THE ROLE OF SOLUBLE SILICATE ON THE FIXATION AND RELEASE OF PHOSPHORUS OF TROPICAL SOILS

A THESIS SUBMITTED TO THE GRADUATE SCHOOL OF THE UNIVERSITY OF HAWAII IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE

JUNE 1956

By
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Approved ________________
(Chairman)
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THE ROLE OF SOLUBLE SILICATE ON THE FIXATION AND RELEASE OF PHOSPHORUS OF TROPICAL SOILS

INTRODUCTION

The added phosphorus to many of the soils is made less available to the plants by a process whereby the readily soluble phosphorus is changed to a less soluble form by reaction with inorganic or organic fractions of the soil.

It has been shown by various investigators (1, 7, 8, 10, 17) that the application of soluble silicates to the soil has made more phosphorus available to the plants.

Chu and Sherman (3) have shown the high capacity of Hawaiian tropical soils to fix phosphorus. Sherman, Chu, and Sakamoto (22) have also found a definite relationship between the soluble silicate in the soil and the available phosphorus in the soil. They have shown, furthermore, an increase in the growth of Sudan grass with the application of soluble silicate to the soil.

There is a further need to study the change of the fixation capacity and the release of phosphorus when soluble silicate is applied to the soil. The objectives of this investigation, therefore, are to determine the effects of added soluble silicate on the capacity of typical tropical soils to fix phosphorus and on the release of difficultly soluble phosphorus from typical tropical soils.
REVIEW OF LITERATURE

The effect of soluble silicates in increasing the assimilation of phosphoric acid by the plant was recognized as early as 1864. During the period 1864 to 1904, Hall and Morison (10) obtained a considerable increase in the yield of barley with the application of sodium silicate to the soil.

Gile and Smith (8) grew millet in sand culture treated with colloidal silica to determine the effect of the latter on phosphate uptake by plants. Their results indicated that silica gel greatly increased the growth of plants supplied with rock phosphate, and only slightly increased the growth of plants supplied with acid phosphate. They believed that the beneficial effect of silica gel to the plants supplied with rock phosphate was due to the increased assimilability of this phosphate by increasing the quantity of phosphoric acid in solution. They also found that the growth of the plants in the test was related to the concentration of phosphorus in the plants, and seemed to show no relation to the concentration of the silica.

Bastisse (1) obtained a definite increase in phosphate availability and uptake by plants when silicate ions in solution were supplied.

By studying the response of sugar cane to phosphate fertilization, McGeorge (16) found that there was a definite relation between the availability of silica and phosphoric acid in some of the soils of the Hawaiian Islands. He
reported that soil reaction and lime also influenced the availability of the phosphoric acid in certain soils.

The application of sufficient silica was recommended by the sugar people in Hawaii (17) as one of the methods to improve the soils of high phosphate fixation. They stated that silica and molasses tended to decrease the fixing power of soils.

With other forms of silicates, Elliott (6) found that silico-superphosphate, a reverted phosphate prepared by mixing ground serpentine with superphosphate, showed distinct possibilities as a fertilizer for grasslands, and he stressed its value on soils which made water-soluble phosphates unavailable to the plant. Mariakulandai et al. in Nilgiris found increased availability of $P_2O_5$ in the lateritic soils with the application of silico-phosphate. The addition of lime or organic matter, however, had no effect on the availability of $P_2O_5$ (15).

Other workers have found that soluble silicate had no definite effect on the availability of phosphorus. Studies were made by Dewan and Hunter (5) to see the effect of silicates on the absorption of phosphorus by soybeans and Sudan grass. These investigators applied silicates of calcium, magnesium, and sodium, finely ground olivine, and finely ground serpentine to two soils, in a factorial combination with two levels of phosphorus. When the plants were analyzed, it was found that in soybeans, silicates had no significant effects upon the yield and the concentration of phosphorus.
Analysis of the Sudan grass at four weeks' growth showed some differences in the concentration of phosphorus in some of the treatments when compared with the check, but these differences were not observed at eight weeks' growth. The silica content of both plants increased with the application of most of the silicates.

Toth (24) found marked absorption of silica by rape, barley, and Sudan grass when grown in silicated soils, and definite increase in barley and Sudan grass yields with the application of calcium and magnesium silicates to the soil. There was no relation between the available phosphate contents of the soils and crop yields when tests were conducted in silicated and limed soils.

In a pot experiment, Laws (14) discovered that the treatment of a calcareous clay soil with soluble silicates did not significantly affect the phosphorus content of the plants. In some cases only, an increase in the crop yield was noted with the application of the soluble silicates.
SOILS USED

The four Hawaiian soils used in this experiment were soils of the Wahiawa, Honolua, Manana, and Lualualei families. These soils represent the great soil groups Low Humic Latosols, Humic Latosols, Humic Ferruginous Latosols, and Dark Magnesium Clays, respectively. The chemical and physical properties of these soils are described by Sherman in a soil survey prepared by Cline et al. (4).

LOW HUMIC LATOSOLS

These soils are developed under a dry to moderately humid climate with an annual rainfall varying from 10-80 inches. They are clay soils with physical properties of silty clay loams and are dominantly kaolinitic.

By the process of laterization, there is less silica and more oxides of iron and titanium in the solum than the parent material. The silica-sesquioxide ratio ranges from 1.2 to 1.7, although commonly between 1.4 and 1.5 for most soils, and the lowest ratios occur in the soils developed under the heaviest rainfall.

HUMIC LATOSOLS

The Humic Latosols are formed under heavier rainfall than the Low Humic Latosols. Profile studies, furthermore, revealed less silica and alumina but more oxides of iron and titanium. It is believed that there are more oxides in the Humic Latosols than in the Low Humic Latosols because more silica has been removed from the former. It is also suggested that profile consists of kaolinitic clays and oxide
clays. The silica-sesquioxide ratio of the colloid ranges from 0.5 to 0.9.

HUMIC FERRUGINOUS LATOSOLS

These soils have an A horizon in which oxides of iron and titanium are concentrated, and this horizon is characterized by a high specific gravity of the mineral particles. In a well-developed Humic Ferruginous Latosol, practically no evidence of any alumino-silicate clays is observed in the solum due to the removal of bases, silica, and alumina. A friable B horizon lies under the layer of high specific gravity. The specific gravity of the minerals in the B horizon is lower than in the A horizon, but there is little evidence of the presence of alumino-silicates in the B horizon. The silica to sesquioxide ratio of the colloid ranges from 0.1 to 1.1.

In the formation of the ferruginous laterite crusts, Sherman (21) has proposed that the hydrated oxides of iron and titanium are stabilized by dehydration in the surface horizon.

DARK MAGNESIUM CLAYS

The Dark Magnesium Clays are soils of semiarid regions, showing evidence of magnesium salinization. Dolomitization has occurred in areas where there is prevailing arid conditions most of the year. Gypsum crystals are also formed in the subsoil. The clays are montmorillonitic in character.
PROCEDURES

LABORATORY RESEARCH

1. The Effect of Added Soluble Silicate on The Fixation of Phosphorus in Soils.

Sodium meta-silicate (Na$_2$SiO$_3$·9H$_2$O) was applied to 100-g. samples of soil which had been passed through a 20-mesh screen. The rates are presented in table I:

<table>
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<tr>
<th>Treatment</th>
<th>Equivalent Rate of Application of Sodium Silicate (pounds per acre)</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>500</td>
</tr>
<tr>
<td>3</td>
<td>1000</td>
</tr>
<tr>
<td>4</td>
<td>2000</td>
</tr>
<tr>
<td>5</td>
<td>5000</td>
</tr>
</tbody>
</table>

The soils were placed in cans, and just enough distilled water was added to these soils to obtain mixtures which were fairly moist, but not to the extent that they became muddy or sticky. These soils were kept under this moist condition, with occasional addition of water, for one week and were then transferred into 500-mL Erlenmeyer flasks.

Ortho-phosphoric acid was used to prepare stock solutions of phosphorus, and 125-mL of the solutions containing 0.001, 0.01, or 0.1 g. of phosphorus were added to the flasks. The concentrations 0.001, 0.01, and 0.1 g. of phosphorus represented 20, 200, 2000 pounds of phosphorus respectively.
per acre of soil.

The flasks were shaken frequently during a period of eight hours, and the soil suspensions were filtered through a Buchner funnel. After the phosphorus solutions were recovered as filtrates, the soils were washed twice with distilled water to obtain a total volume of 200 ml. of filtrate plus washings. Charcoal black was used to decolorize the highly colored filtrates before phosphorus was determined colorimetrically by the molybdenum-phosphoric acid method of Kitson and Mellon (12). It was found that there was no appreciable adsorption of phosphorus by the charcoal black used in this experiment in those filtrates containing less than 150 micro-g. of phosphorus. There was, however, some adsorption of phosphorus in the higher concentrations. Corrections were, therefore, made by testing solutions of known phosphorus concentrations with and without the charcoal black treatment.

The concentration of phosphorus added, minus the concentration recovered after eight hours of frequent shaking, represented the amount of added phosphorus fixed by the soils. The percent fixation of the added phosphorus was calculated for each determination.

2. The Effect of Added Soluble Silicate on The Release of Difficultly Soluble Phosphorus.

The term difficultly soluble phosphorus will refer to the phosphorus which can be extracted with 0.003, 0.03, and 0.3 N hydrochloric acids.
The extraction of the difficultly soluble phosphorus was accomplished by using modified versions of Troug's method (25). The modifications to the original method included the use of 200 ml. of 0.003, 0.03 or 0.3 N hydrochloric acid instead of 400 ml. of 0.002 N sulfuric acid as the extracting agent and the colorimetric determination of the phosphorus in the extract by the method described by Kitson and Mellon (12).

Sodium silicate was also applied here to 100-g. samples of soil equivalent to the rates in table I. These soils were placed in cans, kept moist as previously described in section I, and air-dried. Portions of these air-dried soils equivalent to two g. of oven-dried soil were placed in 500-ml. Erlenmeyer flasks, and 200 ml. of either 0.003, 0.03, or 0.3 N hydrochloric acid were added. The soil suspensions were then mixed on an end-over-end shaker for 30 minutes, and the mixtures were filtered through a Buchner funnel. The filtrates were analyzed for extracted phosphorus after the first portion of the filtrate was discarded in order to avoid the possibility of error through adsorption of phosphorus on the filter paper. Charcoal black was also used to decolorize the soil extracts. The quantity of extracted phosphorus was calculated in micro-g. per g. of soil.

3. The Effect of Added Soluble Silicate on The pH of The Soils.

The pH of all soils were measured at each rate of application of sodium silicate. Suspensions of one part distilled water and one part soil were prepared with the air-dried
soils from the previous section 2. They were allowed to stand overnight, and the pH was determined with a Beckman pH meter.

4. The Effect of Added Soluble Silicate on The Differential Thermal Analysis Curve.

A study was also made to observe the effect of sodium silicate on the differential thermal analysis curve of one of the soils, the Humic Latosol. The quantity of sodium silicate that was used here was in great excess when compared to the quantity used in the other parts of this investigation. The results, therefore, represent only what may happen under a very heavy application of sodium silicate to the soil.

A small portion of the soil was placed in a tall 600-ml. beaker, and digested repeatedly with 30 percent hydrogen peroxide to destroy the organic matter. The soil was air-dried, and a small portion was ground, passed through a 65-mesh screen, and analyzed on the differential thermal apparatus. The portion that was analyzed here represented treatment 1 or the check.

Two-g. samples of the air-dried soil were then placed in small beakers and further treated with sodium silicate at a ratio of 1:1 and 1:2, one part soil to one part sodium silicate, and one part soil to two parts sodium silicate, respectively. Excess distilled water was added to each beaker, and these treated soils were allowed to stand for approximately two months. The samples were occasionally stirred with a glass rod, and additional water was added to
replace the loss from evaporation.

At the end of two months, the excess water was decanted from each beaker, and the soil was allowed to air-dry. The soil was ground, passed through a 65-mesh screen, then kept in a desiccator at 50 percent relative humidity for a few days, and analyzed on the differential thermal apparatus.

GREENHOUSE RESEARCH

The response of a plant to the application of sodium silicate was studied with pot tests using corn, *Zea Mays* var. *Hawaiian Sugar*, as an indicator on the Humic Latosol. The pot studies were divided into parts I and II, involving the fixation capacity of phosphorus and the release of phosphorus, respectively. Each part contained five treatments as outlined in table I and was replicated three times.

Part I contained N, P$_2$O$_5$, and K$_2$O at a rate of 400 pounds each per acre, while part II contained only N and K$_2$O at a rate of 400 pounds each per acre. In both parts, N was applied as ammonium sulfate, and K$_2$O as potassium chloride. In part I, P$_2$O$_5$ was applied as potassium dihydrogen phosphate, with the potassium in this salt being considered into the calculation of the K$_2$O together with potassium chloride.

The salts were mixed into seven pounds of soil and Spergon-DDT dusted seeds were planted in each pot. The seedlings were eventually thinned out to two per pot by eliminating the odd-sized plants, and these plants were harvested at the end of two months.
RESULTS

LABORATORY RESEARCH

1. The Effect of Added Soluble Silicate on The Fixation of Phosphorus in Soils.

Although all of the four soils were affected by the sodium silicate treatments to a certain degree, figures 1, 2, and 3 show that the soluble silicate had the most beneficial effect on the Humic Latosol by decreasing the fixation of the added phosphorus. The greatest decrease in the percent fixation of the added phosphorus, furthermore, was obtained when the most dilute phosphorus solution was added to the soil (see figure 1).

The responses of the Low Humic and Humic Ferruginous Latosols to the sodium silicate treatments were very low when the three different levels of phosphorus were added.

In the Dark Magnesium Clay, the application of 0.001 g. of phosphorus showed a fixation pattern similar to those of the Low Humic and Humic Ferruginous Latosols. The addition of 0.01 or 0.1 g. of phosphorus, however, gave results which were quite different. There was less fixation of the added phosphorus when compared with the latosols.

It is interesting to note that when the different concentrations of phosphorus solution were applied to the soil, the greatest percent fixation of the added phosphorus was obtained with 0.01 g. of phosphorus followed in order by 0.1 and 0.001 g. of phosphorus.
2. The Effect of Added Soluble Silicate on The Release of Difficultly Soluble Phosphorus.

Figures 4, 5, and 6 show the amount of phosphorus extracted from the three latosols with an acid of three different normalities. With the increase in the normality of the extracting agent, it was noted that more phosphorus was extracted per unit weight of soil. With the sodium silicate, definite release of phosphorus was observed only in the Humic Latosol, using 0.003 N and 0.03 N acids. When 0.3 N acid was used, however, there was less response to the silicate in the same soil.

There was hardly any or only a very slight response in the Low Humic and Humic Ferruginous Latosols to the silicate treatment when the three different concentrations of the extracting agent were used.

Figure 7 shows that the amount of phosphorus extracted from the Dark Magnesium Clay was many times greater than the amount extracted from the latosols. In this soil, the strongest extracting agent also released the largest amount of phosphorus. There appeared to be some response to the highest soluble silicate treatment with the strongest acid, but hardly any with the weaker acids.

3. The Effect of Sodium Silicate on The pH of The Soils.

The application of the silicate to the soil caused a greater change in the pH of the Humic and Low Humic Latosols than in the Humic Ferruginous Latosol or the Dark Magnesium Clay (see figure 8). However, the influence on the hydrogen
ion concentration is great in the Humic Ferruginous Latosol because this is the most acid soil and change in the pH in this range represents a greater change in the hydrogen ion concentration.

4. The Effect of Added Soluble Silicate on The Differential Thermal Analysis Curve.

Differential thermal curves was presented by Grim and Rowland (9) for a large number of clay minerals and other hydrous materials. In the analysis of goethite and limonite, they obtained curves showing endothermic peaks at about 400 °C. and 300 °C., respectively. They believed that these peaks may not be the same in all cases due to differences in the material studied and the several forms of hydrated ferric iron oxide.

With gibbsite and diaspore, they obtained curves that were similar to the findings of other workers. There was an endothermic peak at about 350 °C. for gibbsite, and a similar peak was observed at about 550-565 °C. for diaspore.

The reaction of kaolinite was listed as an endothermic peak at 550-600 °C. and an abrupt exothermic reaction at 950-1000 °C. Hydrated halloysite displayed a similar curve as kaolinite with the exception of an additional sharp endothermic reaction at 100-150 °C. accompanying the loss of pore water. In montmorillonite, the endothermic reaction at this low temperature region was attributed to the loss of the swelling water. The characteristic reaction of the montmorillonites was listed as an initial endothermic peak at
100-250 °C., as previously mentioned, a second endothermic peak between 600 °C. and 700 °C. due to the loss of lattice water, and a third endothermic peak at about 900 °C. corresponding to the final breakdown of the montmorillonite lattice, followed by an exothermic effect.

Figure 9 shows that treatment 1, the check, displayed a slight endothermic peak at about 130 °C., another endothermic peak at about 330 °C., and another slight endothermic peak at about 560 °C.

Treatment 2, 1:1 of soil:sodium silicate, however, showed an increase in the peak at about 130 °C., a great decrease in the peak at about 300 °C., and the removal of the peak observed in treatment 1 at about 560 °C.

Treatment 3, 1:2 of soil:sodium silicate, also exhibited an endothermic peak at about 140 °C., slightly more than treatment 2. The peak at about 300 °C. decreased further, and rises in the curve were observed above 600 °C. and 800 °C.

GREENHOUSE RESEARCH

Two to three weeks after the seeds were planted, there was distinct "purpling" of the leaves of plants receiving treatments 1 to 4 in both parts I and II. At one month, the "purpling" began to disappear from the plants receiving treatments 2, 3, and 4. The checks, treatment 1, however, still showed distinct "purpling."

In part I, at two months or harvest time, no "purpling" was observed. In part II, however, slight "purpling" was still confined to some of the plants receiving treatments 1
and 2. The sheaths of the oldest leaves, furthermore, were observed to be purple on most of these plants.

Tables 2 and 3 show that there was a definite influence of the soluble silicate on the growth of the corn plant at two months. When these two tables are compared, it is interesting to note that the addition of phosphorus to the checks did not make much difference on the plant growth. With the addition of the soluble silicate, however, the plant growth was accelerated in those pots receiving phosphorus. Although no phosphorus was added to the soils of part II, an increase in the plant weight was observed with the silicate treatment. A corresponding increase in percent dry matter was also observed in parts I and II. The soil reactions of both parts are almost similar even though it was slightly more acid in part II.
TABLE II. EFFECT OF SODIUM SILICATE ON THE GROWTH OF ZEA MAYS AT TWO MONTHS ON HUMIC LATOSOL RECEIVING 400 POUNDS EACH PER ACRE OF N, P \(_{25}\), AND K \(_{20}\)

<table>
<thead>
<tr>
<th>Application of Sodium Silicate (lb./acre)</th>
<th>Fresh Weight of Plants (minus roots)</th>
<th>O. D. Weight of Plants (minus roots)</th>
<th>Percent Dry Matter</th>
<th>pH of Soil After Harvest</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>29.6</td>
<td>4.5</td>
<td>15.2</td>
<td>3.9-4.0</td>
</tr>
<tr>
<td>500</td>
<td>43.1</td>
<td>7.1</td>
<td>16.5</td>
<td>3.9-4.0</td>
</tr>
<tr>
<td>1000</td>
<td>43.1</td>
<td>7.2</td>
<td>16.7</td>
<td>3.9-4.0</td>
</tr>
<tr>
<td>2000</td>
<td>73.7</td>
<td>13.2</td>
<td>17.9</td>
<td>4.1</td>
</tr>
<tr>
<td>5000</td>
<td>80.5##</td>
<td>14.5##</td>
<td>18.0</td>
<td>4.3-4.5</td>
</tr>
</tbody>
</table>

# The yield data represent the average weight of three pots with three plants in each pot.

## Weight of one pot only. The other two pots of the three replicates contained only one plant each due to the death of the second plant.
### TABLE III. EFFECT OF SODIUM SILICATE ON THE GROWTH OF ZEA MAYS AT TWO MONTHS ON HUMIC LATOSOL RECEIVING 400 POUNDS EACH PER ACRE OF N AND K₂O #

<table>
<thead>
<tr>
<th>Application of Sodium Silicate (lb./acre)</th>
<th>Fresh Weight of Plants (minus roots)</th>
<th>O. D. Weight of Plants (minus roots)</th>
<th>Percent Dry Matter</th>
<th>pH of Soil After Harvest</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>29.2</td>
<td>4.5</td>
<td>15.4</td>
<td>3.8-3.9</td>
</tr>
<tr>
<td>500</td>
<td>21.6</td>
<td>3.4</td>
<td>15.7</td>
<td>3.9</td>
</tr>
<tr>
<td>1000</td>
<td>33.0</td>
<td>5.4</td>
<td>16.4</td>
<td>3.9-4.0</td>
</tr>
<tr>
<td>2000</td>
<td>37.3</td>
<td>6.3</td>
<td>16.9</td>
<td>3.9-4.0</td>
</tr>
<tr>
<td>5000</td>
<td>49.2</td>
<td>8.0</td>
<td>16.3</td>
<td>4.2-4.3</td>
</tr>
</tbody>
</table>

# The yield data represent the average weight of three pots with three plants in each pot.
DISCUSSION OF RESULTS

Figures 1, 2, and 3 show the high capacity of the Hawaiian latosols used in this study to fix phosphorus when different concentrations of phosphorus solution were used.

Phosphate fixation in the acid Hawaiian soils was found by Chu and Sherman (3) to occur largely by the hydrated free oxides with maximum fixation at pH 3.0-4.0, and the minimum in the neutral to alkaline reactions. The fixation by the 2:1 and 1:1 crystal lattice clays was also shown to be less than the fixation by the hydrated free sesquioxides.

Figures 1, 2, and 3 also indicate that the Dark Magnesium Clay showed less percent fixation of the added phosphorus with the increase in the strength of the phosphorus solution. Chu and Sherman (3) have found that fixation in alkaline soils occurred largely by chemical precipitation by magnesium and calcium ions, with the maximum fixation occurring at pH 10.0 and the minimum at pH 5.0-6.0. It is believed that the change of pH may have been one of the reasons for less percent fixation of the added phosphorus when the stronger phosphorus solution was used.

The application of sodium silicate to the four soils resulted in a decrease in the fixation of the added phosphorus to a certain degree. Treatment with soluble silicate had a greater depressing effect on phosphate fixation in the Humic Latosol than in the other latosols. There was, furthermore, a greater reduction in the percent fixation of the added phosphorus with the addition of the most dilute
phosphorus solution. The reason for the greater percent fixation of the added phosphorus with the addition of 0.01 g. of phosphorus over 0.1 g. is not known.

Kurtz et al. (13) obtained results indicating that the adsorption of phosphorus by a soil increased with the concentration of the phosphorus in the solution. The amount that was adsorbed, however, gradually approached a level above which there was hardly any further adsorption regardless of the increases in the concentration of the phosphate solution.

Reifenberg and Buckwold (19) found that there was a significant release of silica from some Israeli soils and other clay minerals by the orthophosphate anion. They also found that a dilute neutral solution of sodium silicate released the fixed phosphate of the phosphated soils and clay minerals. The presence of the soluble silicate in the phosphated solution with which the soils and clay minerals were being treated, furthermore, depressed the phosphate-retention silica-release reaction. With increasing acidity, the effectiveness of the silicate decreased.

In the study of the effect of the soluble silicates on soil properties, Laws (14) showed that there was an increase in the solubility of the soil phosphorus with increasing amounts of applied silicate when different extracting agents were used to extract the phosphate ion. Other workers who obtained similar results were also cited.

In his study of the displacement of adsorbed phosphate ions from soil, Toth (24), on the other hand, believed that
the displacement was dependent upon the pH and independent of
the silicate-ion concentration. He also found that there was
no displacement of native phosphates from soil colloids sus-
pended in acid solution of sodium silicate (23).

With the addition of the sodium silicate, there was a
definite release of phosphorus from the Humic Latosol, using
0.003 N and 0.03 N hydrochloric acid (see figures 4, 5, and
6). It is not surprising to observe no definite trend when
the soil was extracted with the 0.3 N acid because this acid
may have been of such strength as to extract the entire amount
of phosphorus which may ordinarily be influenced by the so-
dium silicate treatment.

In the Dark Magnesium Clay, response to sodium silicate
was observed with the 0.3 N acid (see figure 7). In this
alkaline soil, the release of the phosphorus may have been
due to two reasons—the occurrence of a more favorable pH
to prevent fixation, and some beneficial effect of the so-
dium silicate at that pH. No beneficial effects were observed
with the 0.003 and 0.03 N acids.

No attempt was made to determine the mechanism by which
the soluble silicate acted to reduce the fixation of the
added phosphorus and to render available the difficultly
soluble phosphorus in the soils. The data obtained from the
differential thermal analysis of the Humic Latosol, however,
suggest that the check was composed chiefly of hydrated
oxides, and by the heavy treatment of sodium silicate, ther-
mal curves other than that of hydrated oxides were obtained.
In a calcareous clay soil, Laws (14) believed that the silicate prevented the adsorption of the phosphate by masking the active adsorption centers of the soil colloid and was held more strongly than the phosphate ion. He pointed out that the dehydration of the colloids from a silicate-treated soil freed of calcium carbonate, organic matter, and free iron and aluminum oxides, indicated that the OH ions were involved in the reaction between the soluble silicates and the colloids.

Iler (11) has attributed the availability of phosphorus to the ability of the silicate ion to displace the phosphate ion from the surface of the soil or colloidal material. Kurtz et al. (13) postulated that the ability of certain anions to replace adsorbed phosphate was related to the tendency of these ions to form stable complexes with ions in the clay mineral lattice. In a discussion, Russell (20) believed that the beneficial effect of sodium silicate in phosphate availability was also due to the ability of the silicate ions to replace the phosphate ions.

To obtain a clear picture of the mechanism at work, it is necessary that chemical analysis, x rays, and other tests be conducted together with the differential thermal analysis.

The greenhouse tests showed that sodium silicate influenced the growth of the corn plant in the Humic Latosol whether phosphorus was added to the soil or not. The addition of phosphorus did not make any difference on the growth of the check plants, where the added phosphorus may have
become unavailable by the high fixation capacity of this soil. The addition of the soluble silicate, however, accelerated the plant growth in those soils receiving phosphorus. By some mechanism, the silicate was responsible for the increased growth of the plants. The beneficial effect was also noted on the growth of the plants which received no phosphorus. The beneficial effects of sodium silicate, furthermore, was noted by the decrease in the "purpling" of the leaves, and the increase in the percent dry matter.

Chu and Sherman (3) obtained better plant growth in soils with free hydrated sesquioxides removed than in soils containing the free hydrated oxides. Montmorillonitic soils, furthermore, gave better plant growth than the kaolinitic soils.

Bonner and Galston (2) stated that, in general, phosphorus deficient plants were stunted in growth with dark green leaves and often developed purple or reddish anthocyanin pigments. Other symptoms which may also be present were the development of areas of dead tissue on leaves, petioles, or fruits, often resulting in leaf fall.

In a monograph prepared by Pierre and Norman (18), Dean and Fried stated that when the supply of the soil phosphorus was the limiting factor in plant growth, the increased addition of phosphorus as a fertilizer resulted in increased yields of the dry matter.
Toth (23) showed that the removal of the free iron oxides from colloids reduced the degree of phosphate adsorption.

Although no definite statement may be made, data obtained from the differential thermal analysis and the growth of the corn plants suggest that the beneficial effect of sodium silicate may be due to the reaction of the silicate with the free hydrated oxides to reduce the fixation of the added phosphorus and to make available some of the difficultly soluble phosphorus in the soil.
SUMMARY

Sodium silicate was applied to typical tropical soils to determine the effects of added soluble silicate on the fixation of the added phosphorus and the release of the difficultly soluble phosphorus. Differential thermal analysis and pot experiments were also conducted on a soil of the Humic Latosols to study further the effect of adding soluble silicate to the soil.

Based on the results of this investigation, the following statements are made:

1. The application of sodium silicate is beneficial to the soils of the Humic Latosols.
2. The application of sodium silicate is not beneficial or is only slightly beneficial to the soils of the Low Humic Latosols, Humic Ferruginous Latosols, and the Dark Magnesium Clays.
3. The effect of sodium silicate on the reduced percent fixation of the added phosphorus is most pronounced with the most dilute phosphorus solution.
4. Although more phosphorus is extracted from the soil of the Humic Latosol with the stronger extracting agents, the greatest effect of the sodium silicate is noted with the weakest extracting agent.
5. The differential thermal analysis of the soil of the Humic Latosols reveals a change in the thermal curves with the heavy addition of sodium silicate.
6. Pot tests with corn, *Zea Mays* var. *Hawaiian Sugar*, in the Humic Latosol show increases in the plant growth and percent dry matter with the application of sodium silicate to the soil.
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APPENDIX
FIG. 1. THE EFFECT OF SODIUM SILICATE ON THE FIXATION OF 0.001 GRAM OF PHOSPHORUS IN FOUR DIFFERENT SOILS

Application of sodium silicate in pounds per acre

Percent fixation of added phosphorus

LHL: Low Humic Latosol
HL: Humic Latosol
HFL: Humic Ferrug. Latosol
DMC: Dark Magnesium Clay
FIG. 2. THE EFFECT OF SODIUM SILICATE ON THE FIXATION OF 0.01 GRAM OF PHOSPHORUS IN FOUR DIFFERENT SOILS

Percent fixation of added phosphorus

Application of sodium silicate in pounds per acre

LHL: Low Humic Latosol
HL: Humic Latosol
HFL: Humic Ferrug. Latosol
DMC: Dark Magnesium Clay
FIG. 3. THE EFFECT OF SODIUM SILICATE ON THE FIXATION OF 0.1 GRAM OF PHOSPHORUS IN FOUR DIFFERENT SOILS

Application of sodium silicate in pounds per acre

Percent fixation of added phosphorus

LHL: Low Humic Latosol
HL: Humic Latosol
HFL: Humic Ferrug. Latosol
DMC: Dark Magnesium Clay
FIG. 4. THE EFFECT OF SODIUM SILICATE ON THE EXTRACTION OF DIFFICULTLY SOLUBLE PHOSPHORUS WITH 0.003 N HYDROCHLORIC ACID IN THREE LATOSOLS

<table>
<thead>
<tr>
<th>Application of sodium silicate in pounds per acre</th>
</tr>
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<tbody>
<tr>
<td>0</td>
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<tr>
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<tr>
<td>Extraction of phosphorus in micrograms per gram of soil</td>
</tr>
<tr>
<td>LHL: Low Humic Latosol</td>
</tr>
<tr>
<td>HL: Humic Latosol</td>
</tr>
<tr>
<td>HFL: Humic Ferrug. Latosol</td>
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FIG. 5. THE EFFECT OF SODIUM SILICATE ON THE EXTRACTION OF DIFFICULTLY SOLUBLE PHOSPHORUS WITH 0.03 N HYDROCHLORIC ACID IN THREE LATOSOLS

LHL: Low Humic Latosol
HL: Humic Latosol
HFL: Humic Ferrug. Latosol

Extraction of phosphorus in micrograms per gram of soil

Application of sodium silicate in pounds per acre
FIG. 6. THE EFFECT OF SODIUM SILICATE ON THE EXTRACTION OF DIFFICULTLY SOLUBLE PHOSPHORUS WITH 0.3 M HYDROCHLORIC ACID IN THREE LATOSOLS

LHL: Low Humic Latosol
HL: Humic Latosol
HFL: Humic Ferrug. Latosol

Extraction of phosphorus in micrograms per gram of soil

Application of sodium silicate in pounds per acre
FIG. 7. THE EFFECT OF SODIUM SILICATE ON THE RELEASE OF DIFFICULTLY SOLUBLE PHOSPHORUS FROM DARK MAGNESIUM CLAY WITH HYDROCHLORIC ACID OF THREE DIFFERENT NORMALITIES
FIG. 8. THE EFFECT OF SODIUM SILICATE ON THE pH OF FOUR DIFFERENT SOILS

Application of sodium silicate in pounds per acre
FIG. 9. THE CURVES RESULTING FROM THERMAL ANALYSIS OF HUMIC LATOSOL TREATED WITH SODIUM SILICATE

1. Check
2. 1:1 of soil:sodium silicate
3. 1:2 of soil:sodium silicate

Temperature °C