THE FEEDING POWER OF PLANTS[1]

DIFFERENT species of plants vary greatly in their feeding power or ability to secure the required elements from the natural mineral matter of the soil or from difficultly soluble phosphate and potash minerals which may be applied as fertilizers. The character of the native vegetation is in many cases determined partly by differences in the feeding power of plants. Of the cultivated plants it is well known that buckwheat will feed much more strongly on rock phosphate than corn. The subject is thus not only of scientific interest but also of great practical importance.

It was formerly believed that the mineral matter of soils was made soluble and available to plants through the action of various acids excreted by the plant roots. Later experiments, especially those by Czapex, indicated that, other than carbonic acid, plants normally excrete at the most only minute quantities of acids. As is now well known practically all plants excrete through their roots large quantities of carbonic acid. Attempts to explain differences in feeding power on the basis of differences in amount of carbonic acid excreted have not been successful.

It might, however, still be argued that it is not necessary for plants to actually give off or excrete the acids in measurable amounts in order that they exercise an influence on the solution of mineral matter; it might be argued that all that is necessary is for the acids to saturate completely the walls of the root hairs which come in intimate contact with the mineral particles. That this is not the correct explanation is evident from what follows.

During recent years, by aid of the hydrogen electrode much valuable information has been secured regarding the acidity of plant juices.[2] This information is aiding greatly to clarify our conception regarding the feeding power of plants and the relation of plant growth to soil acidity and alkalinity. It indicates that the excretion of other acids than carbonic or mere presence of them in the walls of the root hairs is not an important factor in the feeding power of plants, for it is now known that a plant with a nearly neutral sap may feed more strongly on relatively insoluble minerals than one with a decidedly acid sap; *e. g.*, sweet clover and alfalfa with relatively slightly acid root saps of p_H 6 to 7 feed more strongly on feldspar than buckwheat with a relatively strongly acid root sap of p_H 4 to 5. If plants made the mineral matter of soils available through the excretion or presence of acids other than carbonic, then the reverse should be true, that is, the buckwheat should feed more strongly on feldspar than alfalfa and sweet clover because it would excrete or have present much the strongest acid. Similarly corn with a more acid sap than either alfalfa or sweet clover should feed more strongly than the other two on rock phosphate and feldspar if it were a matter of excretion or presence of acids, but again the opposite holds true. Undoubtedly, if data for more species of plants were available many more cases of this kind could be cited.

It is therefore necessary to find some other explanation for certain differences in feeding power than those thus far given, for evidently there are other factors than the excretion of acids which exercise a controlling influence on the feeding power of plants. A number of years ago the writer presented a new theory[3] regarding the feeding power of plants in which the feeding power for rock phosphate was explained on the basis of the law of mass action and chemical equilibrium. The reaction making the phosphorus of rock phosphate available to plants is one between carbonic acid and the tricalcium phosphate in rock phosphate which may be represented as follows:

$$Ca_3(PO)_2 + 2H_2CO_3 \rightleftarrows Ca_2H_2(PO_4)_2 + CaH_2(CO_3)_2.$$

[1] Published with the permission of the director of the Wisconsin Agricultural Experiment Station.

[2] Truog, E., and Meacham, M. R., *Soil Science,* 7, (1919), pp. 469-474; Clevenger, C. B., *Soil Science,* 8, (1919), 217-242; Bryan, O. C., *Soil* Science, 13, (1922), 271-302; Bauer, F. C., and Haas, A. R. C., *Soil Science,* 13, (1922), pp. 461-477.

[3] SCIENCE, N. S., 41, (1915), pp. 616-618; *Research Bulletin 41,* 1918, Wis. Agr. Expt. Sta.

In order that this reaction continue indefinitely, it is necessary that both products of the reaction be removed in somewhat the proportion that they are produced. This is the condition that actually exists with plants like buckwheat and sweet clover which use a large amount of calcium. They are thus enabled to feed strongly on rock phosphate, as is found by experiment. In case the calcium content of a plant is low, and the calcium bicarbonate is not removed in as high a proportion as the soluble phosphate, the rate of solution of the phosphate becomes slower and slower with time and thus the plant is unable to feed advantageously on the rock phosphate. This is the case with plants like oats and corn which have a low calcium content.

This theory may be tested in other ways; *e. g.*, the immediate availability of rock phosphate to plants like corn is much greater on acid soils than on the non-acid ones. This is due to the removal and precipitation of the calcium bicarbonate from solution by the soil acids. The effect on the availability of the phosphate is the same as though the calcium bicarbonate were removed by the plant. Working with quartz cultures, Bauer[4] has shown that the availability of rock phosphate to corn may be increased by leaching the cultures occasionally. This leaching removes the excess of soluble calcium bicarbonate and the effect is again the same as though it were removed by the plant. The addition of ammonium salts has also been found to increase the availability of rock phosphate. This is at least partly due to the effect of ammonium salts in increasing the solubility of calcium bicarbonate, which has the same effect up to a certain point as is produced by removing the calcium bicarbonate.

There is no question but what the application of the law of mass action to a study of the conditions of solution of mineral matter around the plant roots makes possible a correct explanation of many differences in the feeding power of plants. The conditions necessary for the continued solution of mineral matter in which two soluble products are formed at the feeding points of roots are explained by this means. When only one soluble product is formed as is the case in the solution of phosphorus from iron and aluminum phosphate by hydrolysis and the solution of potassium from orthoclase feldspar by either hydrolysis or carbonation, and in fact the solution of most bases from the silicates of the soil, differences in the feeding power of plants for these are not explained directly by the foregoing principle. The reaction of these minerals with the solvent at the feeding points of roots may be represented as follows:

$$FePO_4 + 3H_2O \rightleftarrows Fe(OH)_3 + H_3PO_4.$$

$$2KAlSi_3O_8 + H_2CO_3 + H_2O \rightleftarrows$$
$$H_4Al_2Si_2O_9 + 4SiO_2 + K_2CO_3.$$

In both of the reactions only the last product is soluble and hence is the only product that can be removed either by the plant or in any other way. The conditions of solution are thus the same for all plants since water and carbonic acid are present in all cases. Differences in the feeding power of plants for the essential elements of these compounds must, therefore, be due to differences in conditions in the interior of the plants where the elements are actually used by being precipitated out of solution to form an essential part of plant compounds, making it possible for some plants to utilize more completely the elements from dilute solutions than others. In other words some plants can get along with more dilute solutions of certain elements than others.

The discussion in this connection will be limited to the base-forming elements. These elements are used by plants largely for at least three rather distinct purposes: (1) They are precipitated or held in physical and chemical combination with important colloidal plant compounds or complexes of which they may form an essential part. (2) In the form of the carbonate or bicarbonate they are used for the regulation of the reaction of plant proteins and other compounds, the plant sap, and precipitation of acids like oxalic out of solution. (3) They may act as carriers of acid forming elements. Potassium is used largely for the first purpose. Calcium is used for both the first and second purpose. Some

[4] *Soil Science*, 9, (1920), pp. 235-247.

plants, for example, the cultivated legumes, many of the cruciferæ, and buckwheat, require large amounts of calcium, much of which is probably used for the second purpose. Magnesium is probably used to a considerable extent for the third purpose as a carrier of phosphorus. Calcium and potassium may, of course, also be used for the third purpose, but it is only with the first two purposes that the present discussion is concerned.

In connection with the first purpose it is important to consider the following: There are always at least two important factors which determine how completely an element may be precipitated out of solution; viz., the reaction of the solution and the solubility of the precipitate formed. A proper regulation of the reaction is the most important factor in many precipitation processes. As a rule base-forming elements are more completely precipitated from a slightly acid or neutral solution than from a more acid one.

On this basis plants with a slightly acid or neutral sap especially of the leaves where the most active processes take place should be able to utilize potassium advantageously from a more dilute solution and feed more strongly on a slightly soluble potash mineral like feldspar than those plants with a more strongly acid sap, providing the reaction of the nutrient solution is favorable for the plants. Although the data available along this line are very meager, an examination of what there are indicates that this is actually the case. The sap of sweet clover leaves[5] ranges from slightly acid to slightly alkaline. Of the data known to the writer this is the only case in which the sap is sometimes alkaline. Theoretically the plant should feed strongly on the potash in feldspar and in actual test with quartz cultures Bauer[6] found it able to make a normal growth when forced to obtain all of its potash from feldspar. Of the common agricultural plants for which there are data available buckwheat has the most strongly acid sap of any in the leaves and it feeds very poorly on feldspar as should theoretically be the case. In tests with quartz cultures the writer found that alfalfa and sweet clover can obtain the necessary potassium for normal growth from more dilute solutions than corn and buckwheat which have a more acid sap. Much more data are needed before conclusions can be made definitely for all cases. The available data indicate strikingly the importance of the internal acidity on the feeding power of plants for potassium.

What has just been said in regard to potassium applies only when the nutrient or soil solution has a reaction which is favorable for the plant. If the nutrient solution is distinctly more acid than the plant sap, it will tend to make the plant sap more acid and the situation in regard to feeding for potassium may be greatly disturbed. In this connection it should be noted that alfalfa and sweet clover require relatively large amounts of potassium and quickly suffer from a lack of it, if the even dilute required concentration in the soil solution is not maintained due to a lack of the relatively insoluble potash minerals.

Undoubtedly the solubility of the potassium compounds formed in different plants is also a factor in the feeding power, but it seems reasonable to believe that to some extent the potassium compounds in different plants are similar and hence have somewhat similar solubilities. The solubility factor, therefore, because of its greater probable uniformity would not cause as great differences in the feeding power as the internal acidity factor which varies a great deal.

The relation of the feeding power of a plant for calcium which is to be used for the first purpose stated, to the acidity of the plant sap is probably the same as in the case of potassium. The amount of calcium required for the first purpose is, however, usually relatively small and the amount present in the soil solution relatively large so that the use of calcium for the first purpose is not a critical factor in the feeding power of a plant for calcium.

When plants use high amounts of calcium, the major portion is probably often used for the second purpose previously stated. The feeding power of a plant for calcium for this purpose seems to be related to the acidity of the plant sap, but the relation, as theoretically should be the case, is opposite to what it is

[5] Haas, A. R. C.: *Soil Science*, 9, (1920), pp. 341-368.

[6] *Soil Science*, 12, (1921), pp. 21-41.

with potassium, as is evident from the following: The reaction of the sap of different common agricultural plants has a range of p_H 4 to 8. This range is practically the same as that of the soil solution[7] in the humid region. It thus appears that plants through adaptation have come to have somewhat the same reaction as the medium on which they grow. It is well known that plants growing in solution cultures of unfavorable reaction tend to change the reaction of the culture to a more favorable one which is usually near that of the reaction of the plant itself. The plant does this[8] by utilizing a larger proportion of the acidic or basic constituents of the nutrient medium as the case may be. This again follows from the law of mass action, and the composition of the plant is thereby somewhat altered. Because of the highly buffered condition of the soil, plants can not materialy change its reaction in the way a solution culture is changed.

The unfavorable situation of a plant like alfalfa with a sap reaction of p_H 6 growing on a soil with a soil solution reaction of p_H 5 is thus apparent. This plant requires large amounts of basic material for the second purpose. How can it obtain this basic material for this purpose from a solution or medium which is ten times as acid as its own sap and system? It can not do it advantageously and hence the growth is slow and the content of basic material in the plant becomes lower than normal and even the reaction of the sap may become more acid than is normally the case. In extreme cases the plant not only grows slowly but also becomes sickly in appearance and easily succumbs to unfavorable weather conditions or parasitic diseases.

The buckwheat plant also requires a large amount of basic material. In fact, at the blooming stage it has a higher content of calcium than alfalfa, and yet it grows well on acid soils. The explanation of this is found in the high acidity of its sap, namely p_H 4 to 5. It can thus utilize advantageously a soil solution of p_H 5 as a source of basic material for the partial neutralization and regulation of its own sap and system.

The feeding power of a plant for calcium which is to be used for the second purpose is dependent largely on the normal acidity of the plant sap. The more acid the plant sap the more advantageously can the plant compete with another system—the soil and its solution, for neutralizing material which is largely lime in the case of plants and soils. Plants like oats and corn have a low content of calcium and probably use most of it for the first purpose. They apparently do not produce much acid which needs to be neutralized. Their sap is normally quite acid. They are thus well able to get all the calcium they need from even quite acid soils. The opposite relation of the acidity of the plant sap to the feeding power of many plants for calcium and potassium is now apparent. A high acidity means a low feeding power for potassium in dilute solution and a high feeding power for calcium needed for the neutralization and precipitation of acids.

The nature of the injurious or toxic action of acid and alkali soils on plants is also apparent. Theoretically the nutrient solution most favorably adapted to a plant as regards reaction would be one with a reaction the same as that of the plant sap. In case the plant needed a large amount of calcium and other basic elements, a nutrient solution slightly more alkaline than the plant sap would probably be best. When the nutrient solution is more acid than the plant sap, the plant by mass action is forced to utilize acid forming elements in greater proportion than is normally the case and as a result the composition of the plant is changed giving one with less than the normal amount of basic material. If the nutrient solution is much more acid than the plant sap the solid material of the plant due to lack of bases becomes so much more acid than is normally the case, that the plant sap also becomes more acid. The change in reaction of the whole plant system greatly interferes with the normal plant processes and as a result the plant grows slowly, becomes sickly and may even die. If a plant growing in a nutrient solution of favorable reaction were transferred to one with a much more acid reaction there

[7] Truog, E., *Soil Science*, 5, (1918), pp. 169-195.

[8] Hoagland, D. R., SCIENCE, N. S., 48, (1918), 422-425.

would undoubtedly follow an abstraction of basic elements from the plant compounds by the nutrient solution, and if the change were great enough, the plant would be killed.

In this connection it should be noted that the soil solution of acid soils often contains more calcium than the soil solution of less acid or neutral soils, and yet plants like alfalfa may suffer for lack of calcium in the former case and not in the latter, due to the fact that the acidity makes the calcium less available for certain purposes even though it is in solution. Availability is thus not only a question of solubility. It also depends on the form in which an element exists in solution.

SUMMARY

1. Differences in the feeding power of common agricultural plants for the essential elements of comparatively insoluble minerals are not due primarily to differences in amounts or kinds of acids excreted. The differences are due to several factors, some of which are concerned with external equilibrium conditions around the feeding roots, and others with internal equilibrium conditions inside the plant where the elements are actually used.

2. In case two soluble products are formed in the feeding region of the roots due to the action of carbonic acid on a mineral as is the case with rock phosphate, the feeding power follows the law of mass action and chemical equilibrium, being dependent on the removal of both of the soluble products either by the plant or partly by the plant and partly in other ways; thus plants with a high content of calcium feed strongly on rock phosphate because they remove both the soluble phosphate and soluble calcium bicarbonate in proper proportion.

3. If only one soluble product is formed as is the case with feldspar, the feeding power of the plant for the potassium depends on its ability to utilize potassium from a dilute solution which in turn depends largely on the acidity of the plant sap; the less acid the sap the greater the ability of the plant to utilize potassium from this source due to the fact that potassium is more easily and completely precipitated in the form of plant compounds in the less acid sap.

4. The feeding power of a plant for calcium which is used for the regulation of the reaction of the plant sap and colloidal system, and precipitation of acids, or for other elements used for these purposes, is also dependent upon the reaction of the plant sap but the relation is opposite to that of potassium; the more acid the plant sap the more easily can the plant compete with another acid system—the soil solution of an acid soil, for needed basic material.

5. In the case of base forming elements used for other purposes than regulation of the reaction and precipitation of acids, the relation of the feeding power for these to the plant sap is perhaps the same as for potassium.

6. There are undoubtedly many other factors which affect the feeding power of a plant but it seems that the ones given often exercise a controlling influence.

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THE TEACHING OF EVOLUTION

Every student, teacher and research worker in various fields of science must find cause for sincere regret in any attitude or movement that would limit the search for knowledge, or the presentation of scientific fact in the class room. There certainly is such a menace in the suggested limitation or elimination of the teaching of "evolution." It seems rather strange that such a conflict should be staged in a century made notable by outstanding advance in both pure and applied science. At no previous time have all men profited as much by the efforts of scientific workers. Then why such a hubbub about the teaching of what many think a fundamental concept of biological science?

The trouble seemingly was started by a group of conscientious folk who saw a sharp variance between their beliefs, religious or otherwise, and the theories presented and vigorously promulgated by many teachers. Some prominent men, as Mr. W. J. Bryan, made the matter one for public discussion, and the controlling trustees of certain schools requested or demanded that the doctrine of evo-