# " A STUDY OF THE MITSCHERLICH METHOD OF ASSESSING THE NUTRIENT STATUS OF TROPICAL SOILS."

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## CONTENTS.

THE MITSCHERLICH METHOD. (Ref. I. and Ref. 2.).

Until recently, the only methods in use for the estimation of the manurial requirements of soils, apart from field experiments, have depended on chemical analysis of the soil. All work of this nature is subject to considerable uncertainty since the chemical factors determining the availability of the soil nutrients have not been completely elucidated. Further, the determination of available nutrients in the soil is of little value unless the relationship between the content of nutrient and growth of the plant is known. The estimation of manurial requirement is inseparably related to the investigation of the Growth and Yield Laws; and the only proposed method which is based theoretically on these laws is that of Mitscherlich. However, it is not essential in practice to base a method on exact Yield Laws, so long as it is remembered that any method not so based will be of an empirical nature. Laboratory methods can be used for deducing the manurial requirements of particular crops, provided sufficient practical data are available to correlate the yield of crop or plant under different conditions with the estimate of manurial content.

Previous to Mitschlerich's work, most of the attempts made to explain the effect of a manure on the growth of a plant were based on what is known as the "law of the minimum". Mitscherlich's Method is based on his claim to have established a growth law which is applicable to all plant species. His "Law of the Physiological Relationships" states that the plant yield can be increased by each single growth-factor even when it is not present in minimum, so long as it is not present in optimum, i.e. that each manurial constituent or growth-factor affects the growth of the plant independently. He has also been able to shew, in his Law of Diminishing Returns, that the rate of increase in yields is not proportional to the increase in the growth-factor or manure applied, but decreases in geometric progression with increasing additions, until a point is reached where no further increase in yield can be obtained. He has shewn that this maximum yield is obtained always from the same quantity of manure, no matter how the other constituents are varied, i.e. that the maximum yield obtained by increasing one constituent is always obtained from the same quantity of this manure.

If the yield of dry matter obtained is compared with the value of the maximum yield as defined above, the ratio of these two quantities, which is a measure of the "effect" of the given quantity of manure, is found to be constant, although the actual value of the increase in yield will vary under different conditions of experiment. He claims that the effect-factor is a natural constant for all agricultural crops and for each and every growth factor, i.e. "any physical, chemical, or, if one likes, any biological factor which can exert an influence on the plant yield." This is the most important point in the application of his laws to soil examination, and by far the greater portion of the critical work on this method has concerned the constancy of the effect-factors under different growth conditions, assuming the logarithmic nature of the yield law. It implies that the manurial requirement in a particular soil is the same for all crops.

For his pot experiments in the routine examination of soils, he assumes that the maximum yield can be directly determined in the case of potash and phosphoric acid by the use of sufficiently large quantities of fertilisers, but the corresponding maximum yield for nitrogen is obtained by calculation.

The method, therefore, is essentially a manurial experiment under definite conditions. The value of the crop produced is measured, and from the result the quantity of available manure which produced it can be deduced. Since the quantity of manure which will give the maximum yield is also known, it follows that a reliable estimate of the manurial deficiency in the soil is obtained. The method has certain advantages possessed by no other method in use at present, but it is costly and slow.

The mixture as filled into the pots consists of 2 parts sand and 1 part soil, this procedure being adopted to improve the physical condition of heavy soils, and also to increase the accuracy of the determination. For, owing to the logarithmic nature of the yield curve, small deficiencies are not readily detected if the concentrations in the soil are sufficient for, say, 90% maximum yield.

Pot tests have certain obvious advantages over even the best regulated field trials (Ref. 5. p. 442 and Ref. 6. pp.3-8.), but in all pot tests it is necessary to sample to some arbitrarily chosen depth, in this case 20 cm. As a result of comparative experiments, Mitscherlich believes that he can allow for the effect of the subsoil below this, by doubling the values of the manurial contents obtained from the pot experiments for potash and phosphoric acid. In his nitrogen experiments the use of this factor frequently gave low results, and this appears to be due to the leaching out from the surface soil and accumulation at a lower level of soluble nitrogenous compounds, particularly nitrates, which at a later stage of growth become available to the plant. He proposes, therefore, to use a factor governed by the permeability of the subsoil, ranging from 1.5 for sandy sub-soils to 4.0 for heavy sub-soils. The sampling factor is bound to be a doubtful quantity, and this necessarily renders any comparison with field trials very unsatisfactory.

The values of the effect-factors are given as follows : -

| | |
|---|---|
| N | 0.153 cwts. per acre. |
| $P_2O_5$ | 0.753 " " " |
| $K_2O$ | 1.17 " " " |

Theoretically the 100% yield could only be obtained when the concentration in the soil was infinitely great. However, the concentration required to produce yields approximating to 100% maximum can be obtained.

| | Concentration in soil in cwts.per acre. | Percentage of theoretical maximum yield. | Concentration required for 99% max. cwts. per acre. |
|---|---|---|---|
| Potash | 1.6 | 98.6 | 1.75 |
| Phosphoric acid | 1.75 | 95.2 | 2.66 |
| Nitrogen | 4.8 | 82.2 | 13.1 |

The concentrations required to produce any given percentage yield are inversely proportional to the values of the particu-

-lar effect-factors. It will be noticed that Mitscherlich states from his laws that the maximum yield will be obtained from any soil which contains the given quantities of K, P and N. This may seem at first contrary to practical experience.

The great variation in manurial content from soil to soil that his method has frequently revealed seems to justify his recommendation that less attention he paid to "balance" in the dressings, and more attention to the problem of obtaining the proper "balance" in the soil itself. Although the method is theoretically applicable to the quantitative determination of manurial requirements, the recommendations of the Mitscherlich-Gesellschaft tend to take the form of a qualitative manurial programme to be applied over several years. Its rapid development would seem to indicate that information of this nature has proved of practical value. Mitscherlich's theories have been subjected to very heavy criticism (e.g. Ref. 7) and the scientific proof of his method is still to be demonstrated. It would also appear essential that more attention be paid to the statistical treatment by modern methods of the experimental data.

THE PROBLEM.

This investigation was started by Mr. Coombs and the author in conjunction in November 1932. So far as was known, the method had not been tried in any tropical country with the exception of Hawaii. In carrying out this investigation, therefore, it was intended not so much to investigate specific soil problems by its means, as to find out what modifications would have to be made in the procedure to suit tropical conditions, those of Trinidad in particular; to gain experience of the actual working of the method; and to get some idea of its reliability.

The work of the experiment was delayed for several reasons. The literature on the subject in English was scanty and confused. The issue of a Technical Communication (Ref.I) on the subject had been promised early in 1932, but it was not actually received till December 1932. This Communication collected the scattered information on the working of the method and detailed the most recent modifications adopted, and its suggestions were largely followed as soon as it became available. The only source of information from Tropical countries were two reports from Hawaii (Ref. 3 and Ref. 5). It was suggested in the former that modifications would have to be made during the year. The subsequent report, which came in December 1932, did not, however, shew any big modifications.

The soils used in the experiment were collected by the Soil Science Dept., and, as they were soils of which they had already some data and experience, it was thought that it would be interesting to see whether the experiment bore out the opinions of their nutrient status already entertained.

The first problem was that of finding a good indicator plant. It is well known that certain plants when grown in nutrient-deficient soils, shew specific symptoms, e.g. Tobacco and Tomatoes, and these two were tried. The principle of the method being to measure deficiencies quantitatively by dry weight of plant, rather than by any colourations or deformities of leaf etc., Swamp Rice, Setaria italica and Eleusine coracana were grown (Mitscherlich suggests that Rice and Millets might be suitable for tropical conditions). Maize, Cotton and Sunn Hemp were also tried, the latter because it is a legume. In January 1933 we received some Sudan Grass seed that had been ordered from Texas, and this was used in the remaining series.

**TECHNIQUE.**

(a). Equipment. Mitscherlich has designed a set which consists of a cylindrical enamelled metal pot, 20 cm. in diameter and 20 cm. deep, constructed with a round drainage hole in the base, and provided with an enamelled metal cover plate for the hole. A metal stand is provided on which the pot rests, and which allows a drainage dish to be placed underneath the pot. The price of these is given (Ref. I) as 4.60 Reichmarks at works (Germany). Our containers were simply converted kerosene tins, and, while being inexpensive, they were sufficient for our purpose. They are referred to as 'tins' and 'pots' synonymously.

The pots were housed in a cage, the sides of which were constructed of small meshed wire netting, the roof being covered with mosquito netting to keep out birds and insects. There were four wooden stands, fitted with shelves to hold the underneath dishes, which were also constructed from kerosene tins. Water was available from a tap near the cage. The site of the cage was well sheltered from winds but slightly shut off from the sun. The roof was not satisfactory. The netting could not keep out rain, though it broke the force of it; but the worst feature was that the rain collected along the seams and dripped into certain of the tins, not only filling them to excess with water, but washing away the soil from the roots. It is essential to be able to keep out the rain, as the pots of each series are supposed to be kept at the same moisture content (Ref. 2. p. 4). It would have been impossible for us to do this, however, with the limited assistance we had, even if we had been able totally to exclude the rain. We had a roof constructed of canvas and steeped in linseed oil. This was not completely waterproof, and it kept out the sun. We made shift during the wet season by folding it up when the weather was fine. When the dry season commenced, all the seedlings then being well up, we removed both canvas and roof-netting, and suffered little damage from insects and birds. Some of the plants subsequently grew considerably higher than the roof had been.

The criticism can be made of the Mitscherlich enamelled pots that it is difficult to pour from the drainage saucer without spilling, and that rust accumulated in the saucer, apparently from the plate over the drainage hole.

(b). Materials. The soils were mostly collected some weeks previously to the experiment, and had been sun-dried, and stored under cover. The samples were taken at 6" depth. It is recommended that they be passed through a 1 cm. riddle shortly before filling the pots. This will also help to eliminate nut-grass. In some cases, we might have sieved our soil finer with advantage. Mitscherlich uses a spade which takes a column 25 cm. deep and 6.5 cm. in diameter. At least 50 samples should be taken systematically over the field. We also used the following materials : -

(1). Pure Sand. This was obtained from England, and it is no more expensive, and much more satisfactory than local sand.

(2). Gravel.

(3). Appropriate quantities of solutions containing

(a) 0.6 g. N as Sulphate of Ammonia.

(b) 1.5 g. $K_2O$ as Sulphate of Potash.

(c) 0.8 g. $P_2O_5$ as Superphosphate.

Stewart (Ref. I) suggests somewhat larger applications, and we followed his quantities in the case of the Mitscherlich enamelled pots. He says there that small quantities of Sodium Chloride, Magnesium Sulphate and precipitated Calcium Carbonate should be added. We did not do this in any of the series.

In most of the series we used 2 parts of sand to 1 part of soil, by volume. In the last few series, we had not enough sand left to use these proportions. Most of the seed was obtained from the college farm. The Sudan Grass was obtained from Lubbock, Texas, U.S.A., its description being T.S. 6817.

(c). Filling of Pots, and Treatment during Growth.

A slit was made in the bottom of the kerosine tins for drainage. This was not wide enough to need a metal plate over it. The tins were filled to a depth of 4-5" with gravel and stones.

The appropriate quantities of soil and sand were weighed out and transferred to a large enamel basin, and well mixed. The manures were then added, and thoroughly mixed into the soil. This was done under cover. The tins were arranged on the benches so that replicates were not adjacent. Shadow effects were eliminated as far as possible by interchange of the pots throughout the season. A pegged marking board was used which marked 49 holes equidistantly. Two or three seeds were placed in each hole, in the case of Sudan Grass, Setaria, Eleusine and Rice. In the case of the larger seeds, a few were put in each tin by hand. They were then covered over till germination had taken place. About the second leaf stage the seedlings were thinned out to about 35 per pot, removing the weakest from each hole. For a few days the soil was sprinkled with water, and then the tins were watered daily with a hose. Watering was reduced almost to nothing just before harvesting. In temperate climates, watering can be discontinued entirely 8 days before harvest (Ref. I).

In some cases we disinfected the seed before sowing, but this precaution appeared unnecessary. Covering over of the tins during germination, and the overshadowing effect on the soil of the high sides of the tins, caused some mould on the soil. Several of the plants suffered from caterpillars, but we were able to pick these off by hand. On the cotton we used a spray to kill aphids. Some of the young Eleusine seedlings were attacked by cutworms. We then protected all seedlings with netting, till they were a few inches high.

(d). Harvesting. The grain was stripped off each plant by hand and collected separately from the straw, which was cut off at soil level. The crop was dried for about 3 days in an oven, and then weighed to the nearest tenth of a gram. The total yield is taken as the weight of grain plus the weight of straw. The straw was chopped into 2" lengths with a chaff cutter. Both straw and grain were dried in paper bags.

(e). Calculation of Results. In the soil tests the mean yield from the complete manuring represents the maximum obtainable from $K_2O$ and $P_2O_5$ manuring under the given condi-

-tions, and therefore gives the value of A.

$$\text{Manurial content of soil} = b = \frac{\log A - \log (A - y_0)}{c}$$

The mean yields from the $-K_2O$ and $-P_2O_5$ treatments give the corresponding values of $y_0$, and accepting Mitscherlich's value for the effect-factor c, the concentration of $K_2O$ and $P_2O_5$ in the soil, i.e. b, can be calculated. It is convenient to express the yields as a percentage of the "maximum". In the case of N, the rate of manuring is not sufficient to give the theoretical maximum yield, but this can be calculated from the equation

$$A_n = \frac{ky - y_0}{k - 1}$$

where $y_0$ is the yield from the - N pot

y " " " " " C "

$k = 10^{cx}$, ( c being the N effect-factor and

x " " rate of nitrogenous manuring).

Having obtained the N. maximum yield, the soil concentration b is calculated from the first equation. Tables (Ref. 5, p. 444) are given in Mitscherlich's book, from which the soil concentrations can be read. We found it quicker to work out our results from the original formula.

The concentrations of available N, $K_2O$ and $P_2O_5$ calculated in this way refer to the mixture of 2 parts sand and 1 part soil, and they require to be multiplied by 3 to correct for this dilution. Where we used a mixture in different proportions we have used the corresponding dilution factor. This gives the values for the soil sample, and to translate these to terms of concentration in the field, we have again multiplied, by 2, to allow for the effect of the subsoil below the sampling depth, for all three elements. The calculated field values are compared with the optimum concentrations (Ref. I., Table I.) to obtain an estimate of the manurial requirements.

RESULTS.

These are grouped according to soils, and are expressed firstly as the quantity of $K_2O$, $P_2O_5$ and N readily available in the soil, and secondly as the amount of these nutrients that must be added to the soil to produce that percentage of the theoretical maximum yield given in column2 of the Table on page 4. All values are given as cwts. per acre. In all calculations the yield from the C pots has been taken as the maximum. The full figures for yields are given in an Appendix and the standard deviation is given.

Throughout the thesis

C is used to mean complete treatment, with N, $K_2O$ and $P_2O_5$

-$K_2O$ " " " " " " but without $K_2O$

-$P_2O$ " " " " " " " " $P_2O_5$

- N " " " " " " " " N

## Brasso Clay.

Maize. The results from this were inconclusive. Certain of the tins had been filled before we took over the experiment, and these gave a much smaller yield.

| Sunn Hemp. | Readily Available cwts. per acre | Deficiency cwts. per acre |
|---|---|---|
| $K_2O$ | 2.26 | - |
| $P_2O_5$ | 1.49 | 0.26 |
| N. | No useful figures can be given as this plant is a legume. | |

## Cricket Field.

Maize.

| | | |
|---|---|---|
| $K_2O$ | 1.28 | 0.32 |
| $P_2O_5$ | 0.88 | 0.87 |
| N. | 1.35 | 3.45 |

## Caroni Bad.

Maize. The juice was analysed (Ref. 8). Mean determinations were

| Treatment | $K_2O$ content. | $P_2O_5$ content. |
|---|---|---|
| C | 0.443 % | 0.085 % |
| $-K_2O$ | 0.144 % | 0.080 % |
| $-P_2O_5$ | 0.375 % | 0.012 % |

No variation was observed in the colour of the sap, which was light-brown in colour.

Cotton.

| | | |
|---|---|---|
| $K_2O$ | 3.93 | - |
| $P_2O_5$ | no result | - |
| N | 2.76 | 2.04 |

(continued)

| Caroni Bad. | Readily available cwts. per acre. | Deficiency. cwts.per acre. |
| --- | --- | --- |
| Tomatoes. | | |
| $K_2O$ | no result | - |
| $P_2O_5$ | 17.32 | - |
| N. | 2.63 | 2.17 |
| Eleusine. | | |
| $K_2O$ | no result | - |
| $P_2O_5$ | 10.73 | - |
| N. | 2.27 | 2.53 |
| Setaria. | | |
| $K_2O$ | 7.46 | - |
| $P_2O_5$ | 5.05 | - |
| N. | 0.70 | 4.10 |
| Sudan Grass. | | |
| $K_2O$ | no result | - |
| $P_2O_5$ | 5.07 | - |
| N. | 0.77 | 4.03 |
| **Torrecilla.** | | |
| Sudan Grass. | | |
| $K_2O$ | 1.82 | - |
| $P_2O_5$ | 1.71 | 0.04 |
| N. | 4.35 | 0.45 |
| **Esmeralda.** | | |
| Sudan Grass. | | |
| $K_2O$ | 2.63 | - |
| $P_2O_5$ | 0.47 | 1.28 |
| N | 2.37 | 2.43 |

**Las Hermanas.**

**Sudan Grass.**

| | | |
|---|---|---|
| $K_2O$ | 2.20 | - |
| $P_2O_5$ | 0.88 | 0.87 |
| N | 20.53 | - |

DISCUSSION AND RECOMMENDATIONS.

The general criticism may be made of this method, that it is weakest in determining the nitrogen requirement in soil. Nitrogen is usually the most expensive of the farmer's manures, and the need for it is very marked in the Tropics, through rapid leaching. Reports from Hawaii shew "considerably increased confidence in the method. For potash the results so far shew a reliability to be compared with the better field experiments" (Ref. 4). Potash is very expensive in Hawaii. It is clearly expected there that the method will give very accurate results for Sugar Cane fertilization, and while we obtained no figures of value, it seems probable that under proper conditions, the method can be made to give good results.

The first step towards obtaining accurate results is attained when replications do not vary much from their mean, and when the yields from the complete treatments are not smaller than those from the other treatments. When consistency that satisfies statistical treatment has been attained, then the results must be tested against chemical analyses, field experiments, or practical experience to see whether they are accurate. Our figures clearly do not conform to the first requirement, and the only indication from them is that phosphate appears to be lacking in several of the soils; which agrees with previous experience. This deficiency shewed itself at all stages of growth. Where, as with Caroni Bad, we tried various indocator plants, the several results are inconsistent between, as well as within, themselves. It may be noted, in connection with the fact that the $-K_2O$ and $-P_2O_5$ treatments on several occasions gave bigger yields than the C treatment, that Turner has found that the addition of phosphate to cane soils may depress yields. A further seeming inconsistency appeared, when e.g. Setaria was grown. It was calculated from the yields of this plant, that the Caroni Bad contained 5.05 cwts per acre of readily available $P_2O_5$. It is stated in the Table reproduced on p. 14 that an amount of 1.75 cwts per acre is sufficient to produce a yield of 95.2% of the theoretical maximum yield. Yet those pots from which $P_2O_5$ was omitted only gave 76.8% of the yield from the C. pots.

The control of water-content is a very important part of the procedure, and our inability to maintain an even water-content was probably the chief cause of the uneven results. Sudan Grass was the best of the indicator plants we tried: it germinated well and uniformly, and grew quickly. It is reported from Hawaii (Ref. 4) that it is still the standard plant for Mitscherlich work there. They have "found, however, that when raw rock-phosphate has been applied by a plantation, Sudan Grass indicates considerably less phosphate than seems to be available to cane. Dryland Rice on the other hand is able to feed on raw rock-phosphate to about the same extent as Sugar Cane. When the Sudan Grass, therefore, shows a very low phosphate soil, they now plant four pots of Dryland Rice." Buckwheat alone of the other plants they have tried seems to shew possibilities. With the big plants that we tried, like Maize, there is too much scope for individual variation. The Rice germinated badly, because the seed was too new, and the Tobacco was too delicate to grow from seed.

The author recommends that the experiment be continued next year on these lines: - Sudan Grass be used as the indicator plant and those soils available at the college be tested, following the procedure detailed in Ref. I., Appendix I. Amongst these might be included that of the Permanent Manurial Plots at the Farm.

The kerosene tins that we used were very heavy for moving about to eliminate shadow effects and for photography. Mitscherlich enamel pots, and large enough plant-pots would be very expensive. The fact that several of the deficient treatments gave bigger yields than the complete, and that our plants grew to such a height - which made it almost impossible to move them without injuring them - suggest that we were using too great a quantity of pure soil. If the kerosene tins were cut down to half the height, they might be a more manageable size, holding about the same quantity as the enamel pots. Jagged edges would be troublesome, but this seems better than filling the full sized tins with gravel. They might be whitewashed to keep them cool. The drainage tins should be free from leaks, and well waxed to check rusting. It will be difficult to prevent shadow effects if the tins are crowded on the benches.

The most important point is that a satisfactory rain-cover must be devised. This should be waterproof against rain collecting in hollows, and such as can easily be rolled up, to let in the sun. It is suggested that someone working close at hand should be responsible during the day time for pulling down the cover over the roof when it rains, and that it should be left down overnight during the wet season. Lowering of the benches would prevent injury to the tall plants from the roof, and would facilitate their movement.

The difficulty with the watering is to keep the tins at the same water content, before they are ready to be brought to full water capacity. The latter can be estimated by the outflow into the drainage saucer. The former might be accomplished by using a measuring can, which would be filled from the hose. Stewart (Ref. I., p. 40) has altered the directions for watering that he gave in Ref. 2. The former ref. also says that distilled water is used. This is the only mention of distilled water that we have seen, and Ref. 5 clearly implies that distilled water is not used. There is the further point that the tap-water was suspected of containing phosphate (Appendix III, ). If this is so it should be possible to allow for this in estimating manurial contents, and the use of distilled water seems neither necessary nor practicable.

Finally it should be possible to depute much of the routine work to competent laboratory assistants.

## S U M M A R Y.

A preliminary trial was made of the Mitscherlich Method of Soil Analysis. Several soils and several indicator plants were used. The numerical results were not consistent. One plant appeared to be very suitable as an indicator. Weaknesses in the equipment used were recognized, notably the difficulty in controlling the water-content. It is recommended that the experiment be continued; and it is predicted that accurate results should be obtained if these weak points are remedied.

# APPENDIX I.

**Figures in Full.** in grams.

**Brasso Clay.** 18 lbs Soil 18 lbs Sand.

**Sunn Hemp** was sown after Tomatoes had failed.

Harvested when 14 weeks old.

| Pot. | Treatment. | Weight. | Mean of Total. | Percentage. |
|---|---|---|---|---|
| 1 | C | 88.8 | 76.8 ± 12.0 | 100.0 |
| 2 | | 64.8 | | |
| 4 | $-K_2O$ | 57.2 | 60.0 ± 2.8 | 78.12 |
| 5 | | 62.8 | | |
| 7 | $-P_2O_5$ | 28.1 | 36.5 ± 8.4 | 47.52 |
| 8 | | 44.9 | | |
| 10 | -N | 73.1 | 69.25 ± 3.8 | |
| 11 | | 65.4 | | |

**Maize** was sown, 3 plants being left per tin, after Rice had failed. Harvested when 17 weeks old. **Not** dried

*Tins filled August 1932.

| Pot. | Treatment. | Weight. |
|---|---|---|
| * 3 | C | 85.1 |
| 13 | | 122.7 |
| * 6 | $-K_2O$ | 98.0 |
| 14 | | 277.6 |
| * 9 | $-P_2O_5$ | 78.0 |
| 15 | | 263.1 |
| 12 | -N | 83.7 |
| 16 | | 83.2 |

<u>Cricket Field.</u> 18 lbs 'straight' soil.

<u>Maize</u>, 3 plants per pot, after Rice failed.

Harvested when 11 weeks old.

| Pot | Treatment | Weight | Mean of Total | Percentage | 3 P E |
| --- | --- | --- | --- | --- | --- |
| 90 | C | 95.1 | $116.9 \pm 20.71$ | 100 | 24.19 |
| 93 | | 144.1 | | | |
| 96 | | 111.7 | | | |
| 91 | $-K_2O$ | 108.9 | $96.3 \pm 11.92$ | 82.28 | 13.92 |
| 94 | | 100.1 | | | |
| 97 | | 79.8 | | | |
| 92 | $-P_2O_5$ | 58.9 | $62.6 \pm 3.41$ | 53.53 | 3.99 |
| 95 | | 63.7 | | | |
| 98 | | 65.3 | | | |
| 99 | -N | 45.4 | 45.4 | | |

<u>Caroni Bad.</u> Pots 33 - 46 <u>Tobacco,</u> failed.

Pots 49 - 59 <u>Rice,</u> failed.

<u>Caroni Bad</u> 18 lbs Soil 18 lbs Sand.

<u>Cotton</u> var. acala sown, leaving 2 plants per tin

Harvested when 18 weeks old.

| Pot | Treatment | Boll | Stalk | Mean of Total | Percentage |
|---|---|---|---|---|---|
| 17 | C | 18.4 | 19.6 | 43.05±5.05 | 100.0 |
| 18 | | 22.4 | 25.7 | | |
| 19 | $-K_2O$ | 24.9 | 30.0 | 40.0±14.9 | 92.92 |
| 20 | | 13.5 | 11.6 | | |
| 21 | $-P_2O_5$ | 20.6 | 24.0 | 52.45±7.85 | 121.8 |
| 22 | | 29.7 | 30.6 | | |
| 23 | -N | 6.8 | 7.9 | 17.0±2.3 | |
| 24 | | 8.4 | 10.9 | | |

<u>Tomatoes</u> 10 lbs Soil 26 lbs Sand (1 : 2 by volume) 5 plants were left in each tin. Harvested when 20 weeks old. The first were removed when ripe and their Dry Weight assumed to be 10% of 'green' weight.

Tomatoes (Continued).

| Pot. | Treatment. | Weight. Stalk | Fruit | Mean of total. | Percentage. | 3 x P E |
|---|---|---|---|---|---|---|
| 60 | C | 50.1 | 6.2 | $54.9 \pm 3.15$ | 100.0 | 3.15 |
| 63 | | 44.1 | 13.9 | | | |
| 66 | | 42.8 | 7.5 | | | |
| 62 | $-K_2O$ | 54.3 | 6.2 | $63.5 \pm 2.12$ | 116.0 | 2.48 |
| 64 | | 65.0 | | | | |
| 67 | | 53.2 | 11.8 | | | |
| 61 | $-P_2O_5$ | 55.8 | 4.4 | $54.5 \pm 7.70$ | 99.33 | 9.00 |
| 65 | | 59.7 | | | | |
| 68 | | 35.3 | 8.3 | | | |
| 69 | -N | 15.5 | | 15.5 | | |

<u>Caroni Bad</u> 10 lbs Soil + 26 lbs Sand (1 : 2 by volume).

<u>Elensine</u> Harvested when 16 weeks old.

| Pot. | Treatment. | Weight. Grain. | Straw. | Mean of Total. | Percentage. | 3 x P E |
|---|---|---|---|---|---|---|
| 70 | | 36.5 | 52.9 | | | |
| 73 | C | 38.9 | 50.5 | 83.2 $\pm$ 8.77 | 100.0 | 10.25 |
| 76 | | 36.5 | 44.9 | | | |
| 71 | | 43.4 | 55.5 | | | |
| 74 | $-K_2O$ | 35.9 | 54.6 | 90.2 $\pm$ 7.59 | 108 | 8.87 |
| 77 | | 29.5 | 51.8 | | | |
| 72 | | 41.2 | 53.2 | | | |
| 75 | $-P_2O_5$ | 18.5 | 42.2 | 79.4 $\pm$ 13.82 | 95.5 | 16.15 |
| 78 | | 34.1 | 48.9 | | | |
| 79 | -N | 8.1 | 12.8 | 20.9 | | |

<u>Caroni Bad</u>. 10 lbs Soil + 26 lbs Sand (1 : 2 by volume).

<u>Setaria</u> Harvested when 12 weeks old.

| Pot. | Treatment. | Weight. Grain | Straw. | Mean of Total. | Percentage. | 3 x P E |
|---|---|---|---|---|---|---|
| 80 | | 15.9 | 47.4 | | | |
| 83 | C | 25.6 | 52.5 | 68.7 ± 6.98 | 100.0 | 8.16 |
| 86 | | 21.6 | 43.2 | | | |
| 81 | | 15.8 | 38.0 | | | |
| 84 | $-K_2O$ | 36.3 | 49.9 | 66.4 ± 14.17 | 96.5 | 16.56 |
| 87 | | 20.0 | 39.2 | | | |
| 82 | | 14.6 | 33.7 | | | |
| 85 | $-P_2O_5$ | 19.1 | 34.0 | 52.8 ± 3.56 | 76.8 | 4.17 |
| 88 | | 20.0 | 37.0 | | | |
| 89 | -N | 0.9 | 5.3 | 6.2 | | |

Caroni Bad. 4 lbs Soil $\pm$ 11 lbs Sand (1 : 2 by volume) in enamelled pots. About 35 seedlings of Sudan Grass (Sorghum sudanense) left per pot. Harvested when 15 weeks old.

| Pot. M. | Treatment. | Weight. Grain | Weight. Straw. | Mean of Total. | Percentage. | 3 x P E |
|---|---|---|---|---|---|---|
| 1 | C | 21.3 | 105.5 | 116.1 $\pm$ 7.8 | 100.0 | 9.1 |
| 5 | | 17.4 | 95.8 | | | |
| 9 | | 16.8 | 91.5 | | | |
| 2 | $-K_2O$ | 20.7 | 87.0 | 120.4 $\pm$ 8.1 | 104 | 10.4 |
| 6 | | 28.1 | 95.3 | | | |
| 10 | | 24.8 | 105.2 | | | |
| 3 | $-P_2O_5$ | 15.5 | 72.6 | 89.3 $\pm$ 5.3 | 76.9 | 6.1 |
| 7 | | 13.0 | 69.8 | | | |
| 11 | | 17.0 | 79.9 | | | |
| | | Grain + Straw | | | | |
| 4 | -N | 9.0 | | 8.26 $\pm$ 0.52 | | 0.9 |
| 8 | | 7.8 | | | | |
| 12 | | 8.0 | | | | |

Torrecilla 20 lbs 'straight' soil, a sandy Cocoa soil.

Sudan Grass. Harvested when 14 weeks old.

| Pot. | Treatment. | Weight. Grain | Weight. Straw. | Mean of Total. | Percentage. | .3 x P E |
|---|---|---|---|---|---|---|
| 100 | C | 25.4 | 146.7 | 206.0 ± 27.7 | 100.0 | 32.4 |
| 103 | | 30.7 | 175.9 | | | |
| 106 | | 40.3 | 199.1 | | | |
| 101 | $-K_2O$ | 33.3 | 164.5 | 188.3 ± 17.69 | 91.38 | 20.67 |
| 104 | | 31.1 | 131.9 | | | |
| 107 | | 36.3 | 167.7 | | | |
| 102 | $-P_2O_5$ | 30.8 | 135.1 | 159.3 ± 6.37 | 77.33 | 7.44 |
| 105 | | 25.9 | 133.7 | | | |
| 108 | | 26.1 | 126.4 | | | |
| 109 | -N | 24.0 | 126.5 | 150.5 | | |

**Esmeralda.** 16 lbs Soil + 6 lbs Sand. Coconut Soil.

Sudan Grass. Harvested when 14 weeks old.

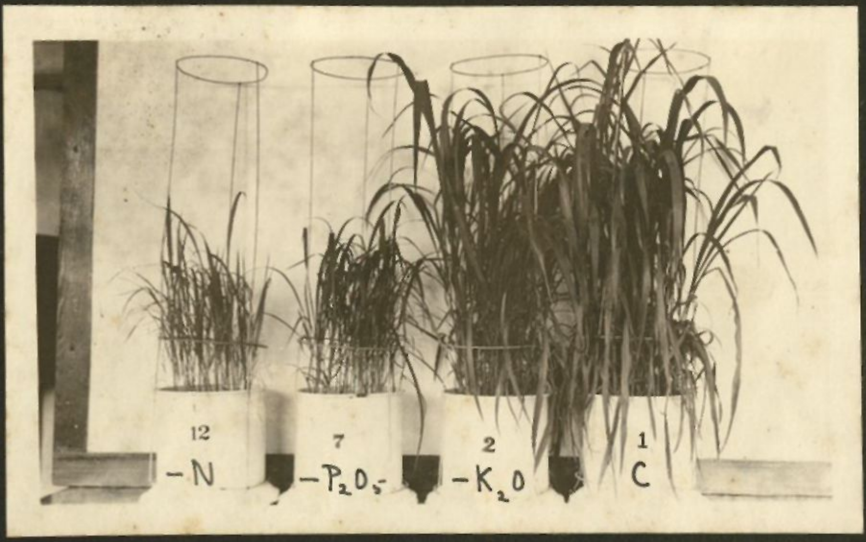
| Pot. | Treatment. | Weight. Grain | Straw. | Mean of Total. | Percentage. | 3 x P E. |
|---|---|---|---|---|---|---|
| 110 | C | 34.2 | 155.0 | 185.2 $\pm$ 13.53 | 100.0 | 15.81 |
| 113 | | 39.0 | 160.4 | | | |
| 116 | | 34.3 | 132.7 | | | |
| 111 | $-K_2O$ | 34.6 | 144.4 | 174.3 $\pm$ 1.34 | 94.1 | 1.56 |
| 114 | | 31.5 | 142.2 | | | |
| 117 | | 28.8 | 141.3 | | | |
| 112 | $-P_2O_5$ | 2.5 | 54.0 | 51.8 $\pm$ 5.11 | 28.0 | 5.97 |
| 115 | | 1.8 | 42.9 | | | |
| 118 | | 2.5 | 51.7 | | | |
| 119 | -N | 12.5 | 76.9 | 89.4 | | |

<u>Las Hermanas</u>. 16 lbs Soil + 6 lbs Sand. A bad Cocoa soil. <u>Sudan Grass</u>. Harvested when 14 weeks old.

| Pot. | Treatment. | Weight. Grain | Straw. | Mean of Total. | Percentage. | 3 x P E. |
|---|---|---|---|---|---|---|
| 120 | C | 48.3 | 122.7 | 163.3 ± 6.28 | 100.0 | 7.35 |
| 123 | | 45.0 | 110.6 | | | |
| 127 | | 39.9 | 123.4 | | | |
| 121 | $-K_2O$ | 33.9 | 97.4 | 148.0 ± 12.49 | 90.65 | 14.59 |
| 124 | | 41.4 | 118.1 | | | |
| 128 | | 37.9 | 115.4 | | | |
| 122 | $-P_2O_5$ | 3.1 | 82.5 | 74.7 ± 8.23 | 45.7 | 9.63 |
| 125 | | 1.3 | 64.4 | | | |
| 129 | | 3.0 | 69.8 | | | |
| 130 | -N | 38.0 | 121.3 | 159.3 | | |

Appendix II

# Caroni Bad. Sudan Grass.




5 weeks.


11 weeks.

# Esmeralda. Sudan Grass.


5 weeks.


14 weeks.

Cricket Field. Maize.


6 weeks.


11 weeks.


Torrecilla. Sudan Grass
14 weeks


Las Hermanas. Sudan Grass
14 weeks.


Caroni Bad. Cotton

18 weeks.


Caroni Bad. Eleusine.

16 weeks.

Experimental Shed.

# APPENDIX III.

## Tapwater Experiment.

The water used in the main experiment was tapwater. In most cases the $-P_2O_5$ pots were slower in growing than the C and $-K_2O$, but in many instances they appeared to recover from this poor start (Appendix II). An experiment was set up to test tapwater, distilled water and rainwater against each other, with reference to the rate of growth of the plants. Their growth lent support to the idea that phosphate was present in the tapwater in sufficient quantity to have a cumulative influence on the growth rate. The experiment was abandoned when the plants were 10 weeks old. Mr. Rodrigues analysed the tapwater in August 1932 and found that it contained 42 parts per million of $P_2O_5$.

## APPENDIX IV.

### Acknowledgments.

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## APPENDIX V.

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