# NODULATION MODIFIES NUTRIENT INTAKE FROM COLLOIDAL CLAY BY SOYBEANS

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# NODULATION MODIFIES NUTRIENT INTAKE FROM COLLOIDAL CLAY BY SOYBEANS[1]

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IF PLANT nutrition is viewed as a phenomenon of ion exchange between the root and the colloidal complex of the soil,[3] the question of the chemical composition of the root as a factor in this exchange readily presents itself. That the root of a legume should be a different force in exchanging ions with the soil than is the root of a nonlegume was the postulate given attention in the study reported herewith.

## PLAN AND METHODS OF THE STUDY

Two sets of soybean crops were each grown with two constant amounts of calcium and each calcium level in combination with three different amounts of potassium. All of the nutrient ions, as given in Table 1, were titrated on to colloidal clay so as to supply them in exchangeable rather than soluble forms. This clay was mixed with a quartz sand to serve as the growth medium. One set of the plants was nodulated while the other was not. Thus, without changes in the plant species, the same colloidal clay complex was tested for its nutrient delivery to plant roots functionally representing a legume in the former series and a nonlegume in the latter. This was an attempt to avoid morphological differences, such as relative mass of active meristematic tissue,[4] that might modify the mechanisms of ion absorption and transformation within the plant. Both crops were started in May, that not nodulated in 1941 that nodulated in 1942.

The crops were grown for 5 weeks in the greenhouse. The tops and roots were harvested, dried at 60° C, weighed, ground, and mixed for chemical analysis.

The samples were ashed by means of nitric and perchloric acids. The determinations of potassium, calcium, magnesium, phosphorus, silicon, and barium were made from the solutions of the ashed samples. The nitrogen determinations were made by the modified Kjeldahl method. All calculations were made on the basis of 50 plants.

## RESULTS

*Nitrogen in the crops.*—Since one of the series was not nodulated, the plants did not fix nitrogen but contained only the total nitrogen offered initially in the seed. The percentages of nitrogen in the dry matter were 1.50 as a minimum and 2.66 as a maximum in the non-nodulated crop, while the corresponding figures for the nodulated crop were 3.24 and 4.00, respectively. The average figures for the six cultures in duplicate in each of these two series were 1.91 and 3.50% nitrogen. The average values for total nitrogen per 50 plants were 349.7 mgms for the non-nodulated crop and 449.7 mgms for the plants with nodules. The nodulated crop was more than 80% more proteinaceous than the non-nodulated plants. It was this difference that would serve to test the hypothesis of this study, namely that the protein on the inside of the root as a colloid itself might be a factor modifying the exchange through the root membrane with the soil colloidal complex on the exterior of the root.

TABLE 1.—*Ions added to clay cultures by titration.*

| Culture No. | Ions added, M.E. | | | | |
|---|---|---|---|---|---|
| | K | Ca | Mg | P | Ba |
| 1 | 5 | 10 | 10 | 7.5 | 25* |
| 2 | 10 | 10 | 10 | 7.5 | 20 |
| 3 | 15 | 10 | 10 | 7.5 | 15 |
| 4 | 5 | 20 | 10 | 7.5 | 15 |
| 5 | 10 | 20 | 10 | 7.5 | 10 |
| 6 | 15 | 20 | 10 | 7.5 | 5 |

*Barium added for series A, non-nodulated, was 5 M.E. higher in every culture than was used in series B, nodulated. Barium was added to make the final clay nearly neutral.

*Crop weights.*—Quite contrary to expectations, the weights of the non-nodulated soybean crop, or of that which was behaving as a nonlegume with reference to its nitrogen, were much larger than of the nodulated crop, as is shown in Table 2. This occurred when both were growing on the same supply of nutrients adsorbed on the colloidal clay. Here then, the mass of

TABLE 2.—*Crop weights according as roots bore nodules or none under the different soil treatments.*

| Culture No. | M.E. offered | | Nodulation | Tops, gms | Roots, gms | Total, gms | Ratio of tops/roots |
|---|---|---|---|---|---|---|---|
| | K | Ca | | | | | |
| 1 | 5 | 10 | + | 7.65 | 2.30 | 9.90 | 3.3 |
| | | | − | 8.03 | 4.82 | 12.85 | 1.6 |
| 2 | 10 | 10 | + | 9.14 | 2.26 | 11.40 | 4.0 |
| | | | − | 14.07 | 5.71 | 19.79 | 2.4 |
| 3 | 15 | 10 | + | 11.17 | 3.09 | 14.26 | 3.6 |
| | | | − | 13.81 | 6.07 | 19.88 | 2.2 |
| 4 | 5 | 20 | + | 10.23 | 2.96 | 13.20 | 3.4 |
| | | | − | 13.06 | 5.89 | 18.95 | 2.2 |
| 5 | 10 | 20 | + | 10.78 | 3.16 | 13.94 | 3.4 |
| | | | − | 16.01 | 6.03 | 22.04 | 2.6 |
| 6 | 15 | 20 | + | 11.92 | 3.33 | 15.25 | 3.5 |
| | | | − | 16.27 | 6.15 | 22.42 | 2.6 |
| Total crop weights | | | + | 60.90 | 16.91 | 77.97 | 3.5* |
| | | | − | 81.27 | 34.68 | 115.95 | 2.3* |

*Means.

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[3]ALBRECHT, WM. A. Adsorbed ions on the colloidal complex and plant nutrition. Soil Sci. Soc. Amer. Proc., 5:8–16. 1940.
[4]MARSH, R. I. Comparative study of the calcium-boron metabolism of representative dicots and monocots. Soil Sci., 53:75–78. 1942.

plant growth was almost 50% larger in total when the series was behaving as a nonlegume.

More significant, however, is the fact that the non-nodulated crop had in contact with the same amount of clay and nutrients a total root mass that was more than double that of the nodulated crop. Nevertheless, its ratio of tops to roots was 2.31, while for the crop behaving as a legume the tops had 3.53 times as much mass as the roots.

This feature deserves emphasis, namely, that the root mass of the nodulated crop was 50% more efficient in producing mass of top as related to mass of roots. If we can assume that the larger root mass represented correspondingly larger total root surface for clay contact, and ionic exchange functions with it, then it is immediately evident that the nodulated root, which is also the more proteinaceous root, is more effective in producing mass of top per unit mass and surface of root. If the legume plant carries in addition, more nutrients taken from the soil, as is common for it, then the root of the leguminous plant must also be a more efficient physico-chemical system for the movement of ions from the colloidal clay complex through its wall into the interior of the root.

*Potassium, calcium, and magnesium in the crops.*—That the roots of the nodulated soybean plants were more active in moving nutrient ions into themselves from the adsorption atmosphere of the colloidal clay is evident from the data for concentrations and totals of the three nutrients, potassium, calcium, and magnesium, in the two crop series given in Table 3.

Perhaps the most interesting fact is the much higher concentration of potassium in the nodulated crop. As an average of the six treatments, this was 3.36% of the plant dry matter for the nodulated crop and only 1.92% for that not nodulated. The total potassium in the nodulated crop was also larger in every treatment in spite of the fact that the mass of the crop was smaller.

TABLE 3.—*Concentrations and totals of potassium, calcium, and magnesium in the crops according as the roots bore nodules or none under the different soil treatments.*

| Culture No. | Nodulation | Potassium | | Calcium | | Magnesium | |
|---|---|---|---|---|---|---|---|
| | | % | Mgms | % | Mgms | % | Mgms |
| 1 | + | 2.85 | 282 | 0.40 | 39 | 0.58 | 58 |
| | – | 1.83 | 234 | 0.43 | 55 | 0.38 | 59 |
| 2 | + | 3.87 | 442 | 0.53 | 47 | 0.45 | 52 |
| | – | 2.07 | 408 | 0.29 | 56 | 0.28 | 55 |
| 3 | + | 4.34 | 620 | 0.38 | 54 | 0.35 | 51 |
| | – | 2.41 | 479 | 0.26 | 52 | 0.21 | 46 |
| 4 | + | 2.13 | 280 | 0.70 | 92 | 0.66 | 88 |
| | – | 1.33 | 251 | 0.60 | 114 | 0.36 | 68 |
| 5 | + | 3.30 | 460 | 0.70 | 98 | 0.46 | 65 |
| | – | 1.80 | 398 | 0.51 | 111 | 0.24 | 55 |
| 6 | + | 3.96 | 600 | 0.67 | 101 | 0.38 | 58 |
| | – | 2.10 | 470 | 0.39 | 86 | 0.27 | 60 |

As for the calcium, the concentration of this element was lower in either the nodulated or the non-nodulated crop as the soil offered less. The total in the nodulated crop increased consistently as more potassium was offered and taken at either level of calcium supplied. In the non-nodulated crop at 10 M.E. of calcium, the totals were all very similar, but at 20 M.E. of calcium they decreased as more potassium was taken. Nevertheless, at the 20 M.E. level of calcium this larger supply results in reduced concentration of potassium in the plants at all levels of the potassium supply. Here, then, the increasing intake of potassium by the nonlegume suggests excluding effect by potassium on the calcium, and the higher calcium similarly on the potassium when both were originally on the clay in exchangeable forms.

The concentrations of magnesium were higher in every case for the nodulated crop. At 10 M.E. of calcium, there was a decrease in concentration of magnesium with increased concentration of potassium in the crop whether behaving as a legume or nonlegume. In the non-nodulated plants to which 20 M.E. of calcium were available, the decrease in magnesium concentration was not as regular.

The largest total amount of magnesium was in the nodulated crop given the maximum of calcium and the minimum of potassium. The lowest total amount of magnesium was in the non-nodulated crop given the minimum of calcium and the maximum of potassium. The fuller significance of these facts must await later discussion.

*Efficiency of use by nodulated and non-nodulated plants of potassium, calcium, and magnesium adsorbed on the clay.*—In order to enhance appreciation of the larger movements of plant nutrients into the roots in consequence of their proteinaceousness, the total amounts of the potassium, calcium, magnesium, taken by the plants were calculated as percentages of the supplies offered on the clay. These data are assembled in Table 4.

TABLE 4.—*Efficiencies with which the potassium, calcium, and magnesium were taken according as the roots bore nodules or none.**

| Culture No. | Nodulation | Potassium, % | Calcium, % | Magnesium, % |
|---|---|---|---|---|
| 1 | + | 76 | 18 | 44 |
| | – | 64 | 26 | 45 |
| 2 | + | 78 | 22 | 39 |
| | – | 73 | 26 | 42 |
| 3 | + | 81 | 26 | 38 |
| | – | 63 | 24 | 35 |
| 4 | + | 76 | 22 | 67 |
| | – | 69 | 27 | 51 |
| 5 | + | 81 | 24 | 49 |
| | – | 71 | 27 | 41 |
| 6 | + | 79 | 25 | 44 |
| | – | 62 | 27 | 46 |

*Percentage of offered supply taken by crop.

Again, the high efficiency with which the potassium moved into the crop and the higher efficiency for the nodulated crop are outstanding. This naturally raises the question whether this larger amount of potassium means more carbohydrate synthesis for its use in plant respiration and synthesis of protein. Certainly the more proteinaceous roots were more efficient in encouraging potassium entrance, when as an average 78.5% of the total on the clay was taken in contrast to 67.0% taken by the non-nodulated, less proteinaceous roots.

The efficiency of consumption of calcium by the non-nodulated crop was not responsive to potassium differences. It was higher, in general, namely, 26.5% as the mean, than for the nodulated crop, mean 23.0%. In the nodulated crop, increasing amounts of potassium meant higher efficiency in the movement of calcium into the plants, but mainly at the lower level of calcium.

In general, the efficiency of magnesium utilization declined as more potassium was offered and there was a suggestion of less efficient use by the non-nodulated crop.

*Phosphorus, silicon, and barium in the crops.*—The concentrations of phosphorus in the crops, whether nodulated or not, responded inversely to the concentrations of the potassium, more particularly when only 10 M.E. of calcium were available. This is shown in Table 5. The concentrations in the nodulated crop were always higher than those in the corresponding treatments of the non-nodulated crop. The total amounts of phosphorus in the crops given 10 M.E. of calcium and nodulated increased as more potassium was offered. Without nodulation at both calcium levels, and with nodulation at the higher calcium level, this relation did not suggest itself.

These facts suggest that for the nodulated legume root, the increasing added potassium encourages increased intake of phosphorus from a constant supply in the soil where the calcium supply is moderate or low, but not when this is more liberal.

The concentration of silicon, even more pronouncedly than that of phosphorus, showed an inverse relation to the concentration of the potassium. Potassium therefore suggests itself as having an excluding effect on silicon. Calcium classifies in the same category since at 20 M.E. the concentrations of silicon were roughly only about one-half those at 10 M.E. of calcium. Increasing the potassium from 5 to 15 M.E. shifted the silicon concentration from 2.54 to 1.46% for the nodulated crop and from 2.28 to 1.10% for the non-nodulated, both grown with 10 M.E. of calcium. With 20 M.E. of calcium, the corresponding shifts were from 1.60 to 0.81 and from 1.13 to 0.91, respectively, with increase in potassium offered. The nodulation permitted a higher concentration of silicon.

When the totals of silicon are considered there was more of it in the non-nodulated or heavier crop. The increasing potassium and the increasing calcium both served to demonstrate their effects of excluding the silicon, or the equivalent of nourishing the plant so that a different physico-chemical situation in the root meant less movement of silicon into it.

The concentrations and totals of barium followed the amounts present in the soil and did not relate themselves in any recognized way to any physiological factors. The non-nodulated series originally given 5 M.E. more of barium to each culture had more total barium in the crop. Barium suggests itself as striking up a kind of an equilibrium between that within and that without the plant.

*Efficiency of use by the nodulated and non-nodulated plants of phosphorus and barium adsorbed on the clay.*—The same supply of phosphorus on the clay was used more efficiently by the nodulated crop grown with 10 M.E. of calcium as more potassium was applied. This is shown in Table 6. There is a suggestion of a similar condition for the non-nodulated crop. At the higher levels of calcium, namely 20 M.E.,

TABLE 5.—*Concentrations and total of phosphorus, silicon, and barium in the crops according as the roots bore nodules or none under the different soil treatments.*

| Culture No. | Nodulation | Phosphorus | | Silicon | | Barium | |
|---|---|---|---|---|---|---|---|
| | | % | Mgms | % | Mgms | % | Mgms |
| 1 | + | 0.45 | 44 | 2.54 | 251 | 1.52 | 151 |
| | − | 0.42 | 54 | 2.28 | 293 | 1.09 | 141 |
| 2 | + | 0.42 | 48 | 2.15 | 246 | 0.65 | 74 |
| | − | 0.34 | 64 | 1.24 | 245 | 0.47 | 96 |
| | + | 0.38 | 54 | 1.46 | 208 | 0.28 | 39 |
| | − | 0.29 | 59 | 1.10 | 219 | 0.26 | 51 |
| 4 | + | 0.38 | 50 | 1.60 | 211 | 0.36 | 47 |
| | − | 0.32 | 61 | 1.13 | 214 | 0.50 | 95 |
| 5 | + | 0.32 | 46 | 1.08 | 151 | 0.22 | 30 |
| | − | 0.27 | 61 | 0.95 | 209 | 0.17 | 37 |
| 6 | + | 0.33 | 50 | 0.81 | 124 | — | — |
| | − | 0.29 | 64 | 0.91 | 193 | 0.15 | 32 |

TABLE 6.—*Efficiencies with which the phosphorus and barium were taken as the roots bore nodules or none.**

| Culture No. | Nodulation | Phosphorus, % | Barium, % |
|---|---|---|---|
| 1 | + | 39 | 11 |
| | − | 47 | 8.2 |
| 2 | + | 42 | 7.2 |
| | − | 56 | 6.9 |
| 3 | + | 47 | 5.8 |
| | − | 52 | 5.1 |
| 4 | + | 44 | 6.9 |
| | − | 54 | 9.2 |
| 5 | + | 40 | 8.8 |
| | − | 53 | 5.4 |
| 6 | + | 44 | — |
| | − | 56 | 4.7 |

*Percentage of offered supply taken by crop.

there were no distinct suggestions. It is interesting to note that from 40 to 55% of the offered phosphorus found its way into the crops, and that, in general, the figure was higher on the non-nodulated crop.

That the nodulated crop which was synthesizing more nitrogen into more protein should use less phosphorus from the soil supply suggests that the non legume was building phosphorus into compounds other than proteins or was merely moving the phosphorus into the crop as a deposition in some inorganic or less complex organic form.

## SUMMARY

Soybean crops grown with different soil treatments point out that the nodulated crops with their more proteinaceous roots represent these as different physico-chemical systems when tested against the colloidal clay of the soil, than are the roots of non-nodulated soybeans. When the concentrations and totals in the crops of the originally adsorbed ions on the clay are considered, the nodulated crop demonstrated more regularities and consistent relations between those within and those outside the crop roots.

Even though the non-nodulated crop masses were larger, the nodulated crops were higher in concentrations and totals of potassium, in concentrations of calcium, of magnesium, and of phosphorus, but lower in totals of the non-nutrient silicon. In terms of the ingo of exchangeable ions from the clay, higher percentages of the potassium and magnesium were taken on consequence of nodulation. Calcium and phosphorus in total moved into the non-nodulated crop as readily as into the nodulated crop.

These results suggest that the composition of the legume forage, in terms of several of the mineral nutrient elements from the soil, is different because the protein nature of the root makes this part of the plant a different physico-chemical system in relation to the colloidal complex of the soil for their intake. Plant nutrition as a movement of adsorbed ions from the clay into the root is not only a matter of kinds and amounts of ions on the clay and of the total clay in the soil, but also a matter of the physiology of the particular root as well.