ON THE PHYSIOLOGICAL BALANCE IN NUTRIENT SOLUTIONS FOR PLANT CULTURES

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Wheat seedlings grown for one day in a dilute solution of KNO_3, the next day in one of $MgHPO_4$, the third day in one of $CaSO_4$, and these changes continued in rotation at twenty-four-hour intervals for four weeks, grew as large and produced approximately as much dry weight as those grown in complete nutrient solutions of the above-named salts and in other three-salt solutions that supplied the same ions. The plants grown in these three single-salt solutions were also much superior to those grown in other types of single-salt solutions that were changed likewise at twenty-four-hour intervals. Altogether, ten different simple nutrient salts were used in the tests, and these were selected to give six different types of nutrient solutions; three or four salts being required for each type, which, with a trace of iron salt added, supplied the essential salt or mineral constituents for plant growth in aqueous solutions. All solutions, with the exception noted below, were of approximately the same osmotic value, this being approximately equal to one atmosphere osmotic pressure. Each single-salt solution, aside from the trace of iron it contained (this being added as $FeSO_4$), supplied the plants with two essential nutrients, both cation and anion of the salts used being of those atoms or groups of atoms considered necessary for plant growth. It required three days to make one rotation to bring the plants in contact with the three nutrient solutions of their respective types, which supplied them with all the essential elements in nutrient solutions, *viz.*: NO_3, SO_4, PO_4, K, Ca, Mg, and Fe.

The salts used for the different types[1] were as follows:

Type I, KH_2PO_4, $Ca(NO_3)_2$, $MgSO_4$; type II, K_2SO_4, $Ca(NO_3)_2$, $MgHPO_4$; type III, KNO_3, $CaHPO_4$ (saturated solution plus enough $Ca(H_2PO_4)_2$ to give together 0.2 atmosphere osmotic value), $MgSO_4$; type IV, K_2SO_4, $CaHPO_4$ (saturated solution plus enough $Ca(H_2PO_4)_2$ to give together 0.2 atmosphere osmotic value), $Mg(NO_3)_2$; type V, KNO_3, $CaSO_4$, $MgHPO_4$; type VI, KH_2PO_4, $CaSO_4$, $Mg(NO_3)_2$.

The change of the cultures from one solution to another successively within each of the several types at twenty-four-hour intervals covered the

[1] For the first mention of these types, see Livingston, B. E., and Tottingham, W. E. A new three-salt nutrient solution for plant cultures. Amer. Jour. Bot. 5: 337–346. 1918. Types II, III, IV, and V were modified by the author by substituting $CaHPO_4$ for $Ca(H_2PO_4)_2$ and $MgHPO_4$ for $Mg(H_2PO_4)_2$, the primary phosphate salts in the original being too acid for these tests.

possibilities respecting order of rotation. All cultures were rinsed with distilled water before being transferred to another solution. The cultures were in contact with the solutions belonging to a type for an equal length of time. The experiment was planned to supply the plants with the nutrients in piecemeal fashion, and not together at one time, as was the case with those grown in complete nutrient solutions.

It was conceived as very probable that some of the nutrient salts would be found better suited for plant growth than others, because of differences in properties due to the composition of the salts. The results of the tests are given in table 1.

TABLE 1. *Dry Weight in Grams of Wheat Seedlings Grown Four Weeks in Six Different Types of Single Salt Solutions and in Complete Nutrient Solutions*
(Averages of 24 cultures of 5 plants per culture for each type and for the six types of complete nutrient solutions)

Type I	Type II	Type III	Type IV	Type V	Type VI	Complete Solutions (All Types)
.51	.61	.59	.40	.96	.43	1.02

The table shows that the salts of type V, that is, KNO_3, $MgHPO_4$, and $CaSO_4$, when used singly gave far better yields than did those of any other type. They were approximately as good as those of any type of complete nutrient solution tested, in which the total osmotic value was divided equally among three salts. As to the order of change of cultures from one solution to another, this appeared to be of only minor importance, and hence no data on this matter need be given; but the kind of salt used in making the changes was of great importance. While the p_H values of the single-salt solutions employed were not the same in all cases, nevertheless they were within the range appropriate to good plant growth in complete solutions, and it is, therefore, assumed that the differences in dry weight produced were due to other causes than reaction of solution. Because only one salt was used at a time, it appears that the cause must be in the way in which two essential ions are paired, that is by the composition of the salt. Observations of the tests and the interpretation of the data given showed that when wheat seedlings absorb nitrates, potassium must be available; the absence of any one of the other essential elements for a period of at least forty-eight hours for these young plants apparently was not injurious. Furthermore, seedlings which were exposed for twenty-four hours in a solution that contained equal concentrations of only magnesium and phosphate ions ($MgHPO_4$) sustained no apparent harmful effects (to either top or roots), but if they were placed for a similar length of time in equally dilute or diluter solutions of $MgSO_4$ or $Mg(NO_3)_2$, they sustained decided injury. $MgHPO_4$ seems to be a very good salt to supply the plants with magnesium and phosphate. Calcium-sulphate solution proved to be a medium which can be used effectively for young wheat seedlings for at least twenty-four hours and without any harmful effects. Furthermore, table 1 shows that when $MgHPO_4$ or KNO_3 was one of the salts of a type (see types II and III), larger plants were produced than when neither of these salts was contained in the type.

In recapitulating the conclusions, it seems that the availability and utilization of essential elements by wheat seedlings are not inconsiderably affected by the way in which these elements, presumably as ions, are paired. There undoubtedly is one kind of ion, or possibly more, of opposite charge with which any one of the essential ions can be used to best advantage by the plants. There is more than presumptive evidence in the results of this experiment that the proper pairing of nutrient elements, or of ions of opposite charge, is an important factor, and one that does account in a large measure for the physiological adaptability of a nutrient solution for plant growth. However, this pairing of any two ions in complete nutrient solutions does not mean that any definite cation-anion ratio must prevail. Investigations have shown that ionic ratios of nutrient solutions can cover a considerable range of values without any apparent physiological effect. However, the interpretation of this test should mean that if a nutrient solution is a poor medium for plant growth because of the large proportion of one ion, it should be improved by the addition of some other ion of opposite charge, even though this be added in the form of a salt that would also add more of the ion already in excess. That this is what actually happens, has been proven experimentally in this laboratory. The above conclusions may also be stated in other words, and, as a concrete example, $Mg(NO_3)_2$ can be used as the source of nitrates for plants in any growth media. But the utilization of nitrates by the plant will be largely influenced by the relative supply of available potassium in the medium; that is, the utilization by young wheat plants of the nitrate anion is closely related to that of the potassium cation, and *vice versa*. A cation-anion relation of other essential ions is apparent from a study of the results, but need not be considered in detail in this paper as the experiments will be discussed elsewhere. It may not, however, be amiss to state that the principle of the method here employed to study the physiological properties of solutions seems to give promise of yielding further information on the nutrition of the higher plants that can not be gained by the use of complete nutrient solutions because of their complexity.

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