AN INVESTIGATION OF A SUSPECTED CASE OF
PHOSPHATE FIXATION

A dissertation submitted in part requirement
for the Associateship of the Imperial
College of Tropical Agriculture

by

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TRINIDAD, B.W.I.

1939.
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The importance to agriculture of an adequate supply of the phosphatic nutrient has long been realized and its addition to the soil in the form of fertilizers has become a world-wide agricultural practice. Tropical soils in particular have been

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Introduction.

The importance to plant growth of an adequate supply of the phosphatic nutrient has long been realised and its addition to the soil in the form of fertilizers has become a world-wide agricultural practice. Tropical soils in particular have been found to be very deficient in this nutrient and its application in such regions has frequently resulted in startling increases in crop yields. Such a deficiency may result from a low total supply of phosphorus in the soil but this is rarely the case; generally it is due to the low availability of that which is present.

Some soils possess the ability of rapidly converting phosphorus added as a soluble phosphate into a form unavailable to the plant and this phenomenon is known as fixation.

Much work has been carried out on the subject of fixation and a good summary of these investigations is to be found in a paper by L.E. Davies (2). Of the various theories advanced in explanation of the phenomenon the most widely accepted is that which ascribes it to the formation of insoluble iron and aluminium phosphates as a result of those metals in the soil solution under suitable conditions of acidity.

The simplest manner in which to overcome the difficulty is obviously to saturate the soil by heavy dressings of soluble phosphates and thus to satisfy its fixation demands but this method is rarely economically possible and other means have been sought. Several workers have recommended the addition of lime to such soils, thus throwing the iron and aluminium out of solution by the alteration of the soil reaction, while others have obtained considerable success by the addition of silicates which combine with
the metals and render them inactive. The use of slowly-soluble compounds, such as organic phosphates, and the localisation of fertilizers in small areas so that high concentrations of phosphate are produced are other methods which have been investigated and in many cases proved successful.

The study of phosphate fixation at this College on the local soils arose from an experiment carried out at the Cotton Station, St. Augustine, in 1936-37. As a result of this, experiments have been designed this year to test for, and possibly modify, the fixation effect.
Table I. Available P$_2$O$_5$ (ppm) on Cotton Station plots, March 1937, after application of superphosphate dressings.

<table>
<thead>
<tr>
<th>Depth of sample (inches)</th>
<th>Superphosphate dressing (cwts/acre)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-12</td>
<td>29  43  67  132</td>
</tr>
</tbody>
</table>
Review of previous experiments at St. Augustine.

1. An experiment was carried out during the season 1936-37 at the Cotton Station to test the effect of superphosphate on the growth of cotton. Four different rates of application (0, 3, 10 and 20 cwts per acre) were tested, while a basal dressing of nitrogen and potash and 5 tons per acre of ground limestone was applied uniformly over the whole field.

Although no measurements were recorded the result was striking in that on plots treated with only 3 cwts of superphosphate per acre or none the growth was extremely bad; on those treated with 10 cwts the cotton was fairly good, but under the 20 cwts dressing the cotton was very good, suggesting that fixation had occurred and that large dressings of phosphate were necessary to counteract it. Analysis of the surface foot of soil in March, 1937, showed that the available phosphate content under the 0 and 3 cwts treatments was less than that usually required for healthy plant growth on that type of soil, that the 10 cwts produced an adequate supply and that the high rate of application had produced an abundance of phosphate available for plants. The relationship between the amount of superphosphate applied and the final available-phosphate content was, however, very nearly linear (see Table I).

2. A further experiment was carried out in 1937-38 in an adjacent field by Corby (1) using a mixed crop of cotton and maize to test the effect of different dressings of superphosphate. Owing to the localisation of the manure in "pockets" (to correspond with briquettes, which were also being tested) near the plants it is
difficult to compare this "3 cwts. per acre" dressing with the normal broadcast rate. The result was an increasing response in the crop from 3, 10 and 20 cwts. per acre, the latter being little better than the 10 cwts. dressing. The briquettes used were useless as a manure, probably owing to the fact that since the superphosphate was mixed with cement all the phosphate was rendered so insoluble as to be unavailable to the plants.

3. Using the same soil in cigarette tins with corresponding dressings of superphosphate, Corby found that there was an increasing response from superphosphate measured by the growth of tomato seedlings. There was a close correlation between plant growth and the available phosphate content of the soil as measured by the Truog method.

The soil under investigation

All the field experiments in this work have so far been carried out at the Cotton Station on a red detrital soil derived from mica schist. It is a sandy soil of low fertility and acid in reaction. The sample used in pot cultures in the experiments to be described was taken from the south side of Field 52 immediately to the north of this year's experiment with cotton and maize, and has had no manurial treatment in recent years. The sample (which will be referred to as sample B) was taken from the side of a pit between depths 6 and 18 inches so as to eliminate the effect of the surface organic matter derived from cane trash.

A second sample of soil (sample A) was taken from a pit
in Professor Hardy's garden about half a mile south of the Cotton Station on land which has been under grass for many years, the sample being collected between the 12 and 24-inch levels. Both "A" and "B" are derived from the same detrital soil and are very low in available phosphate. "A" is more sandy and rather less fertile, containing less nitrogen and organic matter and being slightly more acidic as will be seen from the routine analysis given in Table II.

Table II. Analysis of the soil samples.

<table>
<thead>
<tr>
<th></th>
<th>Sample &quot;A&quot;</th>
<th>Sample &quot;B&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth of sample</td>
<td>12-24&quot;</td>
<td>6-18&quot;</td>
</tr>
<tr>
<td>Index of texture</td>
<td>15</td>
<td>23</td>
</tr>
<tr>
<td>Sand %</td>
<td>46.5</td>
<td>38.5</td>
</tr>
<tr>
<td>Normal pH</td>
<td>6.0</td>
<td>6.7</td>
</tr>
<tr>
<td>Exchange pH</td>
<td>5.3</td>
<td>6.0</td>
</tr>
<tr>
<td>CaCO3</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Org. Matter %</td>
<td>0.89</td>
<td>1.87</td>
</tr>
<tr>
<td>Nitrogen %</td>
<td>0.07</td>
<td>0.14</td>
</tr>
<tr>
<td>C/N ratio</td>
<td>7.8</td>
<td>7.8</td>
</tr>
<tr>
<td>Avail. nutrients</td>
<td>123</td>
<td>40</td>
</tr>
<tr>
<td>Rate of solution</td>
<td>9</td>
<td>15</td>
</tr>
<tr>
<td>Avail. P2O5(ppm)</td>
<td>4</td>
<td>9</td>
</tr>
<tr>
<td>K2O (ppm)</td>
<td>71</td>
<td>67</td>
</tr>
</tbody>
</table>
Fig. 1. Available P content of garden soil (Tracy analysis).

Available P in soil (ppm)

P₂O₅ added as KH₂PO₄ (parts per million of soil)
Laboratory experiments, using the Truog method of analysis for available phosphate.

These experiments consisted in mixing samples of soil with known amounts of phosphate in solution or suspension to form a mud which was then dried and analysed to determine the content of phosphate remaining available, as measured by the Truog test. (6) (This test consists essentially in extracting the phosphate with a N/500 solution of sulphuric acid, which is then analysed colorimetrically by the ceruleo-molybdate method.) In a phosphate-fixing soil it would be expected that small additions of phosphate would produce little or no increase in the available P$_2$O$_5$ content, but that after some limiting value corresponding to the ability to fix, further additions would give proportionate increases in the Truog figure.

First experiment, using potassium di-hydrogen phosphate.

Potassium di-hydrogen phosphate was selected because of its solubility and the fact that it is easily procured in a pure state. A solution of this salt was made up so as to contain 1 gram of P$_2$O$_5$ per litre and portions were added to 50 gram samples of the garden soil ("A") to give known additions of P$_2$O$_5$ ranging from 0 to 500 parts per million. Enough water was added in each case to produce the same consistency of mud (25 ccs of solution plus water for each 50 grams of soil) and the samples were then dried in an oven at 80°C to encourage fixation and analysed by the Truog test. Later trials revealed that this oven-drying reduced the available phosphate content appreciably below that obtained after ordinary air drying such as might occur in the field.

The results, which are shown graphically in fig.1, show that although most of the added phosphate had become unavailable
Fig. 2. Available P₂O₅ content of Cotton Station Soil (Troy analysis)

P₂O₅ added as Superphosphate (parts per million of soil)
the relation between the phosphate added and that remaining available was nearly linear, except at very low values when all the P2O5 added appears to have been fixed.

**Second experiment, using superphosphate.**

A suspension of superphosphate was used in place of potassium di-hydrogen phosphate in an attempt to emulate field conditions a little more closely, as the calcium constituent of this commercial fertilizer may affect the availability in the soil. 200 gram samples of Cotton Station soil ("B") were used and the mud produced by adding the superphosphate suspension was this time dried in the open-air. Fig.2 is a graphical representation of the results, the figures being the means of two duplicates.

Here the loss of available P2O5 is practically 60% throughout and there is little indication of any greater fixation at low concentrations. It must be noted that in these laboratory tests where the phosphate is added uniformly to the whole sample of soil the fixation would tend to be greater than in the field, where the fertilizer is applied at the surface and there is less intimate contact with the soil. Further, it must be remembered that the important consideration is the availability of phosphate to the plant and the Truog test should not be interpreted too literally as an indication of the plant's behaviour without confirmation in pot or field experiments.

**Third experiment: action of phosphate in presence of lime.**

In a phosphate-fixing soil the effect of lime may so alter the pH that the dissociation of Fe and Al ions is reduced and phosphate remains available. In such a case the concentration of lime is important, since an excess would tend to convert the
phosphate present into insoluble calcium salts and render it unavailable.

The following lime and superphosphate treatments were applied to 100 gram portions of the soil "B" from the Cotton Station, the lime requirement of which was 1.5 tons of ground limestone per acre:

**Ground limestone:** 0, 1/2, 1 and 1 1/2 tons per acre, - i.e.,
0, 0.056, 0.112 and 0.168 grams of ground limestone per 100 grams of soil, assuming that fertilizers are effective to a depth of 6 inches and that the weight of an acre-6 inch of soil is 2 million tons.

**Superphosphate:** 0, 6, and 12 cwts per acre, - i.e.,
0, 0.034 and 0.067 grams of superphosphate per 100 grams of soil.

Each phosphate treatment was combined with each rate of liming to provide 12 separate treatments in all, the method of mixture into a mud and drying being the same as in the previous experiment. The results, which are the means of two duplicates, are given in Table III.

**Table III.** Available P_2O_5 in parts per million of soil "B" following limestone and superphosphate treatments.

<table>
<thead>
<tr>
<th>Dressing of ground limestone per acre</th>
<th>No lime</th>
<th>1/2 ton</th>
<th>1 ton</th>
<th>1 1/2 tons</th>
</tr>
</thead>
<tbody>
<tr>
<td>No superphosphate</td>
<td>15</td>
<td>17</td>
<td>15</td>
<td>18</td>
</tr>
<tr>
<td>6 cwts/acre supers.</td>
<td>29</td>
<td>29</td>
<td>31</td>
<td>32</td>
</tr>
<tr>
<td>12 cwts/acre supers.</td>
<td>51</td>
<td>47</td>
<td>121</td>
<td>160</td>
</tr>
</tbody>
</table>

It appears that the lime has no effect on phosphate availability except with 1 and 1 1/2 tons at the higher level of superphosphate, when there is a large rise in the available phosphate content from about 50 to 120 parts per million.
Owing to the probable interference of the lime with the N/500 sulphuric acid in the Truog extraction conclusions based on these results may be misleading; but it was considered that the problem merited further study and the experiment was repeated later using tomato seedlings grown in cigarette tins as indicators of phosphate availability.
Field experiments at the Cotton Station.

1. Continuation of the 1936-37 experiment.

The experiments carried out this year on the north-east part of Field 54 on the site of the original cotton experiment had the following objects in view:

(1) To determine whether any residual effects remained on the plots from the dressings of superphosphate applied in 1936, as measured by the growth of cotton and maize.

(2) To test whether the original large dressings had a permanent effect in satisfying the phosphate requirements of the soil so that smaller dressings would in future be adequate. The method consisted in halving the original plots, one half of each receiving superphosphate at the rate of 3 cwts/acre and the other half none.

(3) In an attempt to repeat the previous spectacular results from high phosphatic manuring the previous untreated (control) plots were halved, one half receiving superphosphate at the rate of 20 cwts/acre and the other none.

Soil analysis.

In October, 1938, all the original 24 plots were sampled with an auger at successive 6-inch depths down to 18 inches, nine borings being made at random on each plot and the nine cores being bulked so as to give one sample per plot at each level. These samples were then analysed in the laboratory by Truog's method for available phosphate. The results are given in Table IV. It will be seen that the differences between the means lie almost entirely in the top 6 inches and that the
Fig. 3. Plan of cotton and maize experiment.

Superphosphate applied in 1936:
1. Control (no super.)
2. 3 cwts/acre
3. 10 cwts/acre
4. 20 cwts/acre

Superphosphate applied in 1938:
X. 20 cwts/acre
p. 3 cwts/acre
o. None
available phosphate content of the plots which had received the 20 cwt/acre dressing of superphosphate was significantly greater than the rest.

Table IV. Available P\textsubscript{2}O\textsubscript{5}(ppm) on Cotton Station plots two years after application of superphosphate dressings.

<table>
<thead>
<tr>
<th>Depth of sample</th>
<th>Supers. treatment (cwt/acre)</th>
<th>Signif. difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>(inches)</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>0-6</td>
<td>35</td>
<td>25</td>
</tr>
<tr>
<td>6-12</td>
<td>21</td>
<td>19</td>
</tr>
<tr>
<td>12-18</td>
<td>53</td>
<td>51</td>
</tr>
<tr>
<td>0-18</td>
<td>36</td>
<td>33</td>
</tr>
</tbody>
</table>

Layout of the experiment.

A plan of the experiment is shown in Fig.3. Two crops, cotton and maize, were tested to see if their reaction to the treatments was the same, but intercropping was considered inadvisable so each plot was halved and the cotton and maize planted in strips (randomised for each line of plots) running the length of the field in such a way that the prevailing wind from the east passed through each crop separately and interference was reduced. A green cover crop was cut and carted off in October and the field was ploughed, harrowed and marked out with pegs. The original plots were halved to give plots 27\frac{1}{2} feet by 31 feet and appropriate half-plots were dressed with 6.6 lbs. of superphosphate, corresponding to 3 cwts/acre, or (in the case of plots which had received no superphosphate in 1936) 44 lbs, corresponding to 20 cwts/acre. The field was then ridged in a north-south direction so that each plot contained six 4-ft. ridges and was separated from adjacent plots by a guard bank 3\frac{1}{2} ft. wide. No basal manurial dressing was applied since the land was said to be in sufficiently high condition.

Maize and cotton seed were planted by hand (November 25th)
at measured distances, four or five seeds being set at each point. The cotton was sown at points 2 feet apart on the ridges and guard-banks and the maize 1 foot apart; and where maize was adjacent to cotton a space of 3 feet was left. The variety of maize was I.C.1, a selection from the College Farm, and the cotton was American Upland.

Each ultimate plot for purposes of measurement contained 84 maize plants (6 rows of 14) and 42 cotton plants after singling, discard strips 3 feet wide running E-W being left between plots and sub-plots. This layout is open to the criticism that the plots were small (14 ft. by 24 ft.); appreciable discards were necessary owing to the exact position of the original plots laid down in 1936 being doubtful, and the distance apart of plots for comparison was greatly increased by the insertion of the second crop. All these factors would tend to increase the errors associated with the experiment.

The whole field was hand-hoed in December and the plants singled down to one maize or cotton plant. The maize grew well throughout but the cotton germinated badly and had to be supplied three times up to the middle of January. Wet weather in the latter part of 1938 tended to cause waterlogging on the southern side of the field and here the maize was poor while the cotton germinated better than on the rest of the area. While the crops were growing there were no appreciable differences visible at any time corresponding to the applied treatments except on the original control plots, where the 20 cwts/acre dressing of superphosphate appeared to be increasing the height of the maize. The height of each maize plant was measured on January 12th and the increase in height due to the last 20 cwts/acre dressing of superphosphate was found to be 14%; but this and all other differences were
### Table V. Maize cob weights in lbs (each a mean of 6 plot yields)

<table>
<thead>
<tr>
<th>1936 superphosphate dressing (cwts/acre)</th>
<th>0</th>
<th>3</th>
<th>10</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Super applied 1938*</td>
<td>22.3</td>
<td>22.1</td>
<td>22.2</td>
<td>20.4</td>
</tr>
<tr>
<td>No super applied 1938</td>
<td>20.4</td>
<td>20.3</td>
<td>21.2</td>
<td>25.1</td>
</tr>
</tbody>
</table>

### Table VI. Maize cob numbers (means of 6 plot counts)

<table>
<thead>
<tr>
<th>1936 superphosphate dressing (cwts/acre)</th>
<th>0</th>
<th>3</th>
<th>10</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Super applied 1938*</td>
<td>69.5</td>
<td>65.0</td>
<td>69.7</td>
<td>65.1</td>
</tr>
<tr>
<td>No super applied 1938</td>
<td>59.9</td>
<td>65.1</td>
<td>62.1</td>
<td>73.5</td>
</tr>
</tbody>
</table>

### Table VII. Maize straw weights in lbs (each a mean of 6 plot yields)

<table>
<thead>
<tr>
<th>1936 superphosphate dressing (cwts/acre)</th>
<th>0</th>
<th>3</th>
<th>10</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Super applied 1938*</td>
<td>32.0</td>
<td>32.7</td>
<td>31.3</td>
<td>28.3</td>
</tr>
<tr>
<td>No super applied 1938</td>
<td>29.8</td>
<td>28.8</td>
<td>28.7</td>
<td>31.2</td>
</tr>
</tbody>
</table>

* 3 cwts/acre of supers applied on original "3", "10" and "20" plots
20 cwts/acre of supers applied on original "0" (control) plots.
insignificant. There was an appreciable trend from good plants on the north side to poor plants on the south side of the field where drainage water tended to accumulate.

A tassel count made on January 27th indicated that on high phosphate plots maturation was hastened although the results were not statistically significant. A similar count a week later showed much less differences, i.e., maturity as measured by tasselling differed by about a week. At this time observations were made on the cotton plants and marks awarded according to appearance, but these differences were quite insignificant as the cotton was very uneven throughout the whole experiment, owing to the protracted germination period.

Maize harvest.

The maize started to ripen during the end of February and was picked on March 28th and 29th, lack of labour delaying this operation by about a week. The crop was fairly good although slightly damaged by rain just before harvesting. The cobs were husked in the field and taken to the farm to be weighed, without further drying, and the straw was cut and weighed in the field with a spring balance on April 6th.

There were no significant differences in weight or number of cobs or in the weight of straw. (See Tables V, VI and VII). The figures from the original control plots were treated in a separate analysis of variance from the rest since these plots were split in a different way from the others in this experiment (see Appendix) and as there were only six replications of this comparison between "0" and "20 cwt/acre" treatments the error was high, increases of 34% and 53% in cob weight and straw weight respectively being required for significance.
Table VIII. Weight of seed cotton in grams (each a mean of 6 plot yields)

<table>
<thead>
<tr>
<th>1936 superphosphate dressing (cwts/acre)</th>
<th>0</th>
<th>3</th>
<th>10</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Super applied 1938*</td>
<td>885</td>
<td>1096</td>
<td>1094</td>
<td>783</td>
</tr>
<tr>
<td>No super appld.1938</td>
<td>1013</td>
<td>1125</td>
<td>873</td>
<td>712</td>
</tr>
</tbody>
</table>

* 20 cwts/acre of supers applied on original "0" (control) plots
  3 cwts/acre of supers applied on remainder of the plots.
Cotton picking.

The cotton was picked as the bolls ripened, the whole field being covered on five occasions from April 3rd until May 12th. The seed cotton was attacked by pink boll-worm and later by soft rots and was in rather a dirty condition; but only that which could be ginned was picked. The results, which are given in Table VIII, show that the manure applied in 1938 had no significant effect on the yield of seed cotton, but that a significant decrease of 33% (P<0.05) had resulted from the original 20 cwts dressing of superphosphate applied in 1936 as compared with that which had received only 3 cwts/acre. The most probable explanation of this anomalous result on land which normally responds well to applications of phosphate is that the fertility of the high-phosphate plots had been reduced by the luxuriant growth obtained on them in 1937, for no further basal manurial dressing had since been applied. (Although a green cover crop was grown prior to this experiment it was cut and carted off.) The differences in yield as a result of the last phosphatic manuring were small and insignificant.

The experiment this year has failed to repeat the results obtained in 1937. It is probable that the large dressing of lime which was applied immediately before the superphosphate in that case "fixed" the phosphate in the form of insoluble calcium salts and except where the concentration of superphosphate was high (on plots fertilized at the rate of 10 and 20 cwts per acre) little or none would remain available to the plants. In subsequent seasons the insoluble phosphate would gradually be liberated, - an effect noted by Scarseth and Tidmore (5) and Naftel (4). Further enquiries* elicited the information that the crop of maize which followed the 1936-37 experiment was

* Private communication from Dr. E. Phillis.
uniformly good over the whole field, indicating that the lime was by that time exerting a beneficial effect and differences between high and low phosphate plots were no longer noticeable to the eye. Confirmation of this action of lime was obtained in pot experiments which are described later in this paper.
Treatments:
1. Control - no superphosphate
2. 3 cwt supers
3. 10 « w
4. 20 « n
5. 3 « it
6. 10 « it
7. 20 « superphosphate per acre, broadcast.
8. « n
9. it
10. > applied as briquettes.
2. Continuation of the 1937-38 experiment.

The object of the experiment this year was to measure any residual effect of the treatments applied in 1937 by Corby (1) on Field 54 at the Cotton Station. These consisted of three levels of superphosphate manuring (3, 10 and 20 cwts/acre) applied either as briquettes or loose in each case, so as to give six phosphate treatments and one control having no superphosphate. The experiment was laid out in 6 randomised blocks (see plan in Fig. 4). A crop of maize was grown after the conclusion of Corby's experiment but no measurements were taken. It was decided to broadcast Sunn hemp over the whole area and measure the effects of the different phosphate treatments by the vegetative growth and yield of this crop, Sunn hemp being chosen as a crop which would cover the ground evenly and provide a satisfactory measure of fertility.

The maize was removed in October and the field ploughed and harrowed down to form a good seed bed. The seed was broadcast on December 2nd by means of a "fiddle" at the rate of 58 lbs per acre, the work being well done and a very even distribution obtained. Germination was good over the whole area but on reaching a height of about 6 inches many of the plants suffered from Wilt (Fusarium vasinfectum), especially on the south and west sides of the field where the crop was very considerably reduced. Where this occurred the growth of weeds was profuse but otherwise the Sunn hemp provided an effective cover.

Flowering started about the end of January and the crop was cut when in full flower on February 6th and weighed at once in the field with a spring balance. A discard of 3 feet was left around the outside boundary and 6-feet discards between the
### Table IX. Fresh weight of Sunn hemp in lbs (means of 6 plot yields)

Superphosphate dressing in cwts/acre

<table>
<thead>
<tr>
<th></th>
<th>0</th>
<th>3</th>
<th>10</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manure broadcast</td>
<td>52.3</td>
<td>65.2</td>
<td>74.0</td>
<td>59.8</td>
</tr>
<tr>
<td>Manure briquetted</td>
<td>-</td>
<td>53.7</td>
<td>59.3</td>
<td>60.5</td>
</tr>
</tbody>
</table>

### Table X. Dry weight of Sunn hemp in lbs (means of 6 plot yields)

Superphosphate dressing in cwts/acre

<table>
<thead>
<tr>
<th></th>
<th>0</th>
<th>3</th>
<th>10</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manure broadcast</td>
<td>19.5</td>
<td>24.2</td>
<td>28.7</td>
<td>22.3</td>
</tr>
<tr>
<td>Manure briquetted</td>
<td>-</td>
<td>19.0</td>
<td>22.5</td>
<td>25.0</td>
</tr>
</tbody>
</table>

### Table XI. Dry-matter percentage of Sunn hemp (means of 6 plot figures)

Superphosphate dressing in cwts/acre

<table>
<thead>
<tr>
<th></th>
<th>0</th>
<th>3</th>
<th>10</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manure broadcast</td>
<td>38.0</td>
<td>37.5</td>
<td>38.8</td>
<td>38.5</td>
</tr>
<tr>
<td>Manure briquetted</td>
<td>-</td>
<td>36.3</td>
<td>38.2</td>
<td>41.5</td>
</tr>
</tbody>
</table>
plots, so that the size of each plot from which the produce was weighed became 18 feet by 24 feet instead of 24 feet by 30 feet as laid out by Corby. These wide discard strips were left to allow for movement of the original dressings by tillage, etc., and the possibility of movement of the pegs remaining from last year. After cutting and weighing, the material from each plot was left in a heap on the ground and allowed to dry out as "hay" in the sun for 4 days before weighing again to obtain the air-dry weight. It was hoped that differences in maturity would be apparent in the figures for dry-matter percentage.

Results.

The figures for fresh weight, dry weight and dry-matter percentage are given in Tables IX, X and XI. There were no significant differences in the dry weights or dry-matter percentage, but the fresh weight as a result of broadcasting superphosphate was significantly greater by 14.7% than when it was applied as briquettes (P<0.05). This merely confirms the conclusion of Corby that the briquettes were useless as a manure and shows that the phosphate contained in them has not become more available during the past year. "Control" plots generally yielded less than the rest but this difference was insignificant, the standard errors of a plot being 20.4%, 10.2% and 12.7% of the general means for fresh weight, dry matter percentage and dry weight, respectively.
1. Mitscherlich Pot Experiment.

The Mitscherlich method of pot culture was not strictly used in this experiment, the pots merely being used for growing plants under conditions approximating to those in the field. There was no dilution of the soil with sand and manurial dressings were applied to the surface of the soil without mixing, except in the top inch.

The objects of the investigation were to compare:

1. different levels of phosphate dressing.
2. different phosphatic manures at the same rates (based on total P2O5 content). These were superphosphate, ground rock phosphate and pen manure obtained from a dried sample.
3. the ordinary broadcasting method of incorporation with application in the form of pellets.
4. the effect of varying amounts of lime on the availability of a phosphatic manure.

Rate of application of phosphate.

From the first laboratory experiment it was found that according to the Truog analysis about 200 parts of soluble P2O5 were required per million parts of the garden soil ("A") to raise the content to 50 p.p.m., - a value considered adequate for good plant growth. It was decided to apply about two-thirds and four-thirds of this amount, respectively, in the form of superphosphate, in addition to the control having no phosphatic manure. The total P2O5 content of the three manures was:
Each pot contained 13½ lbs of soil and the superphosphate treatments consisted of 3.75 and 7.5 grams per pot, respectively. Since the surface area of soil in each pot was 47.8 sq. inches and the depth 6 inches, these dressings can be expressed as 9.6 and 19.2 cwts/acre respectively. Ground rock phosphate and pen manure were applied to correspond with these rates of total $P_2O_5$ and the treatments were therefore as follows:

<table>
<thead>
<tr>
<th>Manure</th>
<th>Grams added per pot</th>
<th>Expressed as a field dressing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Superphosphate</td>
<td>0, 3.75 and 7.50</td>
<td>0, 9.6 and 19.2 cwt/acre</td>
</tr>
<tr>
<td>Gr. rock phos.</td>
<td>0, 2.24 and 4.48</td>
<td>0, 5.75 and 11.5 cwt/acre</td>
</tr>
<tr>
<td>Pen manure</td>
<td>0, 106.4 and 216.8</td>
<td>0, 13.6 and 27.2 tons/acre</td>
</tr>
</tbody>
</table>

A basal dressing of quicklime was applied to all these pots at the rate of 3.9 grams per pot (10 cwts/acre). The amount of nitrogen and potash applied was governed by the amount of these elements in the pen manure, in order that the basal dressing should be the same throughout. The total nitrogen content of this was 1.30% and the potash content 0.7%. Assuming that 20% of the nitrogen of the pen manure became available in the first crop (an approximate but conventional estimate), the lower dressing of 13.6 tons/acre contain the equivalent of 3,436 cwts of ammonium sulphate per acre. On all pots not containing pen manure, therefore, this dressing of ammonium sulphate was applied, together with an arbitrary dressing of 0.78 gram of potassium chloride (equivalent to 2 cwts/acre). It would have been impracticable to add the equivalent of the total potash content of the pen manure to the other pots and this 2 cwts/acre application was
thought to be adequate.

**Comparison of broadcasting with briquetting.**

To compare the two methods of application of the fertilizers each level of superphosphate and mineral phosphate was applied in one case broadcast over the surface of the pot (and mixed into the top inch of soil) and again in the form of small briquettes, or pellets, the lower dressing consisting of 10 and the higher of 20 pellets set in the soil at a depth of 1 inch - 1 1/2 inches. The pellets were made by mixing the fertilizer to a thick paste with water and squeezing this through a tube to form a rod 1/4-inch in diameter. This was dried and cut into pellets about 1-inch in length which were stable enough to handle although they disintegrated in water and could be broken down fairly easily under pressure. For the purpose of this investigation, however, the localisation of the manure was the important consideration and the question of the construction of stable briquettes by mixture with other substances did not arise.

**The effect of lime.**

To test the effect of lime and its possible interaction with superphosphate the following five treatments were applied:

<table>
<thead>
<tr>
<th>Treatment Description</th>
<th>Superphosphate (cwt/acre)</th>
<th>Quicklime (cwt/acre)</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.2 cwt superphosphate/acre and no quicklime</td>
<td>9.2</td>
<td>0</td>
</tr>
<tr>
<td>9.2 cwt superphosphate/acre and 20 cwt quicklime</td>
<td>9.2</td>
<td>20</td>
</tr>
<tr>
<td>9.2 cwt superphosphate/acre and 30 cwt quicklime</td>
<td>9.2</td>
<td>30</td>
</tr>
<tr>
<td>9.2 cwt superphosphate/acre and 40 cwt quicklime</td>
<td>9.2</td>
<td>40</td>
</tr>
</tbody>
</table>

The second treatment, with 10 cwt of quicklime per acre, was used at the same time as the "control" in the comparison between the manures.

The whole experiment was carried out in duplicate on both the "A" and "B" soils, although the pen manure was included only in
the Cotton Station soil series. Sudan Grass was used as the test crop since it is known to respond well to phosphate and is capable of easy measurement. About 50 seeds were sown in pairs in each pot and after germination (which was very even throughout the experiment) the plants were singled to 20 plants in a pot. In the early stages of growth some plants died and these were replaced by planting fresh seed to maintain the numbers.

Observations on growth.

A striking response was obtained at an early stage from the superphosphate dressings in both soils, while pots treated with ground rock phosphate bore no better growth than the control. Pen manure produced as good growth as the superphosphate early on but later it became intermediate between this and the control. In all cases the effect of the double dressing of manure was little better than the single one, except on the Garden soil where there was an appreciable extra response. In other respects the two soils were very similar, although the general appearance of the plants grown in the sample "B" was healthier.

Very little difference was produced by applying the fertilizers as pellets, but in the early stages application in this form appeared to give better results in the case of superphosphate at the lower rate, while the reverse was the case with mineral phosphate. These differences were, however, small and as growth proceeded they became almost negligible, the effect probably being due to accessibility or otherwise at a time when the root system was limited.

The plants in the control and rock phosphate pots matured in only a few cases, remaining stunted and in many cases dying off before the rest could be cut. Those grown in pen manure pots
Plate I. Effect of single and double dressings of phosphatic manures on the growth of Sudan grass.

Plate II. Effect of increasing dressings of quicklime on the growth of Sudan grass. (Rates expressed as cwts/acre)
Plate II
I. Effect on Sudan grass of briquetting superphosphate in Garden soil "A".
A 1,2. Control - no supers.
A 3,4. 9.6 cwt/acre supers, broadcast.
A 5,6. 19.2 cwt/acre supers as pellets.

Plate III. Effect on Sudan grass of briquetting superphosphate in Garden soil "A".
A 1,2. Control - no supers.
A 3,4. 9.6 cwt/acre supers, broadcast.
A 5,6. 19.2 cwt/acre supers as pellets.

Plate IV. Effect on Sudan grass of briquetting different phosphatic manures in Garden soil "A".
A 3. 9.6 cwt/acre supers, broadcast.
A 5. 9.6 cwt/acre supers as pellets.
A 7. 19.2 cwt/acre supers, broadcast.
A 9. 19.2 cwt/acre supers, as pellets.
A 11. 3.75 cwt/acre rock phosphate, broadcast.
A 14. 3.75 cwt/acre rock phosphate as pellets.
A 16. 7.5 cwt/acre rock phosphate, broadcast.
A 18. 7.5 cwt/acre rock phosphate as pellets.
Table XII.  Dry weight of Sudan grass in Mitscherlich pots under different phosphate treatments (mean of two pot results, in grams)

<table>
<thead>
<tr>
<th>Phosphatic manure</th>
<th>Rate/acre</th>
<th>Garden soil &quot;A&quot;</th>
<th>Cotton Sta. soil &quot;B&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Broadcast</td>
<td>Pellets</td>
</tr>
<tr>
<td>None</td>
<td>-</td>
<td>1.95</td>
<td>-</td>
</tr>
<tr>
<td>Supers.</td>
<td>9.6 cwts</td>
<td>24.60</td>
<td>29.73</td>
</tr>
<tr>
<td>Supers.</td>
<td>19.2 cwts</td>
<td>30.45</td>
<td>30.60</td>
</tr>
<tr>
<td>Rock phos.</td>
<td>5.75 cwts</td>
<td>1.21</td>
<td>0.85</td>
</tr>
<tr>
<td>Rock phos.</td>
<td>11.5 cwts</td>
<td>2.35</td>
<td>2.35</td>
</tr>
<tr>
<td>Pen manure</td>
<td>13.6 tons</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Pen manure</td>
<td>27.2 tons</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Table XIII.  Dry weight of Sudan grass under different dressings of lime (mean of 2 pot results, in grams).
(9.6 cwts/acre of supers applied in each case).

<table>
<thead>
<tr>
<th>Dressing of quicklime (cwts/acre)</th>
<th>Garden soil &quot;A&quot;</th>
<th>Cotton Station soil &quot;B&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>33.25</td>
<td>32.80</td>
</tr>
<tr>
<td>10</td>
<td>24.60</td>
<td>24.65</td>
</tr>
<tr>
<td>20</td>
<td>19.80</td>
<td>20.00</td>
</tr>
<tr>
<td>30</td>
<td>16.55</td>
<td>18.95</td>
</tr>
<tr>
<td>40</td>
<td>11.05</td>
<td>16.70</td>
</tr>
</tbody>
</table>
were better and did produce flowers but were rather chlorotic in appearance, probably due to nitrogen remaining unavailable.

The effect of lime was bad. The best pots in the whole experiment were those treated with superphosphate and no lime, growth becoming steadily worse under increasing lime dressings in both soils.

After 92 days, when growth of the Sudan grass had ceased, the plants were cut off at the soil level, dried and weighed.

**Results.**

Photographs of the pots were taken shortly before the plants were cut and these are reproduced in Plates I, II, III and IV. The more striking differences can here be seen, but the figures for the dry weight of the Sudan grass are given in Tables XII and XIII.

The great phosphate deficiency of these soils is clearly shown by the poor yield from the control pots while the lower dressing of superphosphate gives a tremendous increase. The lower rate chosen was apparently rather high, since it was almost as effective as the double rate. Ground rock phosphate had practically no effect in this experiment, a possible explanation being that in the presence of the basal lime dressing (10 cwts/acre of quicklime) the solubility of the phosphate is reduced.

The application of the fertilizer in the form of pellets was appreciably different from the broadcast application only in the case of the lower rate of superphosphate, when it will be noticed that the Sudan grass made more vigorous growth in the Garden soil.

On examining the root systems on the pots after cutting no sign of greater concentration of roots near the pellets could be detected, as is sometimes said to occur with briquetted manures.
Fig. 5. Dry wt. of Sudan grass under 9.6 cut surface and different dressings of lime (Garden soil A)
The dressings of pen manure which were based on the superphosphate rates were not strictly comparable owing to the doubtful action of the nitrogen and possibly the potash constituents. It was apparent that the estimate of 20% availability for the nitrogen of the pen manure was too high for the particular sample used, plants dressed with this manure suffering from chlorosis to a greater extent than those which received a basal dressing of ammonium sulphate.

Lime had the effect of reducing the benefit derived from the superphosphate, the decrease varying almost exactly linearly with the concentration of lime (see Fig. 5) until 2 tons of quicklime per acre reduced the yield by 50%. The soluble phosphate had apparently been converted into some form of calcium phosphate unavailable to the plant.

Continuation of the Mitscherlich pot experiment.

In order to test for residual effects in the pots following the crop of Sudan grass it was decided to grow tomato seedlings in the same soil as a second crop, since these form a reliable guide to the phosphate status of soil. The soil in each pot was taken out and sieved to remove old roots and to improve the tilth and then replaced in the same pots without further addition of manures. Tomato seeds were planted and after germination (which was fairly uniform) the seedlings were thinned to five per pot.

At first the plants treated with ground rock phosphate or
### Table XIV. Dry weight of tomato-plants per pot under different phosphate treatments. (mean of two pot results in grams)

<table>
<thead>
<tr>
<th>Phosphatic manure</th>
<th>Rate/acre</th>
<th>Garden soil</th>
<th>Cotton Station soil</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>&quot;A&quot;</td>
<td>&quot;B&quot;</td>
</tr>
<tr>
<td>None</td>
<td>-</td>
<td>0.50</td>
<td>0.13</td>
</tr>
<tr>
<td>Supers.</td>
<td>9.6 cwts</td>
<td>3.71</td>
<td>3.65</td>
</tr>
<tr>
<td>Supers.</td>
<td>19.2 cwts</td>
<td>1.43</td>
<td>3.64</td>
</tr>
<tr>
<td>Rock phos.</td>
<td>5.75 cwts</td>
<td>0.51</td>
<td>0.49</td>
</tr>
<tr>
<td>Rock phos.</td>
<td>11.5 cwts</td>
<td>1.37</td>
<td>1.60</td>
</tr>
<tr>
<td>Pen manure</td>
<td>13.6 tons</td>
<td>-</td>
<td>5.29</td>
</tr>
<tr>
<td>Pen manure</td>
<td>27.2 tons</td>
<td>-</td>
<td>8.71</td>
</tr>
</tbody>
</table>

### Table XV. Dry weight of tomato-plants per pot under different dressings of lime. (Mean of 2 pot results, in grams) (9.6 cwt/acre of supers applied in each case)

<table>
<thead>
<tr>
<th>Dressing of quicklime (cwts/acre)</th>
<th>Garden soil</th>
<th>Cotton Station soil</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&quot;A&quot;</td>
<td>&quot;B&quot;</td>
</tr>
<tr>
<td>None</td>
<td>1.01</td>
<td>2.52</td>
</tr>
<tr>
<td>10</td>
<td>3.71</td>
<td>3.65</td>
</tr>
<tr>
<td>20</td>
<td>3.72</td>
<td>3.13</td>
</tr>
<tr>
<td>30</td>
<td>3.68</td>
<td>4.16</td>
</tr>
<tr>
<td>40</td>
<td>7.75</td>
<td>5.44</td>
</tr>
</tbody>
</table>
no phosphate at all produced the best growth, probably owing to the higher content of other nutrients such as nitrogen and potash in those pots, - nutrients which remained in the soil as the previous growth had been so small. These plants, however, soon showed the characteristic signs of phosphate deficiency, the undersides of the leaves being dark purple in colour, and the good growth was not maintained. After two or three weeks the response of the tomato plants to the treatments was very similar to that of Sudan grass, although the differences were less marked. After the removal of the soil and sieving, the pellets of the first experiment were broken up so the comparison between broadcasting and briquetting no longer existed.

The most interesting result of this experiment was that lime now appeared to have a beneficial effect in the presence of superphosphate. The series of pots with increasing lime rates which had hitherto been worst under the heavier dressings of lime now showed increasingly good growth. It is suggested that free calcium carbonate was by this time no longer present and the unavailable form of calcium phosphate produced at first had gradually become available to the plants.

The dry weight of the produce of each pot was found when the plants were cut off at soil level after two months growth and the treatment means are shown in Tables XIV and XV. It will be noticed that the best growth was associated with the higher rate of pen manure, as was expected in the second crop when there is further liberation of nutrients. The double dressing of superphosphate has had no better effect than the single one in soil "B", while in soil "A" the beneficial effect is considerably less. There was considerable variation between duplicates of this treatment so it is not possible to say whether this effect is real or
by chance as the experiment was not designed for statistical analysis; but the similarity between this and the only significant result obtained this year at the Cotton Station, where the residual effect of the highest dressing of superphosphate applied in 1936 reduced the yield of seed cotton this year, is worthy of note.

The figures in Table XV demonstrate the beneficial action of lime in the second crop. It appears that not only has the phosphate become available but the lime has had time to reach a position of equilibrium in the soil and is itself improving the fertility. The moisture is normally available to a depth of 6 inches the equivalent of 1 in per acre in such a土 in 3/12ths of 0.0417 gram, or 17.3 milligrams.

The treatments applied to the soil in these trials were the same as in the laboratory experiment, namely

Ground limestone: 0, 1/2, 1 and 1 1/2 tons per acre
Superphosphate: 0, 8 and 12 cwt per acre

Each level of liming being associated with each level of superphosphate to give 12 treatments. The experiment was carried out in triplicate, thus requiring 36 plots.

Cotton Station soil (sample "A") was first passed through a 2 mm. sieve and portions mixed with the appropriate weights of limestone and superphosphate to give the twelve treatments in triplicate. Each portion was mixed up with water to a creamy mud, air-dried, broken up, sifted and air-dried again before filling it into a cigarette tin. Lime tomato seeds were sown in each tin and after germination three plants were allowed to remain.

Phosphate deficiency was soon observed in the seedlings which had no dressing of superphosphate. Lime at first had practically no effect in the absence of phosphate but when
2. Cigarette tin experiment to investigate the action of superphosphate in the presence of lime.

This experiment was essentially a repetition of the laboratory tests on the interaction of lime with superphosphate, but tomato seedlings were used instead of the Truog test as a criterion of phosphate availability.

The tins used were 2.5 inches deep and 2.55 sq.inches in cross-sectional area. A dressing of 1 cwt per acre is equivalent to 0.0415 gram over an area of 2.55 sq.in., but if it is assumed that the manure is normally available to a depth of 6 inches the equivalent of 1 cwt per acre in such a tin is 5/12ths of 0.0415 gram, or 17.3 milligrams.

The treatments applied to the soil in these tins were the same as in the laboratory experiment, namely

Ground limestone: 0, 1/4, 1 and 1 1/2 tons per acre
Superphosphate: 0, 6 and 12 cwts per acre
each level of liming being associated with each level of superphosphate to give 12 treatments. The experiment was carried out in triplicate, thus requiring 36 tins.

Cotton Station soil (sample "B") was first passed through a 2m.m. sieve and portions mixed with the appropriate weights of limestone and superphosphate to give the twelve treatments in triplicate. Each portion was mixed up with water to a creamy mud, air-dried, broken up and sieved again before filling it into a cigarette tin. Nine tomato seeds were sown in each tin and after germination three plants were allowed to remain.

Phosphate deficiency was soon observed in the seedlings which had no dressing of superphosphate. Lime at first had practically no effect in the absence of phosphate but when
### Table XVI. Mean height of tomato plants in cms after 5 weeks growth in cigarette tins.

<table>
<thead>
<tr>
<th>Dressing of ground limestone per acre</th>
<th>No lime</th>
<th>½ ton</th>
<th>1 ton</th>
<th>1½ tons</th>
</tr>
</thead>
<tbody>
<tr>
<td>No superphosphate</td>
<td>3.11</td>
<td>3.10</td>
<td>3.43</td>
<td>3.28</td>
</tr>
<tr>
<td>6 cwts/acre supers.</td>
<td>6.00</td>
<td>6.20</td>
<td>5.50</td>
<td>4.33</td>
</tr>
<tr>
<td>12 cwts/acre supers.</td>
<td>9.28</td>
<td>9.54</td>
<td>8.26</td>
<td>7.44</td>
</tr>
</tbody>
</table>

### Table XVII. Mean dry-weight of tomato plants per tin (in grams) after 9 weeks growth.

<table>
<thead>
<tr>
<th>Dressing of ground limestone per acre</th>
<th>No lime</th>
<th>½ ton</th>
<th>1 ton</th>
<th>1½ tons</th>
</tr>
</thead>
<tbody>
<tr>
<td>No superphosphate</td>
<td>0.133</td>
<td>0.217</td>
<td>0.233</td>
<td>0.230</td>
</tr>
<tr>
<td>6 cwts/acre supers.</td>
<td>0.720</td>
<td>0.630</td>
<td>0.653</td>
<td>0.547</td>
</tr>
<tr>
<td>12 cwts/acre supers.</td>
<td>1.077</td>
<td>0.933</td>
<td>0.943</td>
<td>0.797</td>
</tr>
</tbody>
</table>
applied in conjunction with either 6 or 12 cwts of superphosphate per acre increasing rates of lime had an increasingly deleterious effect on the growth of the seedlings. At five weeks measurements of the plants showed that there was a significant positive regression with increasing rates of superphosphate (P<0.01) and a negative regression with increasing dressings of lime (P<0.05). The figures for these heights are given in Table XVI.

After nine weeks the plants were cut and the oven-dry weight determined. The effect of the lime was less marked than in the early stages, the regression now being insignificant; but the effect of the superphosphate was still very much in evidence. The interaction between lime and superphosphate was insignificant, i.e., the lime had the same effect on the seedlings regardless of the amount of superphosphate present. It appeared that the change in the action of lime (noted previously) from a deleterious to a beneficial one in this case was occurring during the first crop. This is quite probable, as equilibrium between lime and the soil should be more rapidly attained when they are first mixed thoroughly.

At the same time a basal dressing equivalent to 3 cts of ammonium sulphate and 2 cts of potassium chloride was applied. The experiment was done on each of the soils "A" and "B" and each was duplicated, so that 16 plots in all were required.

Several cotton seeds (American Upland) were sown at two points 6 inches apart in each tin and when the seedlings were about 4 inches high they were thinned to two plants per tin at a distance apart of 4 inches. This method of growing cotton was found to be bad as the plants never grew to more than 16 inches in height before producing flowers, but this experiment did serve

The object of this experiment was to try to repeat the 1936-37 experiment at the Cotton Station on a small scale, using the same dressings of superphosphate and measuring the effect by the growth of cotton.

The tin used as a container for the soil consisted of a half kerosene tin (the tin being cut longitudinally and waxed on the inside) and soil was placed in this to a depth of 4 inches. The dimensions of the tins were 13.5 inches by 9.5 inches by 4 inches in depth, so that 1 cwt per acre was equivalent to 1.04 grams over such an area. Allowing for the fact that the soil was only 4 inches deep, the dressing taken as the equivalent of 1 cwt/acre was 4/6ths of this, or 0.693 gram. The four treatments given in the first Cotton Station experiment were then applied as follows:

I. No superphosphate
II. 3 cwts superphosphate/acre, or 2.08 grams per tin
III. 10 " " " 6.93 " " "
IV. 20 " " " 13.86 " " "

At the same time a basal dressing equivalent to 3 cwts of ammonium sulphate and 2 cwts of potassium chloride was applied. The experiment was done on each of the soils "A" and "B" and each was duplicated, so that 16 tins in all were required.

Several cotton seeds (American Upland) were sown at two points 6 inches apart in each tin and when the seedlings were about 4 inches high they were reduced to two plants per tin at a distance apart of 6 inches. This method of growing cotton was found to be bad as the plants never grew to more than 18 inches in height before producing flowers, but the experiment did serve
Table XVIII. Height and number of bolls of cotton plants grown in kerosene tins under different rates of superphosphate dressing. (Means of 4 plants.)

<table>
<thead>
<tr>
<th>Superphosphate dressing (cwts/acre)</th>
<th>Garden soil &quot;A&quot;</th>
<th>Cotton Sta. soil &quot;B&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height (cms.)</td>
<td>Number of bolls</td>
<td>Height (cms.)</td>
</tr>
<tr>
<td>None</td>
<td>23.0</td>
<td>21.4</td>
</tr>
<tr>
<td>3 cwt</td>
<td>34.3</td>
<td>30.6</td>
</tr>
<tr>
<td>10 cwt</td>
<td>37.3</td>
<td>37.1</td>
</tr>
<tr>
<td>20 cwt</td>
<td>33.3</td>
<td>39.0</td>
</tr>
</tbody>
</table>

Plate V. Appearance of cotton plants in Garden soil "A"

Plate VI. Appearance of cotton plants in Cotton Sta. soil "B"
to confirm the results obtained by Corby, that 3 cwts of super-phosphate per acre produced an appreciable increase in growth while the 10 and 20 cwt dressings were still better but about the same in action. Measurements of the height of the plants were made at intervals throughout the experiment and after three months the cotton was cut and weighed. Little significance could be attached to the weights of the plants, either fresh or dry, as the variation between plants having the same treatment was so great, depending on whether the bolls had remained on the plant or not. None of the bolls ripened, but in this experiment it was considered that height measurements furnished the most reliable measurement of the effect of the phosphate treatments. Table XVIII gives the heights of the plants and the number of bolls produced at three months, and Plates V and VI show the appearance of the cotton after 10 weeks.
Discussion of results.

All the experiments with Cotton Station or the Garden soil have so far failed to repeat the striking results of the first experiment in the series, when large dressings of phosphate were necessary before any response was apparent in the growth of cotton. The explanation of this (at first sight) anomalous behaviour probably lies in the heavy limestone dressing which was applied in the first case. The significance of this factor was not fully appreciated for some time with the result that experiments were designed to test for phosphate fixation in the soil itself and the present explanation arose chiefly as a result of an attempt to reduce fixation by the addition of lime.

Scarseth and Tidmore (5) have shown that lime depresses crop yields by decreasing the availability of readily soluble phosphates if it is applied to an acid soil immediately before planting; but after equilibrium is established and free calcium carbonate is no longer present the availability of the phosphates is increased and subsequent crops improved. Naftel (4) suggests that over-liming will precipitate phosphates as finely divided particles but that the carbonic acid present in the soil will in time render these available to plants. Confirmation of this effect was found in the Mitscherlich pot experiment described above, while it also affords an explanation of the negative results obtained in field experiments at the Cotton Station.

It would have been useful to have carried out a phosphatic manuring experiment similar to that at the Cotton Station in 1936-1937, the phosphate treatments being applied both in the absence and in the presence of the heavy dressing (5 tons/acre) of ground limestone.
limestone. This would afford a fairly conclusive test of the present explanation; but as this arose as a result of this year's experiments lack of time prevented the attempt.

It may be said that in general there is an increasing response in a crop on these soils from dressings of superphosphate up to 15 or 20 cwts per acre and even from quite small dressings of 3 cwts per acre, indicating that although the soil is deficient in phosphates it has a low fixing ability and should not be classed as a "phosphate-fixing soil". In the presence of a recent dressing of lime the action of superphosphate is considerably reduced so that only the largest applications are effective in the first crop. In following crops, however, the lime appears to improve the fertility while the phosphate becomes available again and has a beneficial action on the crop.
I am greatly indebted to Professor F. Hardy for his advice and criticism and to the Staff of the Chemistry Department for help with the chemical analyses. My thanks are also due to the Staff of the Cotton Station for advice and helpful discussion.
References:


(2) Davies, L.E., Hawaiian Planters' Record, vol.38,1934, p.206

(3) McDonald, J.A., T.A. vol.X. p.108


APPENDIX A. Analyses of variance.

1. Analysis of variance of cotton-maize experiment.

(a) Control plots only (1936 treatment "1"):

<table>
<thead>
<tr>
<th>Factor</th>
<th>Degrees of freedom</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blocks</td>
<td>5</td>
</tr>
<tr>
<td>Super v. control</td>
<td>1</td>
</tr>
<tr>
<td>Error</td>
<td>5</td>
</tr>
<tr>
<td>Total</td>
<td>11</td>
</tr>
</tbody>
</table>

(b) "2", "3" and "4" plots only:

<table>
<thead>
<tr>
<th>Factor</th>
<th>Degrees of freedom</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blocks</td>
<td>5</td>
</tr>
<tr>
<td>&quot;2&quot; v. &quot;3&quot; v. &quot;4&quot;</td>
<td>2</td>
</tr>
<tr>
<td>Error (a)</td>
<td>10</td>
</tr>
<tr>
<td>Whole plots</td>
<td>17</td>
</tr>
<tr>
<td>Super v. control</td>
<td>1</td>
</tr>
<tr>
<td>Interactions</td>
<td>2</td>
</tr>
<tr>
<td>Error (b)</td>
<td>15</td>
</tr>
<tr>
<td>Total</td>
<td>22</td>
</tr>
</tbody>
</table>

2. Analysis of variance of Sunn hemp experiment.

<table>
<thead>
<tr>
<th>Factor</th>
<th>Degrees of freedom</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blocks</td>
<td>5</td>
</tr>
<tr>
<td>Treatments</td>
<td>6</td>
</tr>
<tr>
<td>Super v. control</td>
<td>1</td>
</tr>
<tr>
<td>3 v. 10 v. 20 cwt/acre</td>
<td>2</td>
</tr>
<tr>
<td>Broadcasting v. briquetting</td>
<td>1</td>
</tr>
<tr>
<td>Interactions</td>
<td>2</td>
</tr>
<tr>
<td>Error</td>
<td>30</td>
</tr>
<tr>
<td>Total</td>
<td>41</td>
</tr>
</tbody>
</table>
APPENDIX B. Plot Yields.

Table A. Maize cob weights in lbs from cotton-maize experiment.

<table>
<thead>
<tr>
<th>Block</th>
<th>1938 treatment</th>
<th>1936 treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>I</td>
<td>p</td>
<td>19.3</td>
</tr>
<tr>
<td></td>
<td>o</td>
<td>18.2</td>
</tr>
<tr>
<td>II</td>
<td>p</td>
<td>22.7</td>
</tr>
<tr>
<td></td>
<td>o</td>
<td>23.0</td>
</tr>
<tr>
<td>III</td>
<td>p</td>
<td>18.1</td>
</tr>
<tr>
<td></td>
<td>o</td>
<td>22.5</td>
</tr>
<tr>
<td>IV</td>
<td>p</td>
<td>19.3</td>
</tr>
<tr>
<td></td>
<td>o</td>
<td>15.0</td>
</tr>
<tr>
<td>V</td>
<td>p</td>
<td>25.5</td>
</tr>
<tr>
<td></td>
<td>o</td>
<td>30.0</td>
</tr>
<tr>
<td>VI</td>
<td>p</td>
<td>28.6</td>
</tr>
<tr>
<td></td>
<td>o</td>
<td>13.8</td>
</tr>
</tbody>
</table>

Table B. Maize cob numbers from cotton-maize experiment.

<table>
<thead>
<tr>
<th>Block</th>
<th>1938 treatment</th>
<th>1936 treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>I</td>
<td>p</td>
<td>61</td>
</tr>
<tr>
<td></td>
<td>o</td>
<td>59</td>
</tr>
<tr>
<td>II</td>
<td>p</td>
<td>69</td>
</tr>
<tr>
<td></td>
<td>o</td>
<td>55</td>
</tr>
<tr>
<td>III</td>
<td>p</td>
<td>70</td>
</tr>
<tr>
<td></td>
<td>o</td>
<td>70</td>
</tr>
<tr>
<td>IV</td>
<td>p</td>
<td>69</td>
</tr>
<tr>
<td></td>
<td>o</td>
<td>47</td>
</tr>
<tr>
<td>V</td>
<td>p</td>
<td>64</td>
</tr>
<tr>
<td></td>
<td>o</td>
<td>83</td>
</tr>
<tr>
<td>VI</td>
<td>p</td>
<td>84</td>
</tr>
<tr>
<td></td>
<td>o</td>
<td>45</td>
</tr>
</tbody>
</table>

Treatments: p. superphosphate applied in 1938
o. no supers applied in 1938
1. No supers applied in 1936
2. 3 cwt/acre supers applied in 1936
3. 10 cwt/acre supers applied in 1936
4. 20 cwt/acre supers applied in 1936
### Table C. Maize straw weights in lbs from cotton-maize experiment.

<table>
<thead>
<tr>
<th>Block</th>
<th>1938 treatment</th>
<th>1936 treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>I</td>
<td>p</td>
<td>33</td>
</tr>
<tr>
<td></td>
<td>o</td>
<td>26</td>
</tr>
<tr>
<td>II</td>
<td>p</td>
<td>31</td>
</tr>
<tr>
<td></td>
<td>o</td>
<td>37</td>
</tr>
<tr>
<td>III</td>
<td>p</td>
<td>32</td>
</tr>
<tr>
<td></td>
<td>o</td>
<td>34</td>
</tr>
<tr>
<td>IV</td>
<td>p</td>
<td>22</td>
</tr>
<tr>
<td></td>
<td>o</td>
<td>21</td>
</tr>
<tr>
<td>V</td>
<td>p</td>
<td>34</td>
</tr>
<tr>
<td></td>
<td>o</td>
<td>43</td>
</tr>
<tr>
<td>VI</td>
<td>p</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>o</td>
<td>18</td>
</tr>
</tbody>
</table>

### Table D. Weight of seed cotton in grams from cotton-maize expt.

<table>
<thead>
<tr>
<th>Block</th>
<th>1938 treatment</th>
<th>1936 treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>I</td>
<td>p</td>
<td>687</td>
</tr>
<tr>
<td></td>
<td>o</td>
<td>1099</td>
</tr>
<tr>
<td>II</td>
<td>p</td>
<td>981</td>
</tr>
<tr>
<td></td>
<td>o</td>
<td>1222</td>
</tr>
<tr>
<td>III</td>
<td>p</td>
<td>434</td>
</tr>
<tr>
<td></td>
<td>o</td>
<td>1091</td>
</tr>
<tr>
<td>IV</td>
<td>p</td>
<td>323</td>
</tr>
<tr>
<td></td>
<td>o</td>
<td>851</td>
</tr>
<tr>
<td>V</td>
<td>p</td>
<td>1106</td>
</tr>
<tr>
<td></td>
<td>o</td>
<td>1238</td>
</tr>
<tr>
<td>VI</td>
<td>p</td>
<td>1781</td>
</tr>
<tr>
<td></td>
<td>o</td>
<td>675</td>
</tr>
</tbody>
</table>

**Treatments:**
- **p.** superphosphate applied in 1938
- **o.** no supers applied in 1938

1. No supers applied in 1936
2. 3 cwt/acre supers applied in 1936
3. 10 cwt/acre supers applied in 1936
4. 20 cwt/acre supers applied in 1936
Table E. Fresh weight of Sunn hemp in lbs.

<table>
<thead>
<tr>
<th>Block</th>
<th>Superphosphate treatments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>I</td>
<td>48</td>
</tr>
<tr>
<td>II</td>
<td>48</td>
</tr>
<tr>
<td>III</td>
<td>55</td>
</tr>
<tr>
<td>IV</td>
<td>34</td>
</tr>
<tr>
<td>V</td>
<td>71</td>
</tr>
<tr>
<td>VI</td>
<td>58</td>
</tr>
</tbody>
</table>

Table F. Air-dry weight of Sunn hemp in lbs.

<table>
<thead>
<tr>
<th>Block</th>
<th>Superphosphate treatments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>I</td>
<td>19</td>
</tr>
<tr>
<td>II</td>
<td>15</td>
</tr>
<tr>
<td>III</td>
<td>24</td>
</tr>
<tr>
<td>IV</td>
<td>15</td>
</tr>
<tr>
<td>V</td>
<td>22</td>
</tr>
<tr>
<td>VI</td>
<td>22</td>
</tr>
</tbody>
</table>

Table G. Dry-matter percentage of Sunn hemp.

<table>
<thead>
<tr>
<th>Block</th>
<th>Superphosphate treatments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>I</td>
<td>39.6</td>
</tr>
<tr>
<td>II</td>
<td>31.3</td>
</tr>
<tr>
<td>III</td>
<td>43.7</td>
</tr>
<tr>
<td>IV</td>
<td>44.2</td>
</tr>
<tr>
<td>V</td>
<td>31.0</td>
</tr>
<tr>
<td>VI</td>
<td>38.0</td>
</tr>
</tbody>
</table>

Treatments:  
1. Control - no superphosphate  
2. 3 cwt/acre supers, broadcast  
3. 10 " "  
4. 20 " "  
5. 3 " " , briquetted.  
6. 10 " "  
7. 20 " "