evident that the added aeration afforded by drainage holes does not improve growth conditions when the cultures are maintained at a favorable water content. The quartz sand culture flushed with excess water yielded about 20 percent more than the quartz sand of 15 percent water content; whereas the flushed sand-soil mixture yielded about 20 percent less than the same culture with 15 percent of water. The conclusion here is not certain, since the excess-water cultures differed from the standard cultures in three respects: (1) The excess-water cultures contained a less concentrated salt solution than the standard cultures, since the salts were dissolved in 2,763 cc. of water instead of in 1,175 cc.; (2) the pore space in the excess-water cultures remained filled with water after drainage, whereas the pore space in the standard cultures was little more than half filled by water; (3) the excess-water cultures were flushed 11 times during the experiment.

It is believed that in the case of the sand-soil mixtures the slightly poorer growth in the flushed series than in the standard series was due to the second of the differences just mentioned. When the pore space is filled with water the decomposition of organic matter in the soil may be expected to produce unfavorable conditions. In the case of the pure quartz sand cultures, the slightly better growth in the flushed pots is believed to be due to the third difference. The flushing tended to remove the injurious conditions developed by the roots in the zone of absorption.

These conclusions seem little more than guesses when based on the data of this one experiment. They are, however, substantiated by other data. In connection with the results of the following experiment it is important to bear in mind that in this particular experiment any one or all three of the differences mentioned are responsible for only a slightly increased growth in the pure sand cultures.

It was thought that in the foregoing experiment the pots were not flushed frequently enough to maintain the solution in contact with the roots at approximately the same composition as the solution in the whole pot. Two more experiments were conducted in which the flushing was much more frequent.

In these experiments the regular 1-gallon crocks with drainage holes drilled in the bottom were employed. The all-ammonia mixture of nutrient salts, No. 1 of table 1, was used instead of the standard mixture, in order to provide a more severe test of the efficacy of flushing. With this mixture of salts, growth of millet in quartz sand cultures is especially poor, being only about one-fifth of that obtained in good sand-soil or sand-peat mixtures. Automatic flushing was provided by a siphon dripping from a 5-gallon bottle into a Soxhlet tube. The Soxhlet tube emptied 200 cc. of solution into the pot every hour or two. Such a large volume of water was required for flushing with this apparatus that distilled water could not be used without inordinately reducing the salt concentration in the pot; hence a salt solution was used that contained for every 1,400 cc. of water the quantity of salts applied to one pot. The solution was adjusted to pH 5.5 with sodium hydroxide. As a check on the effect of frequent flushing, some pots were made up with 1,400 cc. of water, which was the maximum amount a pot would hold after excess water had been added and allowed to drain away. After the plants had attained some size, these pots were flushed every 2 days with 200 to 500 cc. of the same solution as that applied to the frequently flushed pots. As a check on the efficacy of flushing, a series of pots was installed with a sand-peat mixture. The peat was a commercial material used for soil improvement and had been limed to a pH of 5.5. It was mixed with the sand in the proportion of 25 gm. of peat to approximately 5,000 gm. of sand.

Automatic flushing could not be started until the plants in the sand were about 1½ inches tall and those in the sand-peat mixture were somewhat taller. The effect of flushing the pots as soon as the plants were up was tried, but the solution burned the leaves badly. In the first experiment the plants were grown from October 24 to December 12 and in the second from January 24 to March 17. The greater growth in the second experiment was due to the more favorable light conditions obtaining in the second period. The results of the two experiments are shown in table 7.

TABLE 7.—*Effect of frequent flushing on yield of millet in quartz sand and in a sand-peat mixture*

Material in pots	Water content of pots	First experiment: Air-dry yield of individual pots		First experiment: Average air-dry yield per pot	Second experiment: Air-dry yield of individual pots		Second experiment: Average air-dry yield per pot
		Grams	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*
Quarts sand only	Normal, 15 percent	0.51	0.58	0.55	1.00	1.15	1.08
Do	Occasional flushing	.60		.60	1.37	1.60	1.49
Do	Frequent flushing	2.06		2.06	5.20	4.58	4.89
Sand plus peat	Normal, 15 percent	2.94	3.86	3.40	8.32	8.10	8.21
Do	Frequent flushing	1.66	1.29	1.48	6.45	6.92	6.69

It is apparent from the results shown in tables 6 and 7 that flushing the pots had a very different effect on pure sand cultures from that on sand cultures containing a small amount of soil or peat. Occasional flushing of the sand-soil mixture depressed the yield slightly, and frequent flushing had the same effect. In the pure sand cultures occasional flushing increased the yield only slightly, but frequent flushing increased the yield so markedly that it seems that this treatment may improve growth conditions in somewhat the same way as soil or peat admixtures. The failure of plants in frequently flushed sand to attain the growth made by plants in the sand-peat mixture is doubtless due in part to the fact that flushing could not be started until the plants were 10 or 11 days old. Possibly, also, frequent flushing did not so fully correct conditions as did the peat admixture.

It is felt that the experiments on flushing strongly support the idea that the beneficial effect of soil or peat admixtures on quartz sand cultures lies in correcting adverse conditions that develop in a zone contiguous to the roots.

COMPARATIVE YIELDS OF MILLET IN QUARTZ SAND AND IN A SAND-SOIL MIXTURE, AS INFLUENCED BY THE MECHANICAL COMPOSITION OF THE SAND

The data that have been discussed were obtained with many different lots of quartz sand, but they were all of approximately the same mechanical grade. Two-thirds of the particles were between 1.0 and 0.5 mm. in diameter. It seemed desirable to determine whether the effects of soil admixtures would be more or less pronounced with other grades of sand. An experiment was therefore begun in which coarser and finer grades of sand were compared with the standard grade. The mechanical analyses of the three kinds of sand (table 8) were made by E. F. Miles, of the Bureau of Plant Industry.

In this experiment the standard mixture of nutrient salts was used and the Spearfish soil was applied at a rate to supply 50 gm. of colloid per pot. Millet was grown from November 1 to December 13.

The results of the experiment were not very informative. The fine grade of sand, both with and without the soil admixture, was so compact that the roots penetrated it only slightly. Many of the roots formed later arched out of the sand without the tips penetrating. A mixture of 25 percent of the finer grade and 75 percent of the stand-

TABLE 8.—*Mechanical composition of three grades of quartz sand*

Diameter of particles (mm.)	Particles in sand of indicated grade		
	Coarse	Standard	Fine
	Percent	*Percent*	*Percent*
2+	27.1	0	0
2–1	68.6	16.7	0
1–0.5	3.7	64.8	.2
0.5–0.25	.5	17.4	1.5
0.25–0.1	.1	.9	84.6
0.1–0.05	0	0	13.1
0.05–0.005	0	0	.6

ard grade was likewise too compact for normal root growth. With the standard grade of sand the soil admixture produced the usual increase in growth. The average weight of plants in this pure sand was 1.61 gm. per pot, and in the sand-soil mixture the weight was 2.43 gm. With the coarser grade of sand the effects of the soil admixture were more pronounced. The pure sand yielded 0.51 gm. per pot and the sand-soil mixture 2.14 gm.

The preceding results indicate that the coarser the sand the more beneficial is the addition of soil. However, in the case of the coarse sand it is possible that part of the beneficial effect of the soil was due to improvement in the water-holding capacity of the medium. In the coarse sand without soil the plants wilted somewhat even when the water content was only slightly reduced.

COMPARATIVE YIELDS OF WHEAT IN QUARTZ SAND AND IN A SAND-SOIL MIXTURE, AS INFLUENCED BY THE MIXTURE OF NUTRIENT SALTS APPLIED

Most measurements of the increased yields produced by adding soil to sand cultures were obtained with millet, but apparently the results apply to most plants. Results similar to those shown by millet were observed with rice (*Oryza sativa* L.), white mustard (*Brassica alba* (L.) Boiss.), cotton (*Gossypium* sp.), and dwarf sunflowers (*Helianthus* sp.). Marquis wheat, on the other hand, yielded almost as much in pure quartz sand as in sand-soil mixtures in several experiments, some of which have been published *(5, 6)*.

It was thought probable that this exceptional behavior of wheat was characteristic only of the particular mixture of nutrient salts applied. An experiment was therefore conducted with a series of nutrient salt mixtures in which the source of nitrogen ranged from all nitrogen as ammonia to all nitrogen as nitrate. The composition of these salt mixtures is shown in table 1. Each of the mixtures contained practically the same quantities of nitrogen, phosphorus, potassium, magnesium, sodium, and minor nutrients, but some mixtures contained different quantities of calcium, sulfate, or chlorine. The soil added to one series of pots, at the customary rate of 50 gm. of colloid per 5,000 gm. of sand, was a sample of the Nacogdoches fine sandy loam having a pH value of 6.3. Marquis wheat was grown from December 11 to January 22. The results of the experiment are given in table 9.

Evidently the growth of wheat in sand cultures may be markedly improved by a soil admixture when the nutrient salts contain an undue

Table 9.—*Effect of different nutrient salt mixtures on yield of wheat in quartz sand and in a sand-soil mixture*

Nutrient salt mixture: No.	Form of nitrogen present	Material in pots	Air-dry yield of individual pots				Average air-dry yield per pot	Yield in sand-soil culture as percentage of yield in sand	Hydrogen-ion concentration of medium at—: Start of experiment	End of experiment
			Grams	*Grams*	*Grams*	*Grams*	*Grams*	*Percent*	*pH*	*pH*
1	All as NH_4	Sand only	1.05	0.80	0.80	0.83	0.87	100	6.0	4.4
2	½ as NH_4	Sand only	2.48	2.32	2.33	2.01	2.29	100	6.0	4.7
3	⅓ as NH_4	Sand only	2.37	2.27	2.37	2.11	2.28	100	6.0	5.2
4	⅙ as NH_4	Sand only	2.75	2.60	2.43	2.76	2.64	100	6.0	6.8
5	All as NO_3	Sand only	1.72	1.95	1.82	2.15	1.91	100	6.7	8.6
1	All as NH_4	Sand plus soil	2.20	2.13	1.96	1.92	2.05	236	6.0	4.6
2	½ as NH_4	Sand plus soil	2.82	2.40	2.98	2.64	2.71	118	6.0	5.0
3	⅓ as NH_4	Sand plus soil	2.21	2.42	2.53	2.58	2.44	107	6.0	5.8
4	⅙ as NH_4	Sand plus soil	2.28	2.44	2.60	2.72	2.51	95	6.0	6.5
5	All as NO_3	Sand plus soil	2.27	2.68	2.77	2.01	2.43	127	6.0	7.6

proportion of either essential cations or anions, as in the case of the all-ammonium and all-nitrate mixtures. But when the standard salt mixture No. 3 was used, the increase produced by soil was only 7 percent in this experiment, and in seven other comparisons involving four different soils the average increase was 9 percent. On the whole, wheat seems less sensitive than millet to conditions in quartz sand, for when the No. 3 salt mixture is used a soil admixture usually increases the growth of millet about 50 percent. And the increases produced in wheat by the application of soil with the other salt mixtures are smaller than those usually produced in millet under similar conditions.

Although wheat seems more tolerant than millet or rice of conditions obtaining in quartz sand cultures, it seems to alter the hydrogen-ion concentration of the medium to about the same extent as millet or rice, as shown by table 10.

Table 10.—*Hydrogen-ion concentration of quartz sand after growth of millet, wheat, and rice with different nutrient salts*

Nutrient salt mixture: No.	Form of nitrogen present	Hydrogen-ion concentraton of quartz sand after growth of—: Millet	Wheat	Rice
		pH	*pH*	*pH*
1	All as NH_4	3.8	4.4	----------
2	½ as NH_4	4.3	4.7	4.4
3	⅓ as NH_4	5.5	5.2	5.5
4	⅙ as NH_4	5.8	6.8	7.3
5	All as NO_3	7.1	8.6	----------

This comparison is not conclusive since the data are the results of single experiments and the hydrogen-ion concentrations developed by millet have been found to vary considerably in experiments conducted at different times. Presumably all conditions that affect the ash composition of the crops would affect the hydrogen-ion concentrations developed. It seems probable, however, from the data at hand, that modifications in the hydrogen-ion concentrations produced by the growth of wheat are not widely different from those produced by millet and rice.

RECAPITULATION OF EVIDENCE CONCERNING THE BENEFICIAL EFFECT OF SOIL ADMIXTURES IN QUARTZ SAND CULTURES

The experimental results reported in this and a previous publication (*3*) strongly support the explanation that has been given for the beneficial effect of adding soil to a quartz-sand culture. The general features of the explanation are that in pure quartz sand an unfavorable hydrogen-ion concentration is developed, owing to a nonequivalent absorption of cations and anions; that the soil admixture improves growth by acting as a buffer to the hydrogen-ion concentration developed; and that the soil also supplies available iron. A recapitulation of evidence bearing on these assumptions follows.

That the roots develop a hydrogen-ion concentration owing to the nonequivalent absorption of nutrient cations and anions was shown by experiments conducted with millet (*3*) and wheat in quartz sand. In these experiments mixtures of nutrient salts containing different proportions of ammonium and nitrate ions were compared. When nitrogen was supplied exclusively as ammonium ions, the quartz sand became plainly too acid for the best growth; and when nitrogen was supplied exclusively as nitrate, the sand became plainly too alkaline, since the plants became chlorotic, owing to an insufficient absorption of iron. When one-third of the nitrogen was supplied in the form of ammonium and two-thirds as nitrate, as in the standard salt mixture, the sand was somewhat more acid at the end of growth than at the beginning. But the acidity developed was not sufficient to curtail growth markedly, if one judged by the hydrogen-ion concentration of all the sand in a pot before and after an experiment. In fact, some sand-soil mixtures were more acid than the pure quartz sand cultures at both times of examination.

However, examination at intervals during growth of sand adhering to the roots showed that, when the standard salt mixture is used, sand close to the roots may be highly acid during early growth and nearly neutral to alkaline during later growth. It appeared, therefore, that hydrogen-ion determinations of all the sand in a pot at the start and end of an experiment showed only the net acidity or alkalinity developed, and not the conditions affecting the roots at any time. Even when the hydrogen-ion concentration of the whole pot is near the optimum, the hydrogen-ion concentration very near the roots may be unfavorable a considerable part of the time.

The difference between conditions obtaining near the roots and throughout the pot is indicated also by the appearance of the plants. Usually the poorer growth of millet in quartz sand than in sand-soil mixtures is apparent when the plants are very small, only 1 to 2 inches tall. At this stage of growth the sand in the pot as a whole could have been altered little by the plants' absorption of ions. In a zone close to the roots, however, the reaction developed could be as unfavorable as that shown by the whole pot at the end of growth when nitrogen is supplied exclusively as ammonium or as nitrate.

Further evdence that in sand cultures an unfavorable condition may develop near the roots is provided by the flushing experiments. When the pots were flushed every 2 to 3 hours, growth was markedly improved in the sand cultures but slightly depressed in the sand-soil and sand-peat mixtures. When the sand cultures were flushed every other day, there was only slight improvement in growth. These facts are in accord with the idea that the unfavorable conditions in sand cultures are strongly localized and develop quickly.

That the soil admixture improves growth by acting as a buffer to the hydrogen-ion concentrations developed is shown by several experiments, most of which are reported in a previous publication (*3*). When the standard salt mixture developing moderate acidity was used, growth in quartz sand was improved by such diverse materials as a neutralized sodium silicate, a ferric oxide gel, activated charcoals, samples of peat having pH values above 5.0, and calcium carbonate plus ferric tartrate. All of these materials had greater or less buffer capacities, especially against acid.

That the capacity of the soil for supplying iron is also concerned in the beneficial effect of soil additions, especially when an alkaline reaction is developed, is indicated by two facts. (1) When an all-nitrate salt mixture was applied to quartz sand, the plants became chlorotic, owing to an iron deficiency. This condition was partly corrected by adding extra iron to the sand. In the soil-sand culture the plants were green and were not improved by additional iron. (2) When a small amount of calcium carbonate was added to quartz sand fertilized with the standard mixture, growth was improved by only 15 percent; but calcium carbonate and extra iron together increased growth by 42 percent.

DISCUSSION

The results obtained in this study emphasize some of the important differences in soil, water, and sand cultures. In a soil culture the solution at the start may be quite different from the salt solution originally supplied, owing to reactions with the colloidal material. This applies particularly to concentrations of hydrogen and phosphate ions. And, since the salt solution is not renewed, it should change with the growth of the plants, except as it is stabilized by the soil colloids. The solution in contact with the roots should be somewhat different from that in the medium as a whole, owing to absorption by the roots, but creation of differences in the root zones is opposed by the colloidal material.

In a water culture, the solution in the container should at the start be the same as that originally supplied, and it should alter little with growth of the plants if the solution is frequently renewed. Also, the solution in contact with the roots should be practically the same as all the solution in the container, particularly if the solution is agitated by aeration. However, there is reason for believing that the solution in the absorption zone of roots may differ from that in the body of the container in the case of water cultures in which precipitates form and adhere to the roots.

Some conditions in a quartz sand culture are midway between those obtaining in water and soil cultures and some are more extreme. In a pure quartz sand culture the solution at the start should, as in a water culture, be the same as that originally supplied. Since the solution is not renewed and is not buffered by a reactive material, it should alter with the growth of the plants more than the solution in a soil culture. Also, the solution in immediate contact with the roots should differ from that in the whole container more markedly than in the case of soil or water cultures.

This difference between the solution in the whole container and in the absorption zone varies with the rate of diffusion from and into the absorption zone. It should also vary with the kind of plant and the composition of the nutrient solution. If a plant absorbed equivalent amounts of the nutrient cations and anions, the hydrogen-ion concentration of the absorption zone would remain neutral or the same as that in the container as a whole. The most pronounced changes in the reaction of the absorption zone are brought about by varying the proportions of ammonium and nitrate ions, since this involves a change in one of the major nutrients absorbed from cation to anion. Other differences in the composition of the nutrient solution should have comparatively little effect on the reaction developed by absorption, since no other major nutrient can be supplied as either cation or anion.

It might be supposed that in sand cultures any hydrogen-ion concentration between pH 4 and 7 could be attained by properly apportioning the nitrogen between ammonium and nitrate ions. This is approximately true for the reaction of the whole medium at the end of a growth period, provided the nitrogen supply is largely utilized. It does not seem to apply, however, to sand close to the roots. Near millet and wheat roots the reaction of the sand may vary between early and later growth from markedly acid to nearly neutral or alkaline, when certain proportions of ammonium and nitrate ions are supplied; when other proportions of ammonium and nitrate are supplied the reaction may remain strongly acid during the whole period. The early acidity developed is doubtless due to the fact that most plants, especially young ones, absorb ammonium ions more rapidly than nitrate. The shift from acidity to alkalinity that sometimes occurs is probably due to a depletion of the ammonium ions.

Even the reaction of the whole culture at the end of a growth period cannot be accurately controlled by varying the proportions of ammonium to nitrate unless the total application of nitrogen is adjusted to growth conditions. Hydrogen-ion determinations have been made on all the sand in a pot after growth of the plants in 14 experiments conducted at different times of the year. In all experiments the same quantity of the 1/3-ammonium, 2/3-nitrate salt mixture was applied. The hydrogen-ion concentrations ranged from pH 4.5 to 6.2 in different experiments, and were closely correlated with the dry weights of the crop. The more acid reactions were obtained in experiments where the growth was less.

It is not certain that a root zone maintained in a wholly neutral condition would be especially favorable for growth. Under such conditions the plants might suffer from an iron deficiency. When water cultures are kept nearly neutral, special procedures have to be followed to keep the plants supplied with available iron. One procedure is to grow the plants part of the time in a phosphate-free solution, where the iron is more available. Another method is to supply the iron in organic form as ferric tartrate or ferric citrate. The solution, however, should be renewed frequently, since the iron does not remain available long even when supplied in these forms. The ferric tartrate dissolves under the influence of sunlight into a ferrous form that reacts with potassium ferricyanide, but as the solution is aerated the iron is precipitated as ferric hydroxide. A third method that has been followed by Von der Crone (*1*) and Zinzade (*12*) is to supply a large amount of iron as ferric phosphate.

It is probably not sufficiently appreciated that the reaction developed where the root is absorbing may be quite different from that of the medium as a whole. It was found by one of the authors years ago that pineapples and rice became chlorotic owing to lack of available iron in calcareous soils but did not become chlorotic in soils rendered alkaline with sodium bicarbonate (*4*). This discrepancy was not explained at the time. Since the nitrogen in these experiments was supplied as ammonium sulfate, it is probable that the plants developed sufficient acidity in the absorption zone to neutralize the sodium bicarbonate in that zone and render iron available, but not sufficient acidity to neutralize the calcium carbonate in contact with the roots. Possibly this theory may explain some of the exceptions found in the distribution of acid-loving plants.

SUMMARY

In a previous publication (*3*) it was shown that millet does not grow so well in pure quartz sand as in quartz sand to which a little soil has been added. How the soil admixture improves growth was not shown with certainty. An answer to this question is provided by data reported in the present paper.

The beneficial effect of a soil admixture with quartz sand appears to be due to the buffer capacity of the soil and to its capacity for supplying iron.

In pure quartz sand unfavorable hydrogen-ion concentrations may develop, owing to the nonequivalent absorption of cations and anions. If the nutrient salts contain all the nitrogen in the form of ammonium, the sand becomes markedly acid; and if the nitrogen is applied exclusively as nitrate, the sand becomes alkaline or so nearly neutral that absorption of iron is inhibited. If nitrogen is supplied partly as ammonium and partly as a nitrate, the reaction is markedly acid at first, owing to ammonium ions being absorbed more rapidly than nitrate ions; later, the reaction developed may be nearly neutral or alkaline if the ammonium ions are sufficiently depleted. This occurred in experiments in which a salt mixture was used that contained one-third of the nitrogen as ammonium and two-thirds as nitrate. In this case hydrogen-ion determinations made on all the sand in a pot at the end of growth showed only the net acidity developed and did not show conditions existing near the root at different times during growth. Sand adhering to the roots may differ widely in reaction from all the sand in a pot. In sand cultures containing soil admixtures, the development of unfavorable reactions in the zone of root absorption is opposed by the soil colloids. The soil colloids may also improve growth by supplying iron in case a nearly neutral or alkaline reaction is developed.

Differences in soil, sand, and water cultures as mediums for growth are pointed out, and the importance of considering the hydrogen-ion concentration of the zone contiguous to the root, rather than that of the whole medium, is emphasized.

LITERATURE CITED

(1) CRONE, G. VON DER.
1904. ERGEBNISSE VON UNTERSUCHUNGEN ÜBER DIE WIRKUNG DER PHOSPHORSAÜRE AUF DIE HÖHERE PFLANZE UND EINE NEUE NÄHRLÖSUNG. 46 pp. Bonn. (Inaug. Diss.)

(2) Gile, P. L.
1933. THE EFFECT OF DIFFERENT COLLOIDAL SOIL MATERIALS ON THE EFFICIENCY OF SUPERPHOSPHATE. U. S. Dept. Agr. Tech. Bul. 371, 50 pp., illus.

(3) ———
1939. GROWTH OF MILLET IN QUARTZ SAND AND IN SAND-SOIL MIXTURES. Jour. Agr. Res. 59: 619–633.

(4) ——— and Carrero, J. O.
1920. CAUSE OF LIME-INDUCED CHLOROSIS AND AVAILABILITY OF IRON IN THE SOIL. Jour. Agr. Res. 20: 33–62, illus.

(5) ——— and Lakin, H. W.
1941. EFFECT OF DIFFERENT SOIL COLLOIDS ON THE TOXICITY OF SODIUM SELENITE TO MILLET. Jour. Agr. Res. 63: 559–581.

(6) ——— Lakin, H. W., and Byers, H. G.
1938. EFFECT OF DIFFERENT SOIL COLLOIDS AND WHOLE SOILS ON THE TOXICITY OF SODIUM SELENATE TO MILLET. Jour. Agr. Res. 57: 1–20, illus.

(7) Nightingale, G. T.
1934. AMMONIUM AND NITRATE NUTRITION OF DORMANT DELICIOUS APPLE TREES AT 48° F. Bot. Gaz. 95: 437–452.

(8) Solberg, P.
1935. UNTERSUCHUNGEN ÜBER DIE WURZELAUSSCHEIDUNGEN VERSCHIEDENER PFLANZEN BEI IHRER KULTURE OHNE UND MIT ZUSATZ VON NÄHRSALZEN. Landw. Jahrb. 80: 891–917, illus.

(9) Stahl, A. L., and Shive, J. W.
1933. FURTHER STUDIES ON NITROGEN ABSORPTION FROM CULTURE SOLUTIONS: II. BUCKWHEAT. Soil Sci. 35: 469–483, illus.

(10) Trelease, S. F., and Trelease, H. M.
1935. CHANGES IN HYDROGEN-ION CONCENTRATION OF CULTURE SOLUTIONS CONTAINING NITRATE AND AMMONIUM NITROGEN. Amer. Jour. Bot. 22: 520–542, illus.

(11) Wadleigh, C. H., and Shive, J. W.
1939. BASE CONTENT OF CORN PLANTS AS INFLUENCED BY PH OF SUBSTRATE AND FORM OF NITROGEN SUPPLY. Soil Sci. 47: 273–283.

(12) Zinzade, S. R.
1927. NEUE NORMALE NÄHRLÖSUNGEN MIT STABILER REAKTION (PH) WÄHREND DER VEGETATIONSPERIODE. Landw. Vers. Sta. 105: [267]–332, illus.

504160—43——2