FURTHER EXPERIMENTS ON THE MITSCHERLICH METHOD OF ASSESSING THE NUTRIENT STATUS OF TROPICAL SOILS.

By D. M. Hanschell, B.Sc., (Edin.).

Dissertation submitted in part requirement for Associateship of the Imperial College of Tropical Agriculture.

1937.
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INTRODUCTION.

The investigations on the Mitscherlich Method of assessing the nutrient status of soils carried out this year at the Imperial College of Tropical Agriculture have aimed mainly at ascertaining what modifications in the technique are necessary before the method may be successfully put into practice under Tropical conditions. They have not been concerned with Mitscherlich's Theory, which has been accepted in its entirety.

Briefly the experiments have entailed the trial of Para Grass as an indicator plant and an investigation of the question of Minor Element deficiencies, and they may be regarded as the continuation of previous work done at the Imperial College. In addition an investigation of the Phosphate status of a composite sample of Antigua Calcareous Clay soils has been carried out. This, in the writer's opinion, constitutes a new problem and it is therefore proposed to divide the present paper into two parts. Part I dealing entirely with the continuation of previous work and Part II with the new problem.

PART I. Continuation of Previous Work.

(A) GENERAL TECHNIQUE.

Since, a complete and detailed account of the Mitscherlich technique is given by Stewart (21) and the general modifications in use at the Imperial College have been recently reviewed by Inniss (12) it is not proposed to deal further with them here. The method of watering is however of sufficient interest to justify especial mention, particularly as its soundness as practised at the College has been in some doubt.

Watering. Mitscherlich recommends the use of distilled water and
and the careful control of watering so that all pots are brought to the same moisture content. At the College rainwater is used and there are no facilities for controlling the moisture content of pots, it being necessary to rely on judgement entirely. In the past, previous workers have pointed to this as possibly being a source of serious error, but in Hawaii, where the Mitscherlich Method has been on trial for a number of years and has been finally adopted as a workable tool, no attempt is made to weigh the pots to bring the water content to any definite percentage. Only sufficient water is provided to keep the plants from wilting, care being taken at the same time to avoid overwatering.

(B) INDICATOR PLANT.

(a) Survey of the literature.

Experiments on the Mitscherlich Method have been carried out for the past four years at the Imperial College and for a longer period in Hawaii, but since these have already been adequately reviewed (Refs. 4, 6, 7, 12.) it is proposed to deal only with those findings which have a direct bearing on the work performed this year.

A large number of indicator plants have been on trial, which are listed below:-

<table>
<thead>
<tr>
<th>I.C.T.A.</th>
<th>Tomato.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sudan Grass (Texas Sta. Var. 2a43)</td>
<td>Tobacco.</td>
</tr>
<tr>
<td>Finger Millet.</td>
<td>Cotton.</td>
</tr>
<tr>
<td>Italian Millet.</td>
<td>Buckwheat.</td>
</tr>
<tr>
<td>Maize.</td>
<td>Hill Rice.</td>
</tr>
<tr>
<td>Swamp Rice</td>
<td></td>
</tr>
<tr>
<td>Sun Hemp.</td>
<td></td>
</tr>
<tr>
<td>Hawaii.</td>
<td>Dwarf Yellow Milo.</td>
</tr>
<tr>
<td></td>
<td>Corn (White Guam)</td>
</tr>
</tbody>
</table>
Fig. 1.

$P_{2}O_{5}$ Curve - Sudan Grass.

(McCreary)

Amounts $P_{2}O_{5}$ in Fractions of "Complete" Treatment.
Corn (White Guam).  Sacolin Sorgo.
Hemp.  Shallu.
Kale.  Sorghum (Early Amber).
Millet.  Spur Ptererita.
Oats.  Para Grass.
Rice.  Saccharum spontaneum.
Rye.
Tomato.
Saccharum sinense.

Of these only Sudan Grass and Para Grass have showed any promise of being suitable.

During 1934-35 McCreary (14) and Tidbury (22) working at the Imperial College attempted to obtain phosphate and potash growth curves for Sudan Grass. The phosphate curve they obtained (Fig. 1) was most satisfactory and indicated the logarithmic relationships necessitated by Mitscherlich’s Law, but they were unable to obtain a similar curve for potash. Their results in the latter case when plotted gave a series of points parallel to the horizontal axis. From chemical analysis of the ashed plants they found that the potash content was proportional in magnitude to the amounts of potash added, though evidently the resulting growth did not show this proportionality (Fig. 2). Moreover, they found that with increasing amounts of potash there was a slight decrease in the nitrogen and phosphate contents and a more marked decrease in the Magnesium Oxide and Calcium Oxide contents. From this they concluded that the soil used already contained sufficient potash for the maximum growth of Sudan Grass and that since potash was not a limiting factor, further additions did not give any increase in growth.

The following year Inniss (11) and Walker (23) again endeavoured to construct a potash curve for Sudan Grass, using soil from the Potash deficient plot of the College permanent
Fig. 2.

$K_{2}O$ Curve - Sudan Grass.

(McCreary)

Amounts $K_{2}O$ in Fractions of "Complete" Treatment.
Fig. 3.

Responses of Sudan Grass to Increasing Amounts of K$_2$O - Grown in Quartz Sand and Complete Nutrient Solution.

$N = 1.1$ gms/pot.

$P_2O_5 = 1.0$ gms/pot.

(Cooke)
permanent manurial experiment. Although the growth of the plants was not satisfactory, their results were similar to those previously obtained by McCreary and Tidbury, and they concluded that Sudan Grass was not a satisfactory indicator plant for potash, although it seemed to be suitable for assessing available phosphate.

During the past seven years considerable work has been done on the Mitscherlich Method in Hawaii, and Cooke (4) working there has obtained a typical potash growth curve for Sudan Grass. The plants were grown on quartz sand and he found that the amounts of nutrients in Mitscherlich's complete fertiliser gave the maximum yield with the amount of Nitrogen used, when however the potash was increased to three grams there was a depression of the yield (Fig. 3).

In a recent communication from Hawaii (6) it is stated that of the many indicator plants tried, they consider Sudan Grass to be the best for potash, when used with a soil: sand ratio of 1:4 and they have been successful in obtaining excellent correlations between their pot tests and field trials. When used with straight soil however, they do not consider Sudan Grass to be sensitive enough to show up small differences. With regard to phosphate, they have now adopted Parra Grass as their standard indicator plant, as they have found that, although Sudan Grass is satisfactory in assessing soils with adequate supplies of phosphate, Parra Grass is more likely to show up real deficiencies. All their tests for phosphate are carried out on straight undiluted soil, and with the highly phosphate fixing soils prevalent in Hawaii they have found it necessary to apply six times the standard Mitscherlich dressing of phosphate.
Experiments 1936-1937.

The suggestions of Inniss and Walker were followed and it was decided to undertake the following problems:

1. The testing of Para Grass as an indicator plant.
2. The construction of a growth curve showing the responses of Para Grass to varying amounts of phosphate.
3. The construction of a growth curve showing the responses of Para Grass to varying amounts of potash.
4. The testing of Panicum fasciculatum as an indicator plant for Potash.

Series of Experiments.

Series I. This consisted of sixteen pots receiving eight different treatments of phosphate, each replicated twice. The experiment involved three separate problems. (i) The observation of Para Grass as indicator plant. (ii) The construction of a growth curve showing the responses of Para Grass to varying amounts of phosphate. (iii) The determination of the phosphate status of Las Hermanas Estate soil, reputed to be low in phosphate content.

Series II. Similar to Series I only in this case the construction of a potash curve for Para Grass was aimed at. Soil from El Carmen Estate Toco, reputed to be low in potash content, was used.

Series III. Trial of Panicum fasciculatum as an indicator plant. This plant was found growing as a common weed on several of the fields of the College Farm. From its habit of growth it was thought that it might prove a suitable indicator and it was therefore decided to give it a trial. Unfortunately all efforts to promote the germination failed. Dr. Phillis of the Cotton Research Station, kindly consented to subject a sample of the seed to low temperature treatment at
at - 78°C with solid Carbon Dioxide for a period of several hours, the seed being first dried in vacuo over Sulphuric Acid. This also proved useless and since the plant did not lend itself to propagation by vegetative means, the experiment was abandoned.

Details of the complete experiments appear in Tables I and II.

Experimental Work. Since the practical work was the same in all essentials as that in previous years and closely followed the instructions given by Stewart (21), only the following points need to be mentioned.

1. Filling of Pots. The mixing of the soil and sand was done by volume. The weights of sand and soil required to fill a standard Mitscherlich pot were determined separately; half of each of these weights were then taken and mixed, when the soil:sand ratio required was 1:1.

2. Minor Elements. In addition to the standard Mitscherlich dressings, the advice of Innis (11) and Walker (23) was followed and each pot received a dilute solution containing the following elements, - Manganese, Copper, Iron, Boron, Zinc and Aluminium (Appendix). This was done to ensure that there would be no deficiency of these elements limiting the growth of the plants.

3. Planting. One eye cuttings of Para Grass were sprouted in quartz sand until they made one-and-a-half inches then growth; when they were transplanted to the pots. It was found that a greater percentage of young plants was obtained by using only the hard lower nodes for cuttings, further, by removal of the leaf bases covering the buds, the time taken for sprouting was greatly reduced.

Transplanting
Transplanting was done by hand, correct spacing being ensured by the use of a circular piece of cardboard with holes drilled in it, and a glass rod. The cardboard was placed on the surface of the soil and by means of the glass rod holes were made to receive the cuttings.

Supplying of blanks was carried out during the first week after transplanting, after which, no further supplying was done.

4. Attention. Great care was needed to avoid overwatering when the plants were young and they were protected from rain by galvanised iron sheets. All watering was stopped one week before harvest.

5. Harvesting. As none of the plants flowered this could not be used as a criterion of maturity. It was, therefore, decided to harvest the plants when they were considered to have ceased making any marked growth.

The method of harvesting and drying the plants was the same as in previous years.

(c) Results. TABLES 1 and 2 and Fig. 4 and 5.

(d) Discussion of Results.

Para Grass as an Indicator. McCreary (14) has given the following features, which he considers necessary for a suitable indicator plant:

1. Good germination.
2. Freedom from pests and diseases.
3. Capability of being grown in sufficient numbers per pot to reduce individual plant variation.
4. Production of an erect, stiff vegetative structure.
5. The possession of a convenient life cycle.
6. The production of a reasonably high vegetative:fruiting ratio.
Fig. 4.

P₂O₅ Curve - Para Grass.

Amounts P₂O₅ in Fractions of "Complete" Treatment.
TABLE 1.

Series I. Phosphate Curve.
Indicator. Para Grass.
Soil. Las Hermanas. Low Phosphate Content.
Soil:Sand Ratio 1:1.
Weight of Pot of Soil. 11 lb. 3½ oz.
Weight of Pot of Sand. 15 lb. 3½ oz.

<table>
<thead>
<tr>
<th>Pot No.</th>
<th>Treatment</th>
<th>Plants/Pot</th>
<th>Yield in gms.</th>
<th>Mean % of Complete</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>F₂O₅</td>
<td>20</td>
<td>92.00</td>
<td>83.50</td>
</tr>
<tr>
<td>2</td>
<td>1/8 F₂O₅</td>
<td>19</td>
<td>75.00</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>1/3 F₂O₅</td>
<td>19</td>
<td>120.00</td>
<td>119.00</td>
</tr>
<tr>
<td>4</td>
<td>2/3 P₂O₅</td>
<td>19</td>
<td>139.20</td>
<td>142.35</td>
</tr>
<tr>
<td>5</td>
<td>2/3 P₂O₅</td>
<td>18</td>
<td>138.00</td>
<td>144.50</td>
</tr>
<tr>
<td>6</td>
<td>1/3 P₂O₅</td>
<td>19</td>
<td>151.00</td>
<td>152.60</td>
</tr>
<tr>
<td>7</td>
<td>2/3 P₂O₅</td>
<td>20</td>
<td>153.50</td>
<td>153.80</td>
</tr>
<tr>
<td>8</td>
<td>Complete</td>
<td>19</td>
<td>164.60</td>
<td>166.00</td>
</tr>
</tbody>
</table>

Phosphate. \( b = \frac{\log 100 - \log 49.7}{0.753} \times 4 = 1.61 \text{ cwts. per acre.} \)

\( b = \frac{\log 100 - \log 49.7}{1.95} \times 4 = 0.60 \text{ gms. per pot.} \)
Fig. 5.

K$_2$O Curve - Fara Grass.

Amounts K$_2$O in Fractions of "Complete" Treatment.
TABLE 2.
Series II. Potash Curve.
Indicator. Para Grass
Soil. El Carmen Estate, Toco. Low Potash Content.
Soil: Sand Ratio 1:1.
Weight of Pot of Soil. 11 lb. 7 oz.
Weight of Pot of Sand. 15 lb. 3½ oz.

<table>
<thead>
<tr>
<th>No. Treatment</th>
<th>Plants</th>
<th>Yield in Pot.</th>
<th>Mean gms.</th>
<th>Mean</th>
<th>% of Complete</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 } P₂O₅</td>
<td>16</td>
<td>100.00</td>
<td>106.00</td>
<td>95.71</td>
<td></td>
</tr>
<tr>
<td>2 } P₂O₅</td>
<td>18</td>
<td>112.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 } 1/8 P₂O₅</td>
<td>18</td>
<td>109.70</td>
<td>103.35</td>
<td>97.83</td>
<td></td>
</tr>
<tr>
<td>4 } 1/8 P₂O₅</td>
<td>19</td>
<td>121.90</td>
<td>113.45</td>
<td>102.43</td>
<td></td>
</tr>
<tr>
<td>5 } 1/3 P₂O₅</td>
<td>18</td>
<td>105.00</td>
<td>103.10</td>
<td>93.09</td>
<td></td>
</tr>
<tr>
<td>6 } 1/3 P₂O₅</td>
<td>20</td>
<td>106.50</td>
<td>106.05</td>
<td>95.75</td>
<td></td>
</tr>
<tr>
<td>7 } 2/3 P₂O₅</td>
<td>17</td>
<td>105.90</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8 } 2/3 P₂O₅</td>
<td>18</td>
<td>119.50</td>
<td>109.85</td>
<td>99.18</td>
<td></td>
</tr>
<tr>
<td>9 } 2/3 P₂O₅</td>
<td>19</td>
<td>100.20</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 } 2/3 P₂O₅</td>
<td>18</td>
<td>103.00</td>
<td>101.85</td>
<td>91.95</td>
<td></td>
</tr>
<tr>
<td>11 } Complete</td>
<td>20</td>
<td>115.00</td>
<td>110.75</td>
<td>100.00</td>
<td></td>
</tr>
<tr>
<td>12 } Complete</td>
<td>18</td>
<td>106.50</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Potash. \( b = \frac{\log 100 - \log 4.5}{1.17} \times 4 = 4.64 \text{ cwts. per acre} \)

\( = \frac{\log 100 - \log 4.5}{3.02} \times 4 = 1.30 \text{ gms. per pot.} \)
With the exception of its failure to flower, Para Grass possesses all these points to a greater or lesser degree. The stand of plants obtained from cuttings was good, it remained remarkably free from insect attack or disease, and it was possible to grow twenty or more plants per pot. It made rapid growth and tillered well, but the plants became inconveniently tall, which made the handling and harvesting difficult, it may be noted here however, that the same criticism has been made of Sudan Grass.

No reason can be given for its failure to flower. But, provided sufficient time has elapsed between planting and harvesting to allow the plant to make full use of the nutrients present in the soil, this should in no way affect the results obtained from a pot test, since the calculations are based on differences from the maximum growth obtained from pots receiving the complete fertiliser and all pots are harvested at the same time.

After harvesting, each pot was examined and in all cases the root penetration was good.

Phosphate Curve.

The curve was obtained by plotting the yields of Para Grass against the various quantities of phosphate applied (Fig. 4). It is in close agreement with the Mitscherlich log yield curve.

The curve, apart from its theoretical interest, is of practical value since, it shows that Para Grass will respond to small variations in phosphate and should therefore prove a suitable indicator for assessing the phosphate status of soil.

It is of interest to note that, McCready (14) and Tidbury (22) used the same Las Hermanas soil, when obtaining data for the construction of a phosphate curve for Sudan Grass. Their results showed 0.953 cwt. of phosphate per acre, whereas
Fig. 6.

Amounts K₂O in Fractions of "Complete" Treatment.
whereas this year's results showed 1.61 cwts. per acre, giving a difference of 0.657 cwts. per acre.

As to which of the two, Sudan Grass or Para Grass, is the better indicator for phosphate cannot be safely said until, further direct comparisons have been made, using the same soil, which should be first chemically analyzed. However, in the writer's opinion and in view of the work carried out in Hawaii, (4,6,7) it may be concluded that Para Grass is as good as Sudan Grass for indicating differences in phosphate content.

**Potash Curve.**

The results of this experiment, when plotted against the various quantities of potash applied, gave a series of points parallel to the horizontal axis and not a curve, as was hoped for (Fig. 5). The plants from each pot were ashed and analysed by the Chemistry Department and the results showed that the potash content had increased in proportion with each additional application of potash, while, the nitrogen content remained more or less at the same level (Fig. 6 and Table 7). These results agree closely with those obtained by McCreary (14) and Tidbury (22) for Sudan Grass.

The failure to obtain a growth curve for potash may be due to either, (i) the presence in the soil of sufficient potash to allow the maximum growth of Para Grass or, (ii) the action of some limiting factor, which would prevent the maximum growth being attained.

The soil used in the experiment was obtained from El Carmen Estate, Toco, and cocoa growing on it there, exhibited abundant leaf-scorch. Chemical analysis showed a potash content of seventy parts per million and since, a soil:sand ratio of 1:1 was used, the concentration in the pots was reduced to thirty-five parts per million. The provisional lower limit of potash adequacy for cocoa growing on this soil type
type, is given as one hundred and twenty-five parts per million, therefore, it would seem that potash must be deficient. Yet, it is now generally accepted that various crops differ in their nutrient requirements, and it may well be that the soil contained sufficient potash for the maximum growth of Para Grass. On the other hand, if some other mineral element is limiting, the potash absorbed by the plant would not be utilised for growth and the same result would be attained.

In either case, the potash absorbed, over and above that utilised for growth, represents the luxury consumed fraction. The only definite conclusion, that may be reached from the above experiment, is that the potash applied was absorbed by the plant, but, owing to the operation of either of the two factors stated above, the potash was not utilised for growth.

Further experiments are necessary before the potash requirements of Para Grass are determined and its suitability as an indicator plant decided. These experiments should include treatments with other mineral elements, such as soil phosphate, magnesium, nitrogen and lime. Leaf analysis for these elements would greatly assist in determining what elements, if any, are limiting, but, they should distinguish between the soluble and insoluble forms. For example, where potash is limiting, additions of this element will lead to a decrease in the soluble nitrogen and phosphate, accompanied by a corresponding increase in the insoluble forms. Chemical analysis of the soil alone, does not give a sufficiently accurate picture of the balance of nutrients present which are available to the plant, especially is this so where, the nutrient requirements of the particular crop are largely unknown. Where available to the plant, their absence gives rise to n

In the writer's opinion, the results of the experiment described above, raise considerable doubts as to the validity of Mitscherlich's basic assumption that the manurial require-
ment in a particular soil is the same for all crops. The chief soil problem is therefore that of the factors determining nutrient availability and chemical

(C) MINOR ELEMENT DEFICIENCY TESTS.

(a) Survey of Literature.

In the course of their investigations on the Mitscherlich Method at the Imperial College of Tropical Agriculture, 1935-36, Inniss (11) and Walker (25) found that the growth of the plants in many of their experiments, was unsatisfactory. The plants grew slowly and remained stunted, the leaves becoming yellow. They could find no causal organism and in consequence they suggested that the condition might be due to a deficiency of some minor element or elements, accentuated by the dilution of the soil with quartz sand. The soil they used was obtained from the College Farm.

The literature on the subject of minor elements and their relation to plant nutrition is immense. It is therefore proposed to only briefly state some of the modern views held and to mention a few of the more outstanding examples of soil deficiencies.

Within recent years, it has been found necessary to increase the number of elements which were first considered to be essential to the plant. Many such as Manganese, Boron and Zinc, which were at first thought to be non-essential, have now to be considered as being essential. Moreover, with improved methods of sand and water culture, it is likely that the number of essential elements will still further be increased.

As yet, little is known of the part played by the minor elements in the nutrition of the plant, except only, that where they are unavailable to the plant, their absence gives rise to metabolic disturbances, which have come to be known as soil deficiency diseases. The minor element requirements of the plant are small and more important than the total quantity
quantity present in the soil; is their availability to the plant. The chief soil problem is therefore that of the factors determining nutrient availability, and chemical analysis can only be of limited use in their determination. Occasionally, a soil deficiency disease results from the presence in excess of some other element; for example, lime-induced chlorosis of fruit trees and other crops, brought about by excess lime rendering the manganese or iron, or sometimes both, unavailable. In a few cases definite leaf symptoms are associated with the deficiency disease, as in the Grey Speck Disease of Oats, which has been recorded in Canada, Australia, Holland and Great Britain and which results from a deficiency of manganese. However, the leaf symptoms produced by the deficiency of a certain element are not always the same for all plants and the leaf symptoms of manganese deficiency of Sugar-Cane differ markedly from those of Grey Speck Disease of Oats, though, the general effect is one of chlorosis. The symptoms associated with a deficiency disease are not always confined to the leaf and the stem also is sometimes affected, as in Heart Rot of Sugar Beet and Swedes resulting from a deficiency of Boron. Further, there may be no definite symptoms present at all and the disease merely takes the form of considerable reduction of yield or complete failure of growth. The failure of crops on the Everglade Soils of Florida, due to a deficiency of Copper, is an example of such. It would seem that definite symptoms only appear in the more advanced stages of the disease.

Besides being necessary to the metabolism of the plant, many of the minor elements appear to have the property of further stimulating growth, even when this is already normal. But, so far as the writer is aware, they have never been used on a commercial scale for this purpose.
It was decided to investigate the following problems:

1. The occurrence of minor element deficiencies in College Farm soil. The second group received no lime. All the
2. The association of leaf symptoms in Sugar-Cane with minor element deficiencies. Series III.

Each six pots, three limed and three unlimed, received one of the following treatments:


Series IV. A series of pots set up by Innis (11) and Walker (23), and harvested by the writer. It consisted of fourteen pots. Each pot received the complete Mitscherlich dressings of nitrogen, phosphate and potash, as well as 0.5 g. of Magnesium Sulphate and Sodium Chloride respectively.

7. Seven pots received a dressing of 1.5 g. precipitated Calcium Carbonate and the remaining seven received no lime. The pots were divided in pairs, one limed the other unlimed, and each pair received one of the following treatments:

1. Nothing.
2. Manganese.
3. Iron.
4. Copper.
5. Boron.
7. Complete. - Mn, Fe, Cu, B and Zn.  

The pots were then planted with Hill Rice seeds, but the plants suffered heavily from an attack of nematodes, and were finally removed as being valueless. Later, the same cultures were planted with Sudan Grass seed. The Sudan Grass grew well and was harvested when it had reached maturity, given in Table 4 and Fig. 5.

Series V. This consisted of an extended pot test along the same
Series VI. A series of sand cultures of sugar-cane, set up to ascertain what leaf symptoms are produced by the deficiency of Manganese, Copper, Boron, Iron and Zinc, respectively. It was thought that, if definite leaf symptoms could be obtained and described, they would be of some practical value in assisting the recognition of similar symptoms in the field.

Seven different treatments were used, each replicated twice. They consisted of:

(a) Complete nutrient solution, including Manganese, Copper, Boron, Iron and Zinc.
(b) Nutrient solution lacking Manganese.
(c) Nutrient solution lacking Copper.
(d) Nutrient solution lacking Boron.
(e) Nutrient solution lacking Iron.
(f) Nutrient solution lacking Zinc.
(g) Nutrient solution lacking Manganese, Copper, Boron, Iron and Zinc.

Experimental Work. The chemical composition of the complete nutrient solution along with the dilutions used, are given in Appendix IV. The other solutions differed only in that they were lacking in certain minor elements under investigations. It was found impossible to obtain all chemically pure salts.

Dilution of stock solutions was done with distilled water, but a sufficient quantity was not obtained for general watering of the cultures and rainwater was therefore used.

A number of three-eye cuttings of Uba Cane were planted in quartz sand and watered. Young shoots, twelve to fourteen inches high, were carefully removed from the parent sets and transplanted to pots of quartz sand. All the shoots transplanted had roots of their own.
Normal Leaf.  

Leaf Showing Symptoms of Manganese Deficiency.
The pots used were ordinary earthenware flower pots, which had been scrubbed clean and coated with paraffin wax. The quartz sand was thoroughly washed with distilled water before being placed in the pots.

The cultures were watered with their respective nutrient solutions two or three times a week, besides being watered with rainwater. Periodically, they received a complete flushing to remove accumulated ions. There is an indication of an increase in yield from the application of manganese with no lime. It is doubtful whether

Growth Observations. For the first two or three months after transplanting, growth in all cultures was normal and tillering was good. The leaves, however, appeared to be somewhat narrower than those of normal plants, under field conditions.

The only symptom observed, during the six months the cultures were under observation, appeared in the culture lacking manganese and in that lacking all five of the minor elements under investigation. In each case the symptoms were the same. On the young leaves a striping was observed. The striping occurred mainly towards the middle and tips of the leaves and did not continue for their full length. The striping took the form of alternating dark green and narrower light green stripes, the latter became yellow and finally almost white. The symptom was localised to only a few leaves on each plant and it was found possible to correct it by the addition of manganese to the nutrient solution. It may be therefore concluded that the symptoms were produced by a deficiency of manganese.

After four or five months, the growth of the plants in all cultures was poor and they suffered severely from lack of water. The plants became too large for the pots and it was impossible to apply sufficient water, without the pots becoming water-logged.
(c) Results. Tables 3 and 4 and Fig. 7.

(d) Discussion of Results.

1. The results of Series IV show increased yields from treatments receiving lime, over those receiving no lime, except only in those treatments which received Boron and Manganese, respectively, where there is a depression of yield. There is an indication of an increase in yield from the application of Manganese with no lime. It is doubtful whether the results show anything more than indications, since they are based on the yields from single pots only.

2. The results from Series V are of little value, in as much as the differences in yields obtained from replicates are, in almost all cases, greater than those between different treatments.

3. The failure to produce deficiency symptoms for Boron, Iron, Copper and Zinc, respectively in Series VI, may be due to contamination of the cultures with the elements under investigation. Possible sources of contamination are:

(a) All the salts used in the nutrient solution were not chemically pure.

(b) Distilled water was not obtainable in sufficient quantities and rainwater from a galvanised iron roof, had to be used.

(c) It was found impossible to keep the pots clear of dead leaves and other extraneous matter, which were continually being blown into them.
**TABLE 3.**

Series IV. Minor Element Pot test (Inniss).
Indicator. Sudan Grass.
Soil. College Farm.
Soil:Sand Ratio 1:3.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Pot Plants Yld gms.</th>
<th>Pot Plants Yld gms.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No. /Pot.</td>
<td>No. /Pot.</td>
</tr>
<tr>
<td>Nothing</td>
<td>1 25 42.4</td>
<td>8 21 40.05</td>
</tr>
<tr>
<td>Copper</td>
<td>2 21 45.0</td>
<td>9 17 44.10</td>
</tr>
<tr>
<td>Iron</td>
<td>3 24 45.2</td>
<td>10 20 45.55</td>
</tr>
<tr>
<td>Manganese</td>
<td>4 22 35.5</td>
<td>11 19 49.50</td>
</tr>
<tr>
<td>Boron</td>
<td>5 19 36.9</td>
<td>12 16 41.85</td>
</tr>
<tr>
<td>Zinc</td>
<td>6 25 43.9</td>
<td>13 23 37.90</td>
</tr>
<tr>
<td>Complete</td>
<td>7 35 35.1</td>
<td>14 23 32.40</td>
</tr>
</tbody>
</table>
### TABLE 4.

**Series V. Minor Elements Pot Test.**

**Indicator.** Para Grass.

**Soil.** College Farm.

**Soil Sand Ratio.** 1:2.


<table>
<thead>
<tr>
<th>Treatment</th>
<th>Pot No. Plants/Pot. Mean</th>
<th>Dry Wt. Mean</th>
<th>Pot No. Plants/Pot. Mean</th>
<th>Dry Wt. Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>LIME.</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nil.</td>
<td>142.2</td>
<td>134.6</td>
<td>141.23</td>
<td>135.5</td>
</tr>
<tr>
<td>2</td>
<td>162.2</td>
<td>134.6</td>
<td>141.23</td>
<td>135.5</td>
</tr>
<tr>
<td>3</td>
<td>127.5</td>
<td>134.6</td>
<td>141.23</td>
<td>135.5</td>
</tr>
<tr>
<td>Manganese</td>
<td>147.2</td>
<td>134.5</td>
<td>139.73</td>
<td>138.83</td>
</tr>
<tr>
<td>5</td>
<td>163.5</td>
<td>134.5</td>
<td>139.73</td>
<td>138.83</td>
</tr>
<tr>
<td>6</td>
<td>137.5</td>
<td>134.5</td>
<td>139.73</td>
<td>138.83</td>
</tr>
<tr>
<td>Copper</td>
<td>139.5</td>
<td>145.5</td>
<td>145.53</td>
<td>141.13</td>
</tr>
<tr>
<td>8</td>
<td>151.6</td>
<td>145.5</td>
<td>145.53</td>
<td>141.13</td>
</tr>
<tr>
<td>9</td>
<td>151.6</td>
<td>145.5</td>
<td>145.53</td>
<td>141.13</td>
</tr>
<tr>
<td>Boron</td>
<td>153.5</td>
<td>128.5</td>
<td>138.85</td>
<td>141.13</td>
</tr>
<tr>
<td>12</td>
<td>133.5</td>
<td>128.5</td>
<td>138.85</td>
<td>141.13</td>
</tr>
<tr>
<td>Zinc</td>
<td>139.0</td>
<td>153.0</td>
<td>143.33</td>
<td>139.63</td>
</tr>
<tr>
<td>14</td>
<td>146.0</td>
<td>153.0</td>
<td>143.33</td>
<td>139.63</td>
</tr>
<tr>
<td>15</td>
<td>153.0</td>
<td>153.0</td>
<td>143.33</td>
<td>139.63</td>
</tr>
<tr>
<td>Iron</td>
<td>137.2</td>
<td>133.0</td>
<td>140.13</td>
<td>136.73</td>
</tr>
<tr>
<td>16</td>
<td>150.2</td>
<td>133.0</td>
<td>140.13</td>
<td>136.73</td>
</tr>
<tr>
<td>17</td>
<td>146.0</td>
<td>133.0</td>
<td>140.13</td>
<td>136.73</td>
</tr>
<tr>
<td>Complete Mn</td>
<td>153.7</td>
<td>133.0</td>
<td>140.13</td>
<td>136.73</td>
</tr>
<tr>
<td>Cu,B,Zn,Fe</td>
<td>132.1</td>
<td>138.2</td>
<td>134.9</td>
<td>124.7</td>
</tr>
<tr>
<td>20</td>
<td>134.5</td>
<td>138.2</td>
<td>134.9</td>
<td>124.7</td>
</tr>
<tr>
<td>21</td>
<td>153.7</td>
<td>138.2</td>
<td>134.9</td>
<td>124.7</td>
</tr>
</tbody>
</table>
(D) Suggestion for Future Work.

1. That a series of straight Mitscherlich tests for phosphate be set up, using a soil of known nutrient status with different dilutions of sand, and with Para Grass and Sudan Grass, respectively, as indicator plants. The aim of the experiment will be to decide:
   (a) Which of the two plants is the more suitable as an indicator for Phosphate.
   (b) The most suitable soil: sand dilution.

2. That further attempts be to obtain potash growth curves for Sudan Grass and Para Grass, in order to determine, as far as possible, their respective potash requirements and hence their suitability as indicators for potash.

3. That, where phosphate or potash growth curves are being obtained, the applications of the mineral should be carried well above the complete Mitscherlich dressing. Further, that every precaution should be taken to avoid other mineral elements proving to be limiting factors in the investigation.

4. That analysis of the soluble and insoluble forms of the minerals present in the leaves carried out in conjunction with growth curve experiments, will greatly assist in the determination of the nutrient requirements of the plant.

5. That sand cultures, of the plant under investigation, might give some preliminary indication of the nutrient requirements of the plant.
1. The modifications of the Mitscherlich technique, as practised at the Imperial College, are described.

2. Previous work carried out on indicator plants is reviewed.

3. A phosphate growth curve for Para Grass was obtained and it was concluded that the plant was as good as Sudan Grass for assessing the phosphate status of soils.

4. An attempt was made to construct a potash growth curve for Para Grass but, was unsuccessful, owing to the operation of one of two factors. Further investigation is suggested.

5. The trial of Panicum fasciculatum was attempted but was unsuccessful, owing to the failure of the seeds to germinate.

6. Two minor element deficiency tests are described, but no definite conclusions could be drawn from them.

7. A series of sand cultures of Sugar Cane were set up with the object of obtaining deficiency leaf symptoms for certain minor elements. The symptoms of Manganese deficiency are described.
SECTION B.


16.------- Studies on the Utilisation of Mineral Elements in the Cotton Plant. (Not yet published).


25. Willis, L.G. 1955. - Bibliography of References to the Literature on the Minor Elements. Published by the Chilean Nitrate Educational Bureau, Inc.


SECTION C.

Although it is possible to distinguish between soluble and insoluble forms of phosphate by chemical methods, solubility does not necessarily mean availability to the plant. Many workers hold the view that, in the operation of such factors as high alkalinity, high saline concentrations, or the presence of some physical property of the soil, the plant may only be capable of absorbing small quantities of the soluble phosphate actually present (2) (4).

Thus, it can be seen that, although chemical methods attempt to distinguish between available and unavailable phosphate, they do not give the true picture of the phosphate status from the plant’s point of view and it is only by...
PART II. Investigation of the Phosphate Status of Antigua Calcareous Clay Soils.

(A) INTRODUCTION.

Within recent years, great advances have been made in the chemical methods of determining the phosphate status of soils, which have tended towards increased rapidity and greater simplicity, making it possible for them to be used in obtaining a vast amount of data in a short time and leading to their wider application. In spite of all modifications, however, with certain soils, modern methods fail to give any more reliable results than the older ones. For example, with Truong's Method, using H/500 sulphuric acid, some Malayan soils give results showing less than one part per million of phosphate, and even where the strength of the acid is increased five times, the results still show less than twenty parts per million of phosphate. All of these soils support some form of vegetation and on many, rubber plantations are situated (1). Again, with highly phosphate-fixing soils, or with soils having a high percentage of calcium carbonate, chemical methods often give results showing high or adequate contents of phosphate, of which little may be available to the plant.

Although it is possible to distinguish between soluble and insoluble forms of phosphate by chemical methods, solubility does not necessarily mean availability to the plant. Many workers hold the view that, owing to the operation of such factors as high alkalinity, high saline concentrations, or the presence of some physical property of the soil, the plant may only be capable of absorbing small quantities of the soluble phosphate actually present (2) (4).

Thus, it can be seen that, although chemical methods attempt to distinguish between available and unavailable phosphate, they do not give the true picture of the phosphate status from the plant's point of view, and it is only by supplementing
supplementing the chemical tests with some biological test, which makes use of the plant as the abstracting agent, can the true picture be attained.

The present paper deals with the investigation, by the Mitscherlich Method, of the phosphate status of a soil, with which, for reasons stated above, chemical methods are suspected of giving unreliable results.

(B) THE SOIL.

The soil used in the investigation was a composite sample of Antigua Calcareous Clay Soils. Chemical analysis show it as having the following characteristics:

1. Very high alkalinity.
2. Fairly high percentage of calcium carbonate.
3. Medium high phosphate content, well above the lower limit of adequacy for sugar cane.
4. Abundant potash content.
5. High nitrogen content.
6. Percentage of manganese oxide below lower limit of adequacy for the soil type.

In addition to the above characteristics, the texture, high moisture retaining capacity and its extreme cohesiveness indicate a high percentage of clay.

(See Appendix II - Table 6).

(C) SURVEY OF THE LITERATURE.

The soils of Antigua have been investigated by Haruy, McDonald and Rodriguez (2) and it is proposed here, to briefly summarise their findings on those soils, which may be classed as calcareous; i.e. those having a calcium carbonate content greater than one per cent.

They state that alkalinitities equal to or greater than pH 8.0 are definitely injurious to the growth of sugar cane and
and they consider that plant roots are less able to absorb phosphate, or for that matter any other nutrient, from soils having a pH 7.6 or over. Moreover, in the calcareous soils they examined, they found that much of the total phosphate, as determined by Truog's Method, was fixed and therefore not available to the plant.

During the course of their investigation they met with many examples of canes showing the chlorotic symptoms of iron and manganese deficiencies, which they considered to be lime induced.

(D) THE EXPERIMENT.

This consisted of:

Series VII. A straight Mitscherlich test for phosphate involving six pots.

Series VIII. A tomato seedling test for phosphate deficiency (3).

Experimental Work.

Series VII. The filling and planting of the pots were carried out in the usual way. Sudan Grass was used as the indicator plant and the soil diluted with an equal volume of sand. Three pots received the Mitscherlich dressings of nitrogen, potash and phosphate; the remaining three received nitrogen and potash only.

Owing to an error, the application of a dressing of minor elements was omitted.

The results are given in Table 5.

Series VIII. The test consisted of six cigarette tins of soil.
Series VII. Mitscherlich Phosphate Test.

**Indicator:** Sudan Grass.

**Soil:** Composite sample of Antigua Calcareous Clay Soils.

**Soil: Sand Ratio 1:1.**


Weight of Pot of Soil. 12 lb.

Weight of Pot of Sand. 15 lb. 14 oz.

<table>
<thead>
<tr>
<th>Plants</th>
<th>Pot. Treatment</th>
<th>Yield in gms.</th>
<th>Mean % of Complete</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>NK</td>
<td>8</td>
<td>23.5</td>
</tr>
<tr>
<td>B</td>
<td>NK</td>
<td>2</td>
<td>14</td>
</tr>
<tr>
<td>C</td>
<td>NK</td>
<td>22</td>
<td>33.7</td>
</tr>
<tr>
<td>D</td>
<td>NPK</td>
<td>22</td>
<td>97.8</td>
</tr>
<tr>
<td>E</td>
<td>NPK</td>
<td>18</td>
<td>19.6</td>
</tr>
<tr>
<td>F</td>
<td>NPK</td>
<td>18</td>
<td>99.5</td>
</tr>
</tbody>
</table>

Phosphate: \[ b = \log 100 - \log 81.01 \]

\[ x4 = 0.046 \text{ cwts. per pot.} \]

Phosphate: \[ b = \log 100 - \log 81.01 \]

\[ x4 = 0.046 \text{ gms. per pot.} \]
soil, three of which received a small dressing of superphosphate. Ten tomato seeds were planted in each tin and when they had germinated all but four were removed. After three weeks the tins were further thinned out and only one single plant left in each pot. From the germination of the seeds, close observation was kept for the appearance of phosphate deficiency symptoms.

The variety of tomato used was Ponderosa.

Growth Observations.

Series VII. The germination of the Sudan Grass seeds in all six pots was excellent. Within five or six days after germination, however, the majority of the plants in the pots receiving no phosphate died off. Supplying was carried out with fresh seed, but again many of the plants died.

When the plants in the three pots receiving phosphate were about three feet high, it was noticed that many of them showed chlorotic symptoms. The leaves became pale green in colour and the general effect was one of striping. The symptoms fairly closely approximated those of Manganese deficiency previously obtained for sugar cane in Series VI. On the application of a dilute solution of manganese sulphate to the pots, all symptoms disappeared in three or four days and the leaves regained their normal green colour.

Series VIII. During the course of observation of this series, the following symptoms were noticed occurring on all of the plants which had received no phosphate.

1. The upward inclination of the seed leaves forming an acute angle.

2. The first pair of true leaves remained unparted at the tips.

3. The second pair of true leaves were very much broader than those on the plants receiving phosphate. They were not
so divided and were of a darker green colour.

4. A purple colour developed on the stems of plants in both treatments, but was more marked on the plants receiving no phosphate. The purple colour did not develop on any of the leaves.

The above symptoms have been described by McDonald (3) as being those of phosphate deficiency.

The dry weights of the plants when harvested were not recorded, since they were too few in number for the results to be of any value.

(E) DISCUSSION OF RESULTS.

The results obtained from the experiments, Series VII and VIII, indicate quite definitely that the soil investigated is deficient in phosphate, although Truog's Method show that the amount present in the soil is more than adequate for most crops. It is concluded therefore, that the phosphate present is largely unavailable to the plant.

The question arises, how far are the results obtained in Series VII, using Sudan Grass as the indicator, applicable to other crops, such as sugar cane. It is known that Sudan Grass is particularly sensitive to phosphate deficiency, whereas, it may well be that the optimum requirements of sugar cane are very much less. It is therefore certain that it is impossible to apply quantitatively, data obtained from Mitscherlich tests to other crops, until, sufficient correlation can be obtained between the results of Mitscherlich tests, with a particular indicator plant, and the results of field trials for the various crops, on the same soils. However, in the writer's opinion, the results of tests, such as those described above, are of value in assisting in the understanding of the phosphate status of a soil, even though they cannot be applied quantitatively.
The experiments give no indication as to the reasons for the unavailability of the phosphate. But, it is suggested that further tests might reveal the extent to which a soil is phosphate fixing. Unfortunately, the quantity of the soil available was limited, and it was therefore impossible to carry out such a test.

The appearance of Manganese deficiency symptoms in Series VII, supports the suggestion that an application of minor elements should be made to all pots in a Mitscherlich series of pot tests. Particularly is this so, where the soil under investigation has a high content of calcium carbonate and on which therefore, lime induced chlorosis is likely to appear.

(F) SUGGESTIONS FOR FUTURE WORK.

1. That further Mitscherlich tests for phosphate should be carried out with soils, on which Truong's method of phosphate determination fails to give reliable results, e.g., Red Earths, and highly alkaline calcareous soils.

2. That in conjunction with 1, additional pots should be included with the phosphate applied as Rock Phosphate or some other insoluble form. These might give some indication as to the best form of phosphate to apply to phosphate-fixing soils.

3. That an investigation of the phosphate status of the Cotton Research Station soil be carried out. This should include a series of pots with increasing quantities of phosphate, the aim being to ascertain the point at which the soil is satisfied with regard to phosphate. When this point has been reached, can it be maintained with small applications of phosphate.

4. As in 3 using College Farm soil which is probably similar to the Cotton Station soil. (Northern Range Detritus).
1. The determination of the phosphate status of soils by chemical methods is briefly discussed.

2. The literature dealing with the investigation of Antigua Calcareous soils is reviewed.

3. A straight Mitscherlich test for phosphate on a composite sample of Antigua Calcareous Clay Soils is described.

4. A tomato seedling test for phosphate deficiency, carried out on the same soil, is described.

5. From the above tests it was concluded that the soil was deficient in phosphate, although Truog's method showed a more than adequate content.

6. The soil also appeared to be deficient in Manganese and it is suggested that a dressing of minor elements should be applied to all Mitscherlich tests.

ACKNOWLEDGEMENTS.

My acknowledgements are due to Professor F. Hardy for his support and the interest he has shown throughout the work, and my thanks to Dr. E. Phillis and Dr. D. W. Duthie for their many suggestions.
LITERATURE CITED.


Series I. - Phosphate Curve - Four Weeks.

Series I. - Phosphate Curve - Before Harvest.
Series VI. — Sand Cultures — Sugar-Cane.

Series VII. — Phosphate Test — Antigua Calcareous
Clay Soil: — Sudan Grass.
APPENDIX I.

Mitscherlich Complete Fertiliser.
(a) 1 grm. $N_2$ as $(NH_4)_2SO_4$ in 20 cc. $H_2O$
(b) 1.5 grm. $K_2O$ as $K_2SO_4$ in 50 cc. $H_2O$
(c) 1.1 grm. $P_2O_5$ as superphosphate in 50 cc. $H_2O$
(d) 0.5 grm. $NaCl$ + 0.5 grm. $MgSO_4$ in 5 cc. $H_2O$
(e) Precipitated $CaCO_3$ 1.5 grm. per pot.

Minor Element dressing in Series I and II.

<table>
<thead>
<tr>
<th></th>
<th>grm./pot.</th>
<th>cwts./acre.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen</td>
<td>0.40</td>
<td>0.155</td>
</tr>
<tr>
<td>Phosphate</td>
<td>1.95</td>
<td>0.753</td>
</tr>
<tr>
<td>Potash</td>
<td>3.02</td>
<td>1.17</td>
</tr>
</tbody>
</table>

Mitscherlich Effect Factors.

Minor Element Dressings applied in Series V.
0.064 grm. $MnSO_4.4H_2O$ per pot, equivalent to 18 lb. per acre foot.
0.052 grm. $ZnSO_4.7H_2O$ per pot, equivalent to 15 lb. per acre foot.
0.034 grm. $H_3BO_3$ per pot, equivalent to 9 lb. per acre foot.
0.012 gr. $CuSO_4.5H_2O$ per pot, equivalent to 3 lb. per acre foot.
0.046 grm. $FeSO_4.7H_2O$ per pot, equivalent to 55 lb. per acre foot.

and 3.00 grm. precipitated $CaCO_3$ per pot, equivalent to 852 lb. per acre foot.
## APPENDIX II.

### TABLE 6.

Soils Used in Mitscherlich Experiments 1936-37.

**Laboratory Analysis.**

<table>
<thead>
<tr>
<th>Soil</th>
<th>Las Hermanas Toco</th>
<th>El Carmen</th>
<th>Antigua College Calc. Clay</th>
</tr>
</thead>
<tbody>
<tr>
<td>M.F.S.</td>
<td>45.6</td>
<td>-</td>
<td>26.1</td>
</tr>
<tr>
<td>Sand</td>
<td>9.2</td>
<td>-</td>
<td>41.7</td>
</tr>
<tr>
<td>I.T.</td>
<td>44.0</td>
<td>19.0</td>
<td>18.0</td>
</tr>
<tr>
<td>Normal Reaction</td>
<td>4.9</td>
<td>5.0</td>
<td>7.4</td>
</tr>
<tr>
<td>Exchange Reaction</td>
<td>4.2</td>
<td>-</td>
<td>7.1</td>
</tr>
<tr>
<td>CaCO₃</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>C.M. %</td>
<td>1.3</td>
<td>2.9</td>
<td>17.8</td>
</tr>
<tr>
<td>N %</td>
<td>0.19</td>
<td>0.21</td>
<td>0.15</td>
</tr>
<tr>
<td>C/N Ratio</td>
<td>4.0</td>
<td>8.0</td>
<td>7.0</td>
</tr>
<tr>
<td>Av. Nutrients mhos x 10⁻⁶</td>
<td>96.0</td>
<td>114.0</td>
<td>195.0</td>
</tr>
<tr>
<td>Rate of Soln. mhos x 10⁻⁶</td>
<td>0</td>
<td>102.0</td>
<td>74.0</td>
</tr>
<tr>
<td>Av.K₂O p.p.m.</td>
<td>122</td>
<td>70</td>
<td>227</td>
</tr>
<tr>
<td>Av.P₂O₅ p.p.m.</td>
<td>31</td>
<td>41</td>
<td>142</td>
</tr>
<tr>
<td>MnO %</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
### APPENDIX III

#### TABLE 7.

Chemical Analysis of Para Grass Plants. Series II.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Pot No.</th>
<th>% Lab: Sample</th>
<th>% Oven Dry Matter</th>
<th>Ratios</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>N</td>
<td>Mean</td>
<td>K2O</td>
</tr>
<tr>
<td>Nil.</td>
<td>1</td>
<td>0.81</td>
<td>0.49</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.69</td>
<td>0.75</td>
<td>0.44</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0.74</td>
<td>0.47</td>
<td></td>
</tr>
<tr>
<td>1/8 K2O</td>
<td>4</td>
<td>0.79</td>
<td>0.76</td>
<td>0.64</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>0.73</td>
<td>0.64</td>
<td></td>
</tr>
<tr>
<td>1/3 K2O</td>
<td>6</td>
<td>0.81</td>
<td>0.77</td>
<td>0.66</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>0.85</td>
<td>0.76</td>
<td></td>
</tr>
<tr>
<td>2/3 K2O</td>
<td>8</td>
<td>0.83</td>
<td>0.84</td>
<td>0.83</td>
</tr>
<tr>
<td></td>
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<td>0.80</td>
<td>0.24</td>
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<td>0.81</td>
<td>1.00</td>
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<tr>
<td>2/5 K2O</td>
<td>11</td>
<td>0.69</td>
<td>0.36</td>
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<td>12</td>
<td>0.83</td>
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<tr>
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<td>1.28</td>
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<td>0.75</td>
<td>0.77</td>
<td>1.22</td>
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<td>16</td>
<td>0.79</td>
<td>0.77</td>
<td>1.36</td>
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</tbody>
</table>
### Stock Solution I.

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ammonium Nitrate</td>
<td>57.14 grm.</td>
</tr>
<tr>
<td>Potassium Sulphate</td>
<td>7.44 &quot;</td>
</tr>
<tr>
<td>Potassium Chloride</td>
<td>6.36 &quot;</td>
</tr>
<tr>
<td>Potassium Phosphate</td>
<td>9.58 &quot;</td>
</tr>
<tr>
<td>Magnesium Sulphate</td>
<td>50.68 &quot;</td>
</tr>
<tr>
<td>Sodium Chloride</td>
<td>6.36 &quot;</td>
</tr>
<tr>
<td>Sodium Phosphate</td>
<td>13.34 &quot;</td>
</tr>
<tr>
<td>Calcium Chloride</td>
<td>18.26 &quot;</td>
</tr>
<tr>
<td>Manganese Sulphate</td>
<td>0.26 &quot;</td>
</tr>
<tr>
<td>Manganese Chloride</td>
<td>0.24 &quot;</td>
</tr>
<tr>
<td>Aluminium Sulphate</td>
<td>0.58 &quot;</td>
</tr>
<tr>
<td>Boric Acid</td>
<td>0.23 &quot;</td>
</tr>
<tr>
<td>Zinc Sulphate</td>
<td>0.50 &quot;</td>
</tr>
<tr>
<td>Copper Sulphate</td>
<td>0.58 &quot;</td>
</tr>
</tbody>
</table>

Stock Solution I made up to 10 litres H₂O.

### Stock Solution II.

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Concentration</th>
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</thead>
<tbody>
<tr>
<td>Ferrous Sulphate</td>
<td>7.09 grm.</td>
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</tbody>
</table>

Stock Solution II made up to 150 cc. H₂O.

### Stock Solution III.

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcium Sulphate</td>
<td>6.65 grm.</td>
</tr>
</tbody>
</table>

### Nutrient Solutions as applied to Cane plants:

- 100 cc. Stock Solution I.
- 200 cc. Stock Solution III.
- 1 cc. Stock Solution II.

All solutions made up to 1000 cc. and applied.