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THE EFFECT OF ONE ELEMENT OF PLANT FOOD UPON THE ABSORPTION BY PLANTS OF ANOTHER ELEMENT

By J. F. Breazeale

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*In coöperation with United States Department of Agriculture, Bureau of Plant Industry.

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THE EFFECT OF ONE ELEMENT OF PLANT FOOD UPON THE ABSORPTION BY PLANTS OF ANOTHER ELEMENT

By J. F. Breazeale

INTRODUCTION

It is well known that if two or more fertilizer salts, sodium nitrate and potassium sulphate, for example, are mixed and added to the soil, the percentage increase in crop yields is usually larger than that obtained from the combined effects of single-salt applications. If an application of sodium nitrate alone gives an increase in yield of 10 percent, and an application of potassium sulphate alone gives an increase of 10 percent upon different plants of the same kind in the same soil, a mixture of the two, when made in a single application, sometimes gives an increase of 100 percent in crop yield. It has been noticed often that negative or unprofitable results with single salts, especially with potash, may be changed into positive and highly profitable results by combining the potash with other plant foods.

Much field work with pot-culture experimentation has been done in recent years along this line. Many of these results are open to criticism, many are contradictory, and the data are so voluminous that it is almost impossible to review the work properly. As this bulletin deals with solution cultures only, and, as the problem under consideration has been investigated in a manner that is different from the methods employed by others, it is submitted without a review of the literature. It must be emphasized that the results were obtained with wheat plants in the seedling stage and no effort has been made to correlate the behavior of the seedlings with that of the mature plant.

ADVANTAGES IN USING SOLUTION CULTURES

So many factors, such as adsorption or replacement, come into play when salts are added to the soil that in field tests and in pot cultures it is practically impossible to maintain in the soil solution a definite concentration of plant food readily available to the plant. In studying the effect of one salt containing a certain element of plant food upon the absorption of another element it was thought necessary to use water cultures exclusively. As these experiments have a direct bearing upon the application of commercial fertilizers, and as the plant-food constituents in fertilizers are nearly always expressed in terms of nitrogen, N, potash, K_2O, and phosphoric acid P_2O_5, this system will be followed in the following discussion.

EXPERIMENTS WITH SALTS CONTAINING NUTRIENT ELEMENTS

The absorption of nutrient elements by the plant was studied under five different conditions: first, with a scarcity or minimum of plant food, 10 parts per million each of nitrogen, potash, and phosphoric acid; second, with an abundance or maximum of plant food, 200 parts per million each of nitrogen, potash, and phosphoric acid; third, with a medium amount, i. e., 80 parts per million each of nitrogen, potash, and phosphoric acid; fourth, with a minimum amount of one of these elements in the presence of maximum amounts of the other two; and, fifth, with a maximum amount of one of these elements in the presence of minimum amounts of the other two. The effect of calcium sulphate, upon the absorption of nitrogen, potash, or phosphoric acid was also determined.

Wheat seedlings were sprouted upon perforated aluminum discs floating in large pans of water, and when the plumule had reached a length of about 1 cm. they were transplanted to other aluminum discs floating in the nutrient solution and placed under observation. With the lower concentrations the solutions were changed once or twice every day in order to have plant food always available, but with the higher concentrations a change every 1 or 2 days was found to be sufficient. The entire set was run in duplicate at different times and many individual determinations were made in triplicate or repeated many more times.

The variations of seedlings in culture work, even under trained hands, is sometimes very great. There are many ways of partially overcoming this variation which cannot be mentioned here. The author has adopted the plan of running each series over and over again until he is confident of the results. The more or less unavoidable variations shown in the tables may seem a little large to those who have never attempted seedling work, but it must be understood that it is impossible to get absolutely uniform results with plants.

As so many determinations were made at different times, under different conditions, and with different varieties of wheat, the figures shown in one table are not necessarily comparable with those shown in the next, but the results in each table are always comparable.

In the water cultures the nitrogen was derived from sodium nitrate, the potash from potassium sulphate, and the phosphoric acid from sodium phosphate.

EFFECT OF POTASH, PHOSPHORIC ACID, AND GYPSUM UPON THE ABSORPTION OF NITROGEN

In Table I are shown the analyses of 100 plants, grown with a minimum amount of nitrogen alone and together with minimum amounts of potash, phosphoric acid, and gypsum.

TABLE I.—EFFECT OF MINIMUM AMOUNTS OF K_2O, P_2O_5, AND $CaSO_4$ UPON THE ABSORPTION OF NITROGEN PRESENT IN MINIMUM AMOUNTS.

	100 plants	
	Dry weight grams	Nitrogen grams
1. Control, distilled water	2.90	.0490
2. 10 p.p.m nitrogen alone	3.50	.1036
3. 10 p.p.m. nitrogen with 10 p.p.m. K_2O	3.90	.1022
4. 10 p.p.m. nitrogen with 10 p.p.m. P_2O_5	3.20	.0980
5. 10 p.p.m. nitrogen with 10 p.p.m. $CaSO_4$	3.20	.0960

The variations in the nitrogen determinations are well within the limit of experimental error, in fact, in duplicate sets the nitrogen in numbers 3, 4, and 5 were found to vary as often above No. 2 as below it. There is no indication from these data that the absorption of nitrogen is affected by the presence of the other plant foods.

TABLE II.—EFFECT OF MAXIMUM AMOUNTS OF POTASH, PHOSPHORIC ACID, AND GYPSUM UPON THE ABSORPTION OF NITROGEN PRESENT IN MAXIMUM AMOUNTS.

	100 plants	
	Dry weight grams	Nitrogen grams
1. Control, distilled water	2.90	.0490
2. 200 p.p.m. nitrogen alone	3.50	.1148
3. 200 p.p.m. nitrogen with 200 p.p.m. K_2O	3.80	.1125
4. 200 p.p.m. nitrogen with 200 p.p.m. P_2O_5	3.10	.0900
5. 200 p.p.m. nitrogen with 200 p.p.m. $CaSO_4$	3.60	.1204

There is no indication from these data that the presence of potash, phosphoric acid, or gypsum, in maximum amounts appreciably affects the absorption of nitrogen.

TABLE III.—EFFECT OF MEDIUM AMOUNTS OF POTASH, PHOSPHORIC ACID, AND GYPSUM UPON THE ABSORPTION OF NITROGEN PRESENT IN MEDIUM AMOUNTS

	100 plants	
	Dry weight grams	Nitrogen grams
1 Control, distilled water	5.10	0700
2. 80 p p m. nitrogen alone	5.40	1966
3. 80 p p m. nitrogen with 80 p p m K_2O	5.50	.1596
4. 80 p p m. nitrogen with 80 p p m P_2O	5.30	1708
5. 80 p p m. nitrogen with 80 p p m $CaSO_4$	4.30	1540

In this set of determinations, No. 2 with nitrogen alone seems to be somewhat higher than the others, but duplicate determinations indicate that this value is relatively high and a similar set run a few months before showed a nitrogen content of .1134, .0966, .1036, and .1148 for Nos. 2, 3, 4, and 5 respectively. There is no reason to believe that the presence of potash, phosphoric acid, or gypsum in medium amounts influences the absorption of nitrogen.

TABLE IV.—EFFECT OF MAXIMUM AMOUNTS OF POTASH, PHOSPHORIC ACID, AND GYPSUM UPON THE ABSORPTION OF NITROGEN PRESENT IN MINIMUM AMOUNTS

	100 plants	
	Dry weight grams	Nitrogen grams
1 Control, distilled water	5.68	1092
2. 10 p p m nitrogen, alone	5.68	2016
3 10 p p m. nitrogen with 200 p p m K_2O	6.70	1800
4. 10 p p m nitrogen with 200 p p m P_2O_5	5.40	2072
5 10 p p m nitrogen with 200 p p m $CaSO_4$	6.00	1988

In this case as in the others, the absorption of nitrogen was not influenced by the other salts.

TABLE V.—EFFECT OF MINIMUM AMOUNTS OF POTASH, PHOSPHORIC ACID, AND GYPSUM UPON THE ABSORPTION OF NITROGEN, PRESENT IN MAXIMUM AMOUNTS

	100 plants	
	Dry weight grams	Nitrogen grams
1 Control, distilled water	5.10	0700
2. 200 p p m nitrogen, alone	4.72	1660
3 200 p p m nitrogen with 10 p p m K_2O	5.50	1764
4 200 p p m nitrogen with 10 p p m P_2O_5	4.80	1792
5 200 p p m nitrogen with 10 p p m $CaSO_4$	4.80	1708

As with the other experiments, these determinations showed no significant differences. The results shown in the preceding five tables indicate that maximum, minimum, or medium amounts of potash, phosphoric acid, or gypsum do not materially affect the absorption of nitrogen, for in all cases tried whether with a minimum, medium, or maximum amount of nitrogen, plant absorption does not seem to be changed materially by the other salts.

The relation of the seedling to nitrogen is especially interesting. Whether present in maximum or minimum amounts, or in the absence or presence of other plant foods or moderate amounts of alkali, the seedling absorbs this element, as if the other substances were absent. The total amount of nitrogen absorbed by the plant, if grown to maturity, will be affected by the size of the plant and this will be determined largely by the limiting factor whatever it may be. In case there is a deficiency of other plant foods in the soil or solution, this fact may limit the development of the plant and thus indirectly affect the absorption of nitrogen. In these experiments, the potash and phosphoric acid were not limiting factors.

These results show that the absorption of nitrogen is not sufficiently affected by other factors such as concentration of the nutrient solution, the presence of a moderate amount of alkali, etc., which may play such an important part in the absorption of the other plant foods.

EFFECT OF NITROGEN, POTASH, AND GYPSUM UPON THE ABSORPTION OF PHOSPHORIC ACID

A set of cultures similar to those described above was carried on with phosphoric acid. The results are shown in Tables VI to X.

TABLE VI—EFFECT OF MINIMUM AMOUNTS OF NITROGEN, POTASH, AND GYPSUM UPON THE ABSORPTION OF PHOSPHORIC ACID, PRESENT IN MINIMUM AMOUNTS

		100 plants	
		Dry weight grams	P_2O_5 grams
1	Control, distilled water	5 70	0340
2	10 p p m P_2O_5 alone	5 80	0510
3	10 p p m P_2O_5 with 10 p p m N	5 60	0640
4	10 p p m P_2O_5 with 10 p p m K_2O	6 20	0570
5	10 p p m P_2O_5 with 10 p p m $CaSO_4$	5 90	0500

TABLE VII.—EFFECT OF MAXIMUM AMOUNTS OF NITROGEN, POTASH, AND GYPSUM UPON THE ABSOPTION OF PHOSPHORIC ACID, PRESENT IN MAXIMUM AMOUNTS.

	100 plants	
	Dry weight grams	P_2O_5 grams
1. Control, distilled water	2.90	.0250
2. 200 p.p.m. P_2O_5 alone	3.40	.0400
3. 200 p.p.m. P_2O_5 with 200 p.p.m. N.	3.10	.0400
4. 200 p.p.m. P_2O_5 with 200 p.p.m. K_2O	4.15	.0490
5. 200 p.p.m. P_2O_5 with 200 p.p.m. $CaSO_4$	3.60	.0410

TABLE VIII.—EFFECT OF MEDIUM AMOUNTS OF NITROGEN, POTASH, AND GYPSUM UPON THE ABSORPTION OF PHOSPHORIC ACID, PRESENT IN MEDIUM AMOUNTS.

	100 plants	
	Dry weight grams	P_2O_5 grams
1. Control, distilled water	5.10	.0360
2. 80 p.p.m. P_2O_5 alone	4.30	.0540
3. 80 p.p.m. P_2O_5 with 80 p.p.m. N.	4.30	.0630
4. 80 p.p.m. P_2O_5 with 80 p.p.m. K_2O	4.50	.0460
5. 80 p.p.m. P_2O_5 with 80 p.p.m. $CaSO_4$	4.10	.0550

TABLE IX.—EFFECT OF MAXIMUM AMOUNTS OF NITROGEN, POTASH, AND GYPSUM UPON THE ABSORPTION OF PHOSPHORIC ACID, PRESENT IN MINIMUM AMOUNTS.

	100 plants	
	Dry weight grams	P_2O_5 grams
1. Control, distilled water	5.10	.0360
2. 10 p.p.m. P_2O_5 alone	4.80	.0500
3. 10 p.p.m. P_2O_5 with 200 p.p.m. N.	4.70	.0490
4. 10 p.p.m. P_2O_5 with 200 p.p.m. K_2O	5.60	.0510
5. 10 p.p.m. P_2O_5 with 200 p.p.m. $CaSO_4$	4.90	.0420

TABLE X.—EFFECT OF MINIMUM AMOUNTS OF NITROGEN, POTASH, AND GYPSUM UPON THE ABSORPTION OF PHOSPHORIC ACID, PRESENT IN MAXIMUM AMOUNTS.

	100 plants	
	Dry weight grams	P_2O_5 grams
1. Control, distilled water	5.10	.0360
2. 200 p.p.m. P_2O_5 alone	5.00	.0530
3. 200 p.p.m. P_2O_5 with 10 p.p.m. N.	5.10	.0694
4. 200 p.p.m. P_2O_5 with 10 p.p.m. K_2O	5.00	.0520
5. 200 p.p.m. P_2O_5 with 10 p.p.m. $CaSO_4$	5.10	.0580

There seems to be a slight tendency for the absorption of phosphoric acid to be stimulated by the presence of nitrogen and not to be particularly stimulated by the presence of other plant foods. In probably 80 percent of the trials, the presence of nitrogen increased the absorption of phosphoric acid. In Table VII, for example, a duplicate carried on at a different time, gave .0590 and .0650 grams of P_2O_5 for Nos. 2 and 3 respectively, giving an increase instead of a slight decrease as shown in the table. The presence of potash did not seem to affect materially the absorption of phosphoric acid. A lower absorption was usually obtained when a maximum amount of gypsum was added to a minimum amount of phosphoric acid, due probably to the precipitation of part of the phosphates. The addition of a minimum amount of gypsum, 10 p.p.m, to a maximum amount of phosphoric acid, 200 p.p.m., usually produced a stimulating effect, as shown in Table XI.

TABLE XI.—EFFECT OF MAXIMUM AND MINIMUM AMOUNTS OF GYPSUM UPON THE ABSORPTION OF PHOSPHORIC ACID, PRESENT IN MAXIMUM AND MINIMUM AMOUNTS.

	100 plants	
	Dry weight grams	P_2O_5 grams
1. 200 p.p.m. P_2O_5	2.90	.0530
2. 200 p.p.m. P_2O_5 with 10 p.p.m. $CaSO_4$	2.42	.0610
3. 10 p.p.m. P_2O_5	3.12	.0432
4. 10 p.p.m. P_2O_5 with 200 p.p.m $CaSO_4$	2.92	.0260

The data shown in Table XI will probably be of interest to those interested in the much-discussed problem in fertilizer practice—the effect of lime upon land fertilized by an application of superphosphate. It may be said safely that the presence of soluble calcium in the soil will tend to decrease the solubility of the phosphates added as fertilizers.

EFFECT OF NITROGEN, POTASH, AND PHOSPHORIC ACID UPON THE ABSORPTION OF CALCIUM

Calcium sulphate was also used in a complete set of cultures similar to those carried out with nitrogen and phosphoric acid. These data indicate that the absorption of calcium is not stimulated by the presence of either nitrogen, potash, or phosphoric acid. As in the case, when the absorption of phosphoric acid was reduced by the presence of an excess of gypsum, the absorption of calcium, when added in small amounts to the solution, was reduced to a minimum by the presence of an excess of phosphoric acid, due to the precipitation of the lime as a slightly soluble salt.

EFFECT OF NITROGEN, PHOSPHORIC ACID, AND GYPSUM UPON THE ABSORPTION OF POTASH

A set of experiments similar to those described under nitrogen and phosphoric acid was carried out with potash, and the results are given in the following tables:

TABLE XII.—EFFECT OF MINIMUM AMOUNTS OF NITROGEN, PHOSPHORIC ACID, AND GYPSUM UPON THE ABSORPTION OF POTASH, PRESENT IN MINIMUM AMOUNTS.

	100 plants	
	Dry weight grams	K_2O grams
1. Control, distilled water	3.80	.0279
2. 10 p.p.m. K_2O alone	4.50	.0888
3. 10 p.p.m. K_2O with 10 p.p.m. N.	4.60	.2087
4. 10 p.p.m. K_2O with 10 p.p.m. P_2O_5	4.70	.1187
5. 10 p.p.m. K_2O with 10 p.p.m. $CaSO_4$	4.50	.0962

It will be seen from the foregoing table that the absorption of potash is affected in a very marked degree by the presence of other plant foods, particularly nitrogen. By subtracting No. 1, the control which was grown in distilled water and, therefore, had no more potash than the original seeds, from No. 2, the potash alone, we find an absorption of .0609 gram of K_2O from the solution. By subtracting the control from No. 3, the potash and nitrogen culture, we find an absorption of .1808 gram of K_2O, or an increase of about 300 percent. This phenomenon will be observed in every case where nitrogen was added to the nutrient solution with potash. The other plant foods usually increased absorption, but seldom in such a striking manner as did nitrogen.

TABLE XIII.—EFFECT OF MAXIMUM AMOUNTS OF NITROGEN, PHOSPHORIC ACID, AND GYPSUM UPON THE ABSORPTION OF POTASH, PRESENT IN MAXIMUM AMOUNTS.

	100 plants	
	Dry weight grams	K_2O grams
1. Control, distilled water	4.88	.0368
2. 200 p.p.m. K_2O alone	5.68	.2425
3. 200 p.p.m. K_2O with 200 p.p.m. N.	7.00	.4268
4. 200 p.p.m. K_2O with 200 p.p.m. P_2O_5	5.80	.2832
5. 200 p.p.m. K_2O with 200 p.p.m. $CaSO_4$	5.98	.2580

TABLE XIV.—EFFECT OF MEDIUM AMOUNTS OF NITROGEN, PHOSPHORIC ACID, AND GYPSUM UPON UPON THE ABSORPTION OF POTASH, PRESENT IN MEDIUM AMOUNTS.

	100 plants	
	Dry weight grams	K_2O grams
1. Control, distilled water	5.10	.0248
2. 80 p.p.m. K_2O alone	4.30	.0892
3. 80 p.p.m. K_2O with 80 p.p.m. N.	5.50	.1707
4. 80 p.p.m. K_2O with 80 p.p.m. P_2O_5	4.50	.1218
5. 80 p.p.m. K_2O with 80 p.p.m. $CaSO_4$	4.10	.1335

TABLE XV.—EFFECT OF MAXIMUM AMOUNTS OF NITROGEN, PHOSPHORIC ACID, AND GYPSUM UPON THE ABSORPTION OF POTASH, PRESENT IN MINIMUM AMOUNTS.

	100 plants	
	Dry weight grams	K_2O grams
1. Control, distilled water	5.10	.0248
2. 10 p.p.m. K_2O alone	5.28	.0985
3. 10 p.p.m. K_2O with 200 p.p.m. N.	5.50	.1591
4. 10 p.p.m. K_2O with 200 p.p.m. P_2O_5	5.50	.1063
5. 10 p.p.m. K_2O with 200 p.p.m. $CaSO_4$	5.50	.1311

TABLE XVI.—EFFECT OF MINIMUM AMOUNTS OF NITROGEN, PHOSPHORIC ACID, AND GYPSUM UPON THE ABSORPTION OF POTASH, PRESENT IN MAXIMUM AMOUNTS.

	100 plants	
	Dry weight grams	K_2O grams
1. Control, distilled water	5.10	0248
2. 200 p.p.m. K_2O alone	5.24	.1458
3. 200 p.p.m. K_2O with 10 p.p.m. N.	5.40	.2801
4. 200 p.p.m. K_2O with 10 p.p.m. P_2O_5	5.40	.2064
5. 200 p.p.m. K_2O with 10 p.p.m. $CaSO_4$	5.80	.1831

The results of Davidson* indicate that the rate of absorption of phosphorus is determined largely by the pH of the solution, that more phosphorus and less potassium are absorbed from a solution of a pH 5 or lower, than from solutions of 6 or 7 pH. His conclusions in respect to potassium are in accord with the results of the experiments that have just been described.

*Davidson, J., Jour Agr. Res. Vol. 35. No. 4. Aug. 15, 1927. Effect of hydrogen-ion concentration on the absorption of phosphorus and potassium by wheat seedlings.

In practically every case tried, the addition of the salts containing plant food, increased the absorption of potash from the nutrient solution. This was more marked with salts containing nitrates than with other salts. This phenomenon took place in solutions that were kept slightly alkaline with sodium bicarbonate and in solutions where an excess of aluminum hydrate was present, indicating that a low absorption of potash was probably not due to any acid condition that might have developed in the cultures containing the potash alone. Even when potash was abundant, 200 p.p.m., the addition of only 10 p.p.m. of nitrogen increased the absorption of potash over 100 percent.

When plants are grown in solutions of potassium chloride or potassium sulphate alone, the tendency of the solution is to become acid, due to the more rapid absorption of K than Cl or SO_4 ions. When seedlings are grown in solutions of sodium nitrate, the reverse of this is true, the solutions tending to become alkaline, due to the more rapid absorption of NO_3 than Na ions. When potassium chloride and sodium nitrate are added together, the tendency is to become slightly alkaline. This is shown in the following experiment: One hundred barley seedlings were grown in 1 liter each of the solutions described below, and the solutions changed every day. After 19 days, the cultures were allowed to grow for a 2-day period, and the pH values of the solutions made.

TABLE XVII.—EFFECT OF BARLEY SEEDLINGS UPON THE PH OF NUTRIENT SOLUTIONS.

	pH of solutions	100 plants	
		Dry weight grams	K_2O grams
1. Distilled water	7.0	4.160	.0324
2. 120 p.p.m. K_2O as KCl	6.8	5.680	.3274
3. 120 p.p.m. K_2O and 22 p.p.m. N. as $NaNO_3$	7.15	6.680	.4145

It will be seen that the addition of sodium nitrate increased the pH value of the solution over that containing potassium chloride alone, yet the absorption of potash was increased. There can be no doubt that an abundance of potash was always present in these nutrient solutions, both soluble and available, yet the plant evidently was unable to absorb it, when present alone, as it did when nitrogen or other plant foods were present. At this age the demand of the plant for potash is out of proportion to its demand for other plant foods, the potash being probably needed in the translocation of carbohydrates from the seed to the growing tissues. The plant's ability to absorb potash seems to depend, to a large extent, upon its ability to obtain an adequate supply of other plant foods. This demand for potash seems to be developed in the plant tissues; the demand is then transmitted to the root tips and is measured by the absorption of the potassium from the nutrient solution.

From the tables here given one might judge that the effect of nitrogen upon the absorption of potash could have taken place either within the tissues of the plant, or in the nutrient solution during the act of absorption, or in both the solution and the plant. In order to determine if the effect took place outside or inside of the plant the experiments which follow were planned.

Three sets of cultures were started as follows: No. 1, the control was kept in distilled water the full time; No. 2 was kept in distilled water for 4 days and then placed in a solution of 100 p.p.pm. potash for 4 days; No. 3 was placed in a solution of 100 p.p.m. nitrogen for the first 4 days, then washed off and transferred to the 100 p.p.m. potash solution for 4 days. The absorption of potash in the second 4-day period is shown in Table XVIII.

TABLE XVIII.—RESIDUAL EFFECT OF NITROGEN UPON THE ABSORPTION OF POTASH.

Culture during			100 plants—K_2O	
First 4-day period	Second 4-day period	Dry weight	In plants	Absorbed from solution
		Grams	Grams	Grams
1. Distilled water	Distilled water	5.40	.0357	......
2. Distilled water	100 p.p.m. K_2O	5.40	.1328	.0971
3. 100 p.p.m. N	100 p.p.m. K_2O	5.80	.1942	.1614

It will be seen from the table that the effect of nitrogen in the first period was carried over and manifested in the second period, although both sets of plants were feeding upon the same solution in the second period. The absorption of potash was markedly stimulated in the plants that had previously received the nitrogen. This phenomenon is shown, not only with nitrogen, but with phosphoric acid and gypsum, as shown in Table XIX, the time in this case being increased to two 8-day periods instead of two 4-day periods.

In this table also may be seen the "carry over," or residual effect, of plant foods upon the absorption of potash. This shows that the phenomenon certainly takes place within the plant tissues. It is also shown that a condition similar to hunger is developed in the plant, which has been deprived of a plant food for a time.

TABLE XIX.—RESIDUAL EFFECT OF NITROGEN, PHOSPHORIC ACID, AND GYPSUM UPON THE ABSORPTION OF POTASH.

Culture during		100 plants	
First 8-day period	Second 8-day period	Dry weight grams	K_2O grams
1. Control, distilled water	Distilled water	2.40	.0206
2. Distilled water	200 p.p.m. K_2O	2.04	.1063
3. 200 p.p.m. N.	200 p.p.m. K_2O	2.40	.1467
4. 200 p.p.m. P_2O_5	200 p.p.m. K_2O	2.28	.1226
5. 200 p.p.m. $CaSO_4$	200 p.p.m. K_2O	2.36	.1148
6. 200 p.p.m. each N, P_2O_5, $CaSO_4$	200 p.p.m. K_2O	2.66	.1878

In Table XX are shown the analyses of 8-day-old plants that had been grown full-time and half-time in the different solutions. In this experiment the plants that are marked one-half time, were grown in one solution one day and in distilled water or another solution the next. No. 3, for example, was grown in 100 p.p.m. K_2O for 1 day, then washed off and placed in distilled water for 1 day, then transferred again to the potash solution on the third day and so on.

TABLE XX.—RESIDUAL EFFECT OF NITROGEN UPON THE ABSORPTION OF POTASH.

	100 plants	
	Dry weight grams	K_2O grams
1. Control, distilled water	5.40	.0357
2. 100 p.p.m. K_2O full-time	6.60	.1437
3. 100 p.p.m. K_2O half-time, distilled water half-time	6.15	.1453
4. 100 p.p.m. K_2O 100 p.p.m. N. full-time	6.00	.2098
5. 100 p.p.m. K_2O 100 p.p.m. N. half-time, distilled water half-time	6.90	.2222
6. 100 p.p.m. K_2O, half-time, 100 p.p.m. N. half-time	6.20	.1732

By a study of this table several facts are brought out. First, that plants grown one-half time in the nutrient solution often absorb as much if not more potash than when grown full-time in the same solution.* Second,

*The effect of full-time and half-time feeding was discussed by the writer in the Journal of Agricultural Research, Vol. XXIV, No. 1—1923, "Nutrition of plants considered as an electrical phenomenon."

that the presence of nitrogen always increased the absorption of potash. Third, that the plants that were grown one-half time with both nitrogen and potash present (No. 5) absorbed more potash than when the nitrogen was given them 1 day and potash the next (No. 6), that is, when the plants were placed in the mixture of nitrogen and potash 1 day, and distilled water the next, they absorbed more potash than did those that were placed in a nitrogen solution 1 day and potash solution the next day. Both sets of plants received the same amount of potash and grew the same length of time in the potash solution, but under different conditions. A duplicate set that was grown at a different time gave .2906 and .1818 gram for Nos. 5 and 6 respectively. The presence of nitrogen at the time of the absorption of the potash seems to be necessary for maximum absorption. The effect of nitrogen upon the absorption of potash, therefore, certainly takes place within the tissues of the plant and probably is also associated in some way with the act of absorption.

The presence of nitrogen, so necessary to the upbuilding of plant tissues, if withheld at any period of growth, would thus limit the absorption of potash. In these experiments no great differences in growth were shown. The experiments were run for only a few weeks at a time, and the growth of the plants was not noticeably affected by a shortage of any necessary element. The rapid absorption of potash in the presence of nitrogen was out of all proportion to the difference in the amount of growth. It is significant also that potash and nitrogen together, gave better results on half-time feedings than when they were applied alone. The evidence seems conclusive that, when nitrogen is present, the plant absorbs potash much more rapidly than when nitrogen is not present in the solution. This occurs even when the supply of nitrogen in the solution is far above the point where it becomes a limiting factor.

In 1903, while working under the direction of Professor Milton Whitney in the United States Department of Agriculture, the writer made the observation that the presence of pyrogallol in small amounts, 10 parts per million or less in solution, would stimulate root development. The effect of this acid is very marked. At that time, Professor Whitney attributed this effect to the oxidizing action of pyrogallol acid upon the toxic compounds in the soil solution or solution cultures. The writer has long thought that it was much more reasonable to assume that the increase in root growth is due to the stimulating effect of pyrogallol acid upon the enzymes of the root tip that are concerned with root elongation. It is of interest to note that while pyrogallol stimulates root development, it does not appear to stimulate the absorption of potash from a nutrient solution. On the other hand, the presence of nitrogen, as a nitrate, tends to stimulate top growth while it retards root development.

The stimulation of top growth and transpiration is accompanied by an increase in the absorption of potash, but no increase in the absorption of potash is noticed when root growth alone is stimulated. The marked effect of nitrogen upon the absorption of potash probably depends upon the demand of the plant and is not correlated with the enzymic activity of the root tip.

THE DEMANDS OF THE PLANT

It is the opinion of the writer that the rate of absorption of plant food may be modified by many factors, such as the concentration of the nutrient solution, and its reaction or pH. But primarily among such factors must be considered the demands of the plant.

The plant is a product of environment. It is practically in equilibrium with all the forces of nature. Ordinarily, plants do best, or behave normally, when placed in an environment under conditions similar to those of their native habitat. The demand of the plant, therefore, is for natural conditions and this demand is shown in its habits of nutrition. Every plant that is growing now is constantly adapting certain of its characters to new or changed conditions. With most characters this change is slow, for changes in natural conditions are usually slow. In its development a plant takes the path of least resistance. Any observation connected with the nutrition and development of plants that disagrees with these fundamental facts is likely to be erroneous.

As an example, most plants of economic importance thrive in a calcareous soil, or in a soil that maintains a pH of about 8 in its solutions. In growing water cultures, the writer found long ago that the presence of a slight excess of calcium carbonate added to the vitality of most seedlings. When it is not possible to use calcium carbonate, a little sodium carbonate will answer the same purpose. When we realize that our best soils, the soils that most plants are adapted to, are usually calcareous it is unreasonable to expect most cultivated plants to function normally in a solution that has a pH of below 7, or neutrality.

When potassium chloride is added alone to a solution in which plants are growing, the tendency of the solution is to become acid as the potassium is absorbed more rapidly than is the chlorine radical. When sodium nitrate alone is added, the solution will become slightly alkaline due to the rapid absorption of the nitrate radical. When the two are added togther the tendency will be to form a neutral solution, or one that is slightly alkaline. If the observations reported in this bulletin are correct and the addition of sodium nitrate stimulates the absorption of potassium in a culture solution, we must conclude that the absorption of potassium is not increased by an acid reaction.

NATURAL CONDITIONS AND NORMAL PLANTS

Natural conditions produce normal plants, and unnatural conditions tend to produce abnormal plants. Observations upon the nutrition of normal plants may be of much value, while observations upon abnormal plants may be worse than useless for, if generally applied, they may be misleading. Even under the best conditions, a poor technique may also produce abnormal plants and observations upon the nutrition of such plants, even if intelligently made, are true for those plants only. The results cannot be applied accurately to other plants that have been grown under different conditions. It is the opinion of the writer that poor technique, or the inability to handle seedlings properly, is responsible for many of the discrepancies that are noticed in reports of work upon plant nutrition. And, too, it cannot be assumed safely that all habits of nutrition are fundamental and fixed. The demand of the plant for food elements may change with its environment. Seeds of the same variety of wheat, if planted in widely different sections will grow and function differently. Bluestem wheat, if grown in Manitoba, will produce a medium-sized stalk and grain that is high in protein, while the same wheat, if planted in Arizona, may produce a large vegetative growth and a small amount of grain that is low in protein. The demand of the plant for nutrient material may be different in one locality from what it is in another. Plants demand what they need in their metabolism, and a plant that is producing a large amount of protein will probably demand more nitrogen than one producing a large amount of starch and little protein.

The writer has often found it difficult, if not impossible, to duplicate certain work with plants at different times in different sections of the country. Plants do not seem to function the same, and they do not have the same demands, when grown in the cool, moist atmosphere of Washington, D. C., as they do when grown in Minneapolis or in southern California, or in the hot, dry climate of Arizona. Any observation upon the nutrition of plants must, therefore, take into consideration the reasonable demand of the plant under particular conditions, and caution should be exercised in giving observations too wide application. Certain factors of plant nutrition are fundamental, and of course, have wide application, but other factors are changeable and this proves that they are not fundamental.

DISCUSSION OF RESULTS

In considering the stimulating effect of nitrate upon the absorption of potash, it seems probable that, at the early period of growth, potassium is needed by the plant in the capacity similar to that of a catalizer. It is much concerned in the translocation of the carbohydrates and in the building up of vegetative tissue. The little wheat seedling begins growth with a strong demand for potash and, if this plant food is available it is absorbed in greater amounts than are other plant foods. At this age the starch in the seeds is being converted into sugar and this is being translocated very rapidly into the growing tissue for the purpose of building up such compounds as cellulose. The absorption if nitrogen is also very rapid, and this goes into protein or other nitrogenous compounds.

There seems to be a direct relation between the absorption of potash and the absorption of nitrogen. The potash is probably necessary in the process of building up the protein-like compounds, although it does not enter into their chemical composition. If nitrogen is available, much potash may be necessary and it will be demanded by the plant. If nitrogen is not available, a small amount of potash will be demanded for this building-up process, and only enough will be absorbed for the other needs of the plant. In this way the supply of nitrogen may be the limiting factor in the absorption of potash.

CONCLUSIONS

1. The absorption of nitrogen from solutions by wheat seedlings does not seem to be affected by the presence of potash, phosphoric acid, or gypsum.

2. The absorption of phosphoric acid from solutions seems to be slightly increased by the presence of nitrogen, and diminished by an excess of gypsum.

3. The absorption of calcium does not seem to be affected by the presence of nitrogen, potash, or phosphoric acid.

4. The absorption of potash from solutions is increased by the presence of other plant foods, particularly nitrogen.

5. The effect of nitrogen upon the absorption of potash is carried over from one period when nitrogen is present to another period when nitrogen is absent. This indicates that the effect is due, in part to a demand within the tissues of the plant. This same phenomenon is true in the effect of phosphoric acid and gypsum upon the absorption of potash.

6. The effect of nitrogen upon the absorption of potash seems to be manifested both within the tissues of the plant while the plant is not feeding and also during the act of absorption. This is shown by the more rapid absorption when solutions containing nitrogen and potash are mixed and the plant is grown half-time in this mixture and half-time in distilled water.

7. The marked effect if nitrogen upon the absorption of potash is closely correlated with a stimulated top growth and transpiration and not correlated with a stimulated root growth.