CONFIRMATION OF THE NUTRIENT MOBILITY CONCEPT OF SOIL-PLANT RELATIONSHIPS

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In an earlier paper (6), it was pointed out that the nutrient requirements of crops are determined to a great extent by the mobility in the soil of the available soil forms of the nutrients.

The concept was stated (6, p. 19) as follows: "As the mobility of a nutrient in the soil decreases, the amount of that nutrient needed in the soil to produce a maximum yield (the soil nutrient requirement) increases from a variable 'net' value, determined principally by the magnitude of the yield and the optimum percentage composition of the crop, to an amount whose value tends to be a constant. The magnitude of this constant is independent of the magnitude of the yield of the crop, provided the kind of plant, planting pattern and rate, and fertility pattern remain constant, and provided relatively similar soil and seasonal conditions prevail."

At one end of the mobility scale are the relatively immobile nutrient forms, such as the sorbed form of phosphorus and the exchangeable forms of potassium, calcium, and magnesium. Under the usual conditions existing in well-drained silt and clay loam soils, these available forms have little mobility. In effect, plant roots have to explore for them. The highly developed root-hair system of plants may have resulted from the need for an intensive feeding mechanism for these relatively immobile soil forms. In contrast, water plants have very simple root systems.

Because of the low mobility of the sorbed and exchangeable soil forms, a plant "feeds" from them in proportion to the size of its root and root-hair system, which is in proportion to the size of the plant. The level of a nutrient just adequate for the smaller yields obtainable in unfavorable seasons will, therefore, be equally adequate for the larger yields obtainable in more favorable seasons. The larger root system, with its larger numbers of root hairs, contacts proportionately more of the relatively immobile available forms. When there is an even distribution of sorbed phosphorus or exchangeable potassium in adequate amounts in the soil, each root hair obtains relatively the same amount of these nutrients. When seasonal conditions are unfavorable, plant growth will be restricted, but the sufficiency of a relatively immobile nutrient remains the same. The smaller plants still obtain adequate amounts and their composition is the same as that of the larger plants growing in a more favorable season.

Differences in planting pattern and/or planting rate require different levels of the relatively immobile nutrient forms. As the rate of planting is increased the number of root systems increase and competition between roots is intensified. The nutrient level adequate for the lower rate of planting is now inadequate for the higher rate of planting. The root hairs from roots of adjoining plants are now providing increased competition between plants for the nutrients. For example, with two corn plants in a hill the competition is less than with four plants in the hill. It follows that the sufficiency for yield of any given level of a nutrient is less with four competing corn plants, and that the nutrient requirements increase as the rate of planting increases. This means that the sufficiency for yield of the available soil form decreases as root systems of adjoining plants compete more strongly with each other.

Different kinds of plants, such as corn and wheat, have different rooting habits, and therefore differ in their ability to obtain the relatively immobile nutrient forms. Different kinds of plants also differ in composition at optimum yield, and the levels of the relatively immobile nutrients needed for optimum yield are, therefore, not directly related to size of yield, but are determined by (a) the kind of plant, (b) the planting pattern and rate of planting, (c) the form of the nutrient, and (d) the distribution of the nutrient in the soil in relation to the planting pattern.

A single plant growing in a very small pot requires a different distribution of nutrients than the same plants growing in a large pot.
phosphorus or exchangeable cationic amounts in the soil, in relatively the same amount.
When seasonal conditions are growth will be restricted, but relatively immobile nutrient.
The smaller plants still counts and their composition of the larger plants growing the season.
Planting pattern and/or plant-level densities of the relatively immobile nutrients. As the rate of planting larger but system increases between roots is intensified, due to the lower rate of uptake for the higher rate of nutrient uptake from roots of adjoining plants and increased competition for the nutrients. For example, in a hill the competition is more plants in the hill. It follows or yield of any given level of nutrient with four competing corn or nutrient requirements increase in planting increases. This is due for yield of the available as root system sizes of adequate more strongly with plants, such as corn and rooting habits, and thereby to obtain the relatively immobile nutrients. Different kinds of composition at optimum yield are, therefori to size of yield, but are a kind of plant, (b) the rate of planting, (c) the amount and (d) the distribution pattern relative to the nutrient composition.

The method of applying the fertilizer may be drilling in the row with the seed, broadcasting and disk, placing in the hill, or any similar method.

Once the c and c values for b and x, respectively, have been determined for a given crop, planted at a certain rate and in a certain pattern, the fertilizer requirement for each soil test value can be calculated for any desired approach to the 100 per cent yield level, provided the soil test used to measure b is the same as that used for the original correlation.

According to the mobility concept, it is because exchangeable potassium and the sorbed form of phosphorus are relatively immobile soil forms that they follow the Mitscherlich-Baule percentage efficiency concept (2).

Because nitrogen is relatively mobile in the soil, it is highly available. The net nitrogen needs, exclusive of leaching or other losses, are determined, therefore, by the size of the crop and its nitrogen composition at optimum yield, that is by the nitrogen content. Because of this, nitrate nitrogen follows Liebig’s law of the limiting nutrient (11).

For example, a 100-bushel corn yield contains, at maturity, around 150 pounds of nitrogen; the net nitrogen needs, exclusive of leaching or other losses or gains are, therefore, around 150 pounds of nitrogen per acre. As the yield possibility A varies with the favorableness of the soil and the season, or with the rate of planting, so will the nitrogen requirements vary. In corn belt soils, nitrogen is seldom deficient for the first stages of growth, and nitrogen deficiencies are rare in winter. A test of the leaf will generally give a positive nitrate test value. But as the corn grows, the tissue test value decreases on nitrogen-deficient soils, and a negative test is soon obtained. Typical nitrogen-deficiency symptoms follow and the yield will be reduced in proportion to the nitrogen deficiency. A potentially deficient level of nitrogen can be more than adequate during the first stages of growth, but will become deficient in the later stages of growth. The yield will be restricted in proportion to the nitrogen deficiency. Thus a crop’s net nitrogen needs are directly related to the size and nitrogen composition of the crop, because nitrate nitrogen is following Liebig’s law of the limiting nutrient. One amount of nitrate nitrogen can be adequate for only one yield of a given size and composition (11).

In contrast, when either phosphorus or potassium is inadequate, yield is restricted during all stages of growth; and, at all stages, as the yield varies with soil and season, the composition of the plant will be a deficient one.
Variations in method of application also vary the requirements for the relatively immobile nutrient forms, since the application pattern influences the availability of these forms for plant uptake.

Experiments have shown that when wheat is planted in 8-inch rows, at the rate of 90 pounds of seed per acre, and P₂O₅ is broadcast and disked ahead of planting, the yield equation becomes

\[ \log(A - y) = \log A - 0.0184b - 0.25 \log x \tag{8} \]

Here \( b \) is the \( P_1 \) soil test value in pounds of phosphorus per 2 million pounds of soil when the native phosphorus is rather evenly distributed in the soil, and \( x \) represents the pounds per acre of \( P_2O_5 \) applied in a broadcast and double-disked pattern ahead of planting. The values of \( A \) and \( y \) can be expressed either as percentage yield values or in terms of bushels of wheat per acre (7). In all the equations given in this paper, the value of \( b \) is in terms of \( P \) or \( K \) as pounds per 2 million pounds of soil, and \( x \) is in terms of \( K_2O \) or \( P_2O_5 \) also as pounds per 2 million pounds of soil.

These \( c_1 \) and \( c \) values for wheat, when the phosphate was broadcast, were found to hold equally well the following season, although the yields for all rates, on all four fields included in the study, were almost 50 per cent higher than in the previous year. However, the \( c_1 \) and \( c \) values, and hence the percentage sufficiency values, remained the same for both years.\(^1\)

Neither did the variations in soil type and season that occur along a 200-mile north-south line in Illinois from Dixon Springs to Urbana vary the \( c \) values for the four fields. When soils vary widely in chemical properties, changes in \( c_1 \) and \( c \) can be expected.

In the case of \( P_2O_5 \) for wheat, the 0.25 \( \log x \) form of the equation means that \( c \) for \( x \) varies with the rate of application when \( x \) is broadcast and disked. A value of 0.0088 for \( x \) for \( x \) is an equivalent value for the \( cx \) term, but is not as precise as the 0.25 log term.

The phosphorus composition of the wheat grain in the above study varied with the rate of application when the \( P_2O_5 \) was broadcast and disked, giving the composition equation

\[ \log(0.583 - y) = \log(0.583 - 0.0143b - 0.00117z) \tag{4} \]

where 0.583 is \( A \) and represents the maximum phosphorus composition of the grain (1). In contrast, when \( P_2O_5 \) was drilled in the row with the wheat, the phosphorus composition of the grain on all the treated plots was the same as on the check plots, that is, there was no change in composition with rate (18).

The yield equation for \( P_2O_5 \) drilled in the row with the wheat grain is

\[ \log(A - y) = \log A - 0.0184b - 0.0178z \tag{6} \]

which is a much higher efficiency of \( x \) for yield than for the broadcast method.

A study of the response of corn to potassium when corn was planted four kernels to the hill and phosphorus was broadcast and disked ahead of planting,\(^3\) gave the equation

\[ \log(A - y) = \log A - 0.0054b - 0.0068z \tag{6} \]

when \( b \) is the exchangeable potassium in an air-dried sample in terms of \( K \) in 2 million pounds of soil, and \( x \) is in terms of \( K_2O \) per acre, broadcast and disked. Another part of the same study gave the equation

\[ \log(A - y) = \log A - 0.015b - 0.02 P_2O_5 \tag{7} \]

for \( P_2O_5 \) when broadcast and disked ahead of planting.

For the same planting pattern, when the \( P_2O_5 \) is placed on two sides of the hill, 1½ inches away from and 1 inch below the seeds, using 4 seeds to the hill, the equation is

\[ \log(A - y) = \log A - 0.051b - 0.032 P_2O_5 \tag{8} \]

The value of 0.032 is based on the studies of Webb and Pesek using their data from non-calcareous soils (19). The Iowa group have also studied the residual effects of this method of application (6).

Tentative \( c \) values for soybeans\(^3\) planted in 40-inch rows are

\[ \log(0.583 - y) = \log(0.583 - 0.05b - 0.01 P_2O_5) \tag{9} \]

when the \( P_2O_5 \) is broadcast, disked, and plowed under, using a seeding rate of one bushel per acre in 40-inch rows. The low value of 0.01 for \( P_2O_5 \) is due in great part to the method of application, which involves much more mixing of the \( P_2O_5 \) with the soil than of application as dry granules.

The \( P_1 \) soil test value is an amount of the soil that is a "measure of" the "hidden" available phosphorus. In contrast, the condition suggested by the \( P_2O_5 \) test is practically the condition of the soil added from an air-dried sample.

Recent data by the \( P_1 \) test and by the rock phosphate test, both Illinois experiments, show that the native apatite fraction added have any effect on the rock phosphate test. Increase in yield of phosphorus is slightly higher when phosphorus is added, but yield increases are due by the \( P_2O_5 \) test. When added have left the rock phosphate test for phosphorus as the same as before.

The initial response observed is probably in soluble forms present in the rock phosphate test and added first applied.

It is now recognized (5), which also forms of phosphorus in the application program, that the rock phosphates are not uniform in growth. The "P₂O₅" test (14) based on the rock phosphates (4) also dissolves phosphorus as a test for phosphorus, but it does not dissolve phosphorus in the same proportion as the test for phosphorus (17) and the test for phosphorus (17). In contrast, the test (14) and the test (18) is satisfied with the citric acid extract, but not the mineral tests.

The soil test value is determined by the test for phosphorus (16) of the total amount of phosphorus in the soil. The test for phosphorus is based on the availability of phosphorus and the plant nutrient suggested by the "P₂O₅" test (14).

1 Unpublished data, 1955.
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of the \(P_2O_5\) with the soil than do such methods of application as drilling, disk ing, or hill dropping.

The \(P_1\) soil test does not extract the total amount of the sorbed phosphorus; it is, rather, a "measure of" the total amount, in that it extracts a proportionate part of the total. In contrast, the concentrated sodium acetate solution suggested by the writer in 1932 extracts practically the total exchangeable potassium from an air-dried sample (4).

Recent data by Hassan, involving a study of the \(P_1\) test and the response of corn to residual rock phosphate applications of 4 tons on the Illinois experiment fields, show that neither the native apatite forms nor the rock phosphate added have any direct effect upon yield. Where rock phosphate had been applied, the small increase in yield obtained was directly related to a slighter higher level of the sorbed form of phosphorus on the rock-phosphated plots, as measured by the \(P_1\) test. The 4 tons of rock phosphate added have left the soil almost as deficient in phosphorus as the plots receiving no phosphorus. The initial response to rock phosphate sometimes observed is probably due to a small amount of soluble forms present in the rock phosphate when first applied.

It is now recognized that the Illinois \(P_1\) test (5), which extracts both the sorbed and apatite forms of phosphorus, has no place in a soil-testing program, because the native apatite and rock phosphate forms are not available for crop growth. The "Universal" soil extracting solution (14) based on the writer's 1932 potassium test (4) also dissolves the unavailable apatite forms, but it does not effectively remove the available sorbed phosphorus, and is, therefore, valueless as a test for available phosphorus. The same is true of Truong's soil test for available phosphorus (17) and the writer's first phosphorus test (3). In contrast, the soil test suggested by Dyer in 1894, is satisfactory for soil phosphorus, because citric acid extracts only the sorbed phosphorus, not the unavailable apatite forms (8).

The soil test correlations described above are based on tests which measure, or are a measure of, the total amount of the available soil form of a nutrient. The idea that a soil test should measure the availability of a soil nutrient form, as suggested by Peach (16) and Hibbard (10), is untenable, because each nutrient form has a different efficiency for different kinds of crops, each planting pattern, and each planting rate. It is only when a test measures either the total amount or a proportionate part of a relatively immobile available soil form of a nutrient that it is possible to correlate the test value with the efficiency of the soil and fertilizer forms through the Mitscherlich-Baule percentage sufficiency concept as limited by the nutrient mobility concept.

The nutrient mobility concept serves to restrict the law of the limiting nutrient and the percentage sufficiency concept to those situations where they apply. This makes it possible to plan experiments which recognize the role played by each nutrient form in soil-plant relationships, especially those experiments designed for soil-test correlations which measure the efficiency of the soil and fertilizer forms for each crop.

That nitrogen follows Liebig's law of the limiting nutrient is illustrated by the well-known and accepted fact that a given level of nitrate nitrogen can be more than adequate for the first stages of growth, yet can become highly deficient in the later stages of growth, thus limiting yield to a certain number of tons or bushels of a nitrogen-deficient crop. In contrast, a certain level of sorbed phosphorus or exchangeable potassium, having a given distribution pattern in the soil, will have the same percentage sufficiency for yield, as the yield varies widely with the soil and season, provided the kind of crop and its planting pattern and rate remain constant.

The constancy of \(c_1\) and \(c_2\) for the soil and fertilizer forms, as yields vary widely with the soil and season, confirms the role they play as nutrients following the Mitscherlich-Baule percentage sufficiency concept (12, 13).

Liebig recognized that the soil nutrients could exist in relatively immobile forms and that "roots extract nutrients from those portions of the soil, penetrated with water, which are in direct contact with their absorbent surfaces" (11). Liebig did not, however, recognize that such sorbed forms would not follow his law of the limiting nutrient.

The rather simple role of the nitrate form of nitrogen as a limiting nutrient has now been generally recognized and accepted, and nitrogen recommendations are based principally on an
estimate of the probable yield and nitrogen composition of the mature crop.

But the role of phosphorus, potassium, and other exchangeable or sorbed nutrients as relatively immobile soil forms, following the percentage efficiency concept, has been generally overlooked. Very few field studies leading to correlations of soil forms with fertilizer requirements, through soil tests and the percentage efficiency concept, have been reported. F. van der Prau, who has also applied the percentage efficiency concept to soil fertility studies through the yield equation, is one of the few who recognize that c₁ and c can vary as other factors vary (15).

The failure of those interested in fertilizer requirements to successfully apply the Mitscherlich-Baule percentage efficiency concept to their results may be due in part to the fact that nitrogen was originally believed to follow the percentage efficiency concept, making it impossible to demonstrate the concept when nitrogen was deficient.

Given the c₁ values for exchangeable potassium and sorbed phosphorus and the soil test values for each, when b is in terms of pounds of P and K per acre 2 million pounds of soil, as measured by the soil tests for these nutrient forms, it becomes possible to illustrate the percentage efficiency concept. According to the percentage efficiency concept, as modified by the nutrient mobility concept, the percentage efficiencies of phosphorus and potassium for yield can be measured only when nitrogen is adequate, since it acts as a limiting nutrient. If phosphorus is 90 percent sufficient for a certain crop planted at a certain rate and in a certain pattern, and potassium is 80 percent sufficient, then 80 percent of a 90 percent yield will be obtained, or 72 percent of A, the yield possibility, as it varies from season to season. The percentage efficiency concept is illustrated in table 1 by the data of Hassan, mentioned above, who calculated the A values from the b, c₁, and y₀ values in the equation

$$\log (A - y₀) = \log A - c₁b$$

where b is the soil test value for either phosphorus or potassium and c₁ is the corresponding efficiency factor for the soil test value. In this case, y₀ is the yield of corn while b is the soil test value for either the P₁ test or the test for exchangeable potassium.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>P₁ Exchange</th>
<th>Yield</th>
<th>$P_1$</th>
<th>$K_1$</th>
<th>$P_x$ K</th>
<th>Yield Efficiency (4)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F/A.</td>
<td>K/A.</td>
<td>%</td>
<td>bu./A.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corn (Enfield field, 1944-1947)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RL</td>
<td>14.0</td>
<td>116</td>
<td>36.4</td>
<td>79</td>
<td>75</td>
<td>69</td>
</tr>
<tr>
<td>RLrP</td>
<td>17.2</td>
<td>123</td>
<td>38.7</td>
<td>87</td>
<td>76</td>
<td>66</td>
</tr>
<tr>
<td>RLrPK</td>
<td>19.0</td>
<td>208</td>
<td>52.2</td>
<td>88</td>
<td>96</td>
<td>84</td>
</tr>
<tr>
<td>Wheat (Carthage field, 1946)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RL</td>
<td>17</td>
<td>208</td>
<td>51.3</td>
<td>51.5</td>
<td>49.0</td>
<td>54</td>
</tr>
<tr>
<td>RLP</td>
<td>21</td>
<td>200</td>
<td>30.3</td>
<td>66.9</td>
<td>55.9</td>
<td>54</td>
</tr>
<tr>
<td>RLrPK</td>
<td>18</td>
<td>282</td>
<td>53.4</td>
<td>50.8</td>
<td>52.5</td>
<td>53</td>
</tr>
</tbody>
</table>

$c₁$ for exchangeable K = 0.0054
$c₁$ for the P₁ test value = 0.051

The data illustrated that, when the $c₁$ value for corn for exchangeable potassium and for the sorbed form of phosphorus are known, it is possible to calculate the percentage efficiency of each nutrient, and, hence, the A value for each treatment, from the soil test value. The product of their percentage efficiencies is the percentage of A obtainable, when both remain deficient, making it possible to calculate A from the yields obtained.

The data for corn, wheat, and soybeans from 18 experiment fields in Illinois over two different 4-year periods were analyzed by Hassan, with results confirming the c₁ and c values for the P₁ and exchangeable potassium tests as applied through the Mitscherlich-Baule percentage efficiency concept. The data serve to confirm the percentage efficiency concept, as limited by the nutrient mobility concept. They also demonstrate that applying rock phosphate and native apatite forms, have, as such, no availability for plant growth. The small increases in yield, where 4 tons of rock phosphate were applied, are associated with an increase of 2 or 3 pounds in the P₁ test value, leaving the soil almost as deficient as the untreated plots. The data also serve to illustrate the ineffectiveness of the native apatite forms, and they emphasize the fact that soil tests, such as the Universal soil testing solution, which extracts the sorbed apatite forms, and which extracts the sorbed apatite forms, are working with the available sorbed forms.

The correlations reported illustrate that fertility requirements form the available sorbed forms of yield. Variations in the amount of the soil and the factors that can vary yields widely require requirements for phosphorus. In contrast, the net yield is related to the size of yield increase and vary widely.

Evidence has been presented of the role of the relative size of the nutrients as for the Mitscherlich-Baule percentage efficiency concept. This evidence is in the c₁ values which show that when c₁ is added, and the average of the c₁ present, give yield and the dependent size of yield of the kind of crop, the size of planting, the form of distribution pattern and the planting pattern. This is illustrated by the phosphorus and potassium planting patterns and by different distribution patterns for different nutrient forms in the soil in a pattern. The c₁ and c values obtained remain constant for favorableness of the c₁ and c values for a crop, planting pattern, and with the form of the nutrient pattern of the nutrient in the planting pattern.

In contrast, c₁ values, representing as a relative highly available nutrients, inclusive of leaching were greater than the average of the c₁ present. Hence nitrate nitrogen is the limiting nutrient.

This establishes the Mitscherlich-Baule concept and of Liebig.
TABLE 1

Nutrient mobility concept and A values for field, 1941-1947 rotation period (yield = Carthage field, 1956)

<table>
<thead>
<tr>
<th>Fertilizer</th>
<th>Yield</th>
<th>Sulfate</th>
<th>Nitrates</th>
</tr>
</thead>
<tbody>
<tr>
<td>P</td>
<td>K</td>
<td>Pu K</td>
<td></td>
</tr>
<tr>
<td>20 lb. A</td>
<td>12 lb.</td>
<td>6 lb.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>50 lb.</td>
<td>25 lb.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>75 lb.</td>
<td>37 lb.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>100 lb.</td>
<td>50 lb.</td>
<td></td>
</tr>
</tbody>
</table>

The correlations reported in this paper illustrate that fertility requirements for the relatively immobile soil forms are unrelated to size of yield. Variations in the physical favorableness of the soil and the favorableness of the season can vary yields widely without changing the requirements for phosphorus and potassium. In contrast, the net nitrogen needs are directly related to size of yield and the nitrogen composition and vary widely as yields vary.

SUMMARY

Evidence has been presented which confirms the role of the relatively immobile soil forms of the nutrients as forms which follow the Mitscherlich-Baule percentage sufficiency concept. This evidence is in the form of field studies which show that the soluble fertilizer forms added, and the available soil forms already present, give yield responses which are independent of size of yield obtained, but depend on the kind of crop, the planting pattern and rate of planting, the form of the nutrient, and the distribution pattern of the nutrient relative to the planting pattern.

This is illustrated by field studies with phosphorus and potassium involving different crops, planting patterns and rates of planting, and different distribution patterns of the nutrient forms in the soil in relation to the planting pattern. The p and c values which have been obtained remain constant as yields vary with the favorableness of the soil and the season. But the c and e values vary widely with the kind of crop, planting pattern and rate of planting, and with the form of nutrient and distribution pattern of the nutrient in the soil in relation to the planting pattern.

In contrast, the nitrate form of nitrogen, acting as a relatively mobile nutrient form, is so highly available that the amount required, exclusive of leaching or other losses or gains, is no greater than the crop content at optimum yield. Hence nitrate nitrogen follows Liebig's law of the limiting nutrient.

This establishment of the validity of the Mitscherlich-Baule percentage sufficiency concept and of Liebig's law of the limiting nutrient confirms the nutrient mobility concept of soil-plant relationships.

REFERENCES

(16) Preece, M. 1948 Chemical methods for


APPLICATION OF GOUY'S DIFFUSE DOUBLE LAYER

Application of Gouy’s diffuse double layer has been developed for use with minerals by Schofield (6), Llout (5), and others. The present chapter was developed from a theoretical study of the work of de Boer, Verwey and others. The applications are derived from the relations dealing with the properties of the diffuse double layer, and a special case of the Boltzmann equation was developed. The equalities of the Boltzmann equation are:

\[ \sigma = \frac{e^{\frac{\psi - \psi_0}{2}}}{e^{\frac{\psi - \psi_0}{2}} + e^{-\frac{\psi - \psi_0}{2}}} \]

where \( \sigma \) is the ionic activity coefficient, \( \psi \) is the electric potential, \( \psi_0 \) is the electrical potential at the surface of an isolated particle, \( e \) is the charge of an electron, and \( \Lambda \) is the Debye length. The equation is valid for a suspension of colloid particles, in which one of the terms is zero.

It is easily seen that the behavior of a colloid such as clays, a negative potential takes place. It is visualized that the ion concentration at equilibrium is the oxidation of the suspension, the potential being found in the suspension. Properties of the colloid, such as electrical potential \( \psi_0 \), or electrical surface \( \sigma \), may be deduced from measurements.

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