# THE BENEFICIAL EFFECT OF FILTER PRESS CAKE ON PINEAPPLE GROWTH, DEVELOPMENT, AND PRODUCTION

## I. EFFECT ON THE PLANT CROP

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## INTRODUCTION

Pineapple is the third most important agricultural export crop in Puerto Rico, being preceded only by sugarcane and tobacco, in that order. During the fiscal year 1948–49, the total value of fresh pineapples exported amounted to $1,164,039 while that of the canned fruit and juice exports amounted to $2,550,370, making a grand total of $3,714,409 (1).[2]

Because pineapple production has great potentialities in the years to come there is incentive to exert effort towards the solution of the most urgent physiological and agronomic problems of pineapple production in the Island.

One of the problems that received special attention in the past by Hopkins and his coworkers in Puerto Rico (6) was that of the minor elements iron and manganese as bearing on pineapple growth. Under greenhouse conditions he demonstrated the importance of the interrelationship of iron and manganese in the metabolism of pineapples. In preliminary pot-test work with beans grown in soil obtained from a typical pineapple-growing area, he prevented severe chlorosis of the first trifoliate leaves characteristic of manganese toxicity by adding calcium carbonate to raise the pH of the soil to 6.2. This led him to suggest that manganese toxicity chlorosis of pineapples could be prevented by raising the pH of the soil with calcium carbonate. From this, it may be inferred that a great proportion of the soil manganese is unavailable or insoluble to such an extent that the available iron in the soil is not antagonized by the remaining available manganese, and thus pineapple chlorosis does not occur.

As a result of Hopkins' findings, and following his suggestions with respect to the possible usefulness of calcium carbonate in the control of

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[2] Numbers in parentheses refer to Literature Cited, p. 280.

excessive soluble manganese in the soil, two pineapple experiments were established in the fall of 1947. In addition to the use of calcium carbonate as one of the treatments the addition of organic matter in the form of filter press cake was also tested. Filter press cake is a byproduct of the sugar mills of Puerto Rico. The purpose of this study was to develop remedial treatments which would counteract the adverse effects of iron-manganese imbalance in the soil upon the growth, development, and production of pineapples.

## Materials and Methods

### CULTURAL TECHNIQUE

The first of the two pineapple experiments was started on November 25, 1947. Pineapple slips of the Red Spanish variety selected for uniformity in size and weight were planted in the open site, in ebonol-painted half-drums in soil obtained from a typical pineapple area in Palo Blanco, Arecibo. This lateritic soil is classified as Bayamón silty clay (8). It has been in continuous pineapple cultivation for about 20 years. The average pH of this soil as determined with a glass electrode was 4.49, a relatively high acidity.

The second pineapple experiment was started also on November 25, 1947. The same variety of pineapple slips were used but these were planted in Fajardo clay soil, which is an acid lateritic soil derived from ashy shales (4). This soil was obtained from the Experiment Station Farm near Río Piedras. The average pH of this soil as determined with the glass electrode was 4.48.

Both pineapple experiments were established following a randomized block arrangement. There were 5 treatments, each treatment was replicated 10 times, making a total of 50 plants in each experiment. A general view of the experiments is presented in figure 1.

The treatments tried in both experiments were as follows: A, Soil treated with calcium carbonate to raise its pH to 6.2; B, soil treated with calcium carbonate to raise its pH to 7.2; C, filter press cake mixed with the soil; D, ferrous sulfate sprays applied to the plants; and E, control or untreated plants and soil. The lime-requirement determinations to bring the soil pH to the expected values were made according to the method of Riera (9). Filter press cake was added and mixed with the top 6 inches of soil in amounts equivalent to 10 percent of the weight of the soil used per drum. The ferrous sulfate spray was prepared by dissolving commercial ferrous sulfate in tap water at the rate of 25 lbs. of the salt in 100 gallons of water, equivalent to a 3-percent solution of the salt. Only one spray treatment was given to the plants approximately 4 months after planting.

All pineapple plants undergoing the various treatments received commercial pineapple fertilizer, formula 12[3]–6–10, at the rate of 1½ tons per acre. Four applications of this fertilizer were made during the vegetative cycle of the plants, a method ordinarily used in commercial pineapple plantations.

Seven months after planting, on June 30, 1948, leaf samples were taken from plants representatives of each treatment, and chemical determinations were made of total and soluble iron and manganese. The active or largest leaf of each plant was selected for this purpose (12). The leaves

FIG. 1.—General view of pineapple experiments established in Bayamón silty clay from Palo Blanco, Arecibo and Fajardo clay from Experiment Station Farm, Río Piedras.

from the plants under each treatment were cut with a stainless steel knife, the midsection being utilized for the chemical analyses. These were first washed with distilled water as completely as possible and then rinsed in fresh distilled water. All the midsections of leaves corresponding to a treatment were put together and sectioned into small pieces so that there was a composite sample of leaf tissue for each treatment. The composite sample was well mixed and divided into two similar portions, one of which was dried in an oven at 65°C. for 48 hours to be used for determina-

[3] As ammonia ($NH_3$)

tions of total iron and manganese. The second portion of the leaf-tissue was frozen quickly in a refrigerator at approximately minus 20°C. until ready for analysis.

To induce flowering, the plants from both experiments were treated with acetylene on November 30, 1948, approximately 1 year after being planted. This consisted in applying to the crown of the plant about 25–30 ml. of a solution made by dissolving 2 ounces of calcium carbide in 5 gallons of water in a closed container.

## ANALYTICAL METHODS

Aliquot portions of the finely ground tissue for the determination of total iron and manganese were gradually digested with 2-ml. concentrated $H_2SO_4$ and approximately 2-ml. $H_2O_2$ until the solution was completely clear. This was made to volume in a 50-ml. volumetric flask and aliquots of this solution were used for the determination of total iron and manganese. Iron was determined according to the Saywell and Cunningham orthophenanthroline method (10) while manganese was determined by the periodate method as described by Peech (7). A Coleman spectrophotometer, model 14, with filter PC-4 at a wave length of 490 mu and with filter PC-4 at a wavelength of 525 mu was used for the determinations of iron and manganese, respectively.

For determinations of soluble iron and manganese the leaf samples which had been frozen immediately after harvest were thawed, wrapped in a piece of muslin of suitable size, and subjected to a pressure of 2,750 pounds per square inch in a Carver press for three consecutive periods totaling 4 minutes. Approximately 30 ml. of distilled water were used with each sample at each period to aid in the removal of the cell sap. The extracted plant juices and washings were filtered through a No. 5 Whatman filter paper, and the residue was added to the pressed sample which, after being removed from the muslin, was covered and dried in an oven at 70°C. for 48 hours. The filter paper was ashed and added to the pressed sample. The material was then ground in a semimicro Willey mill to a fine powder as were the samples used for the determination of total iron and manganese. Aliquots of the ground tissue were used for iron and manganese determinations.

The soluble iron and manganese content of the juice or cell sap was obtained by subtracting the iron and manganese found in an extracted sample from the quantities obtained by analysis of an unextracted sample. In other words, the iron and manganese that remained in the press cake after extraction were regarded as the insoluble or unavailable portions of these elements in the plant tissue analyzed.

### HARVESTING PROCEDURES

The pineapple fruits from the plant, or first crop, of both experiments were harvested during May and June of 1949. In addition to yield of fruits number of slips and number of suckers were considered as criteria in obtaining the results to be discussed in this paper. Slips are the axillary offshoots which arise from the buds found nearest to the base of the fruits in the fruiting stalk of the plants and which are used for commercial plantings. Suckers are the axillary offshoots which arise from the buds found at the base of the stem of the plant and which give rise to the ratoon or second crop.

The results of each experiment will be considered separately, but they will be considered jointly in the discussion.

## Experiment on Soil Type Bayamon Silty Clay from Arecibo

### EXPERIMENTAL RESULTS AND STATISTICAL INTERPRETATION

#### Effect of Treatments on Plant Growth

During the vegetative cycle a striking difference was observed in the growth made by plants which received filter press cake as a soil remedial treatment and those subjected to other treatments (figure 2). These plants made considerably more vegetative growth, were more vigorous, were greener in color, and practically all of them had produced suckers before the application of calcium carbide to induce flowering. The stems of these filter-press-cake-treated plants were stouter and the leaves were wider than those of plants undergoing other treatments. The filter-press-cake-treated plants were greener in color than the plants which received the ferrous sulfate spray, while the lime-treated plants were light green. In fact, it was very easy to select among all plants those that grew in soil which was treated with filter press cake since they were the tallest, stockiest, and darkest green among the plants, as can be observed in figure 1. These same plants developed thicker flower stalks than the others. Judging from the size of these plants and the thickness of their flower stalks it was logical to assume that their fruit yields would be greater than those of plants undergoing other treatments; this was found to be true on harvesting.

#### Effect of Treatments on Yield of Fruits

The data obtained with respect to mean weight of fruits under each treatment are presented in table 1; table 2 presents the statistical analysis of the yield data. It can be seen from table 2 that the $F$ value for the experiment is highly significant, indicating that there are highly significant

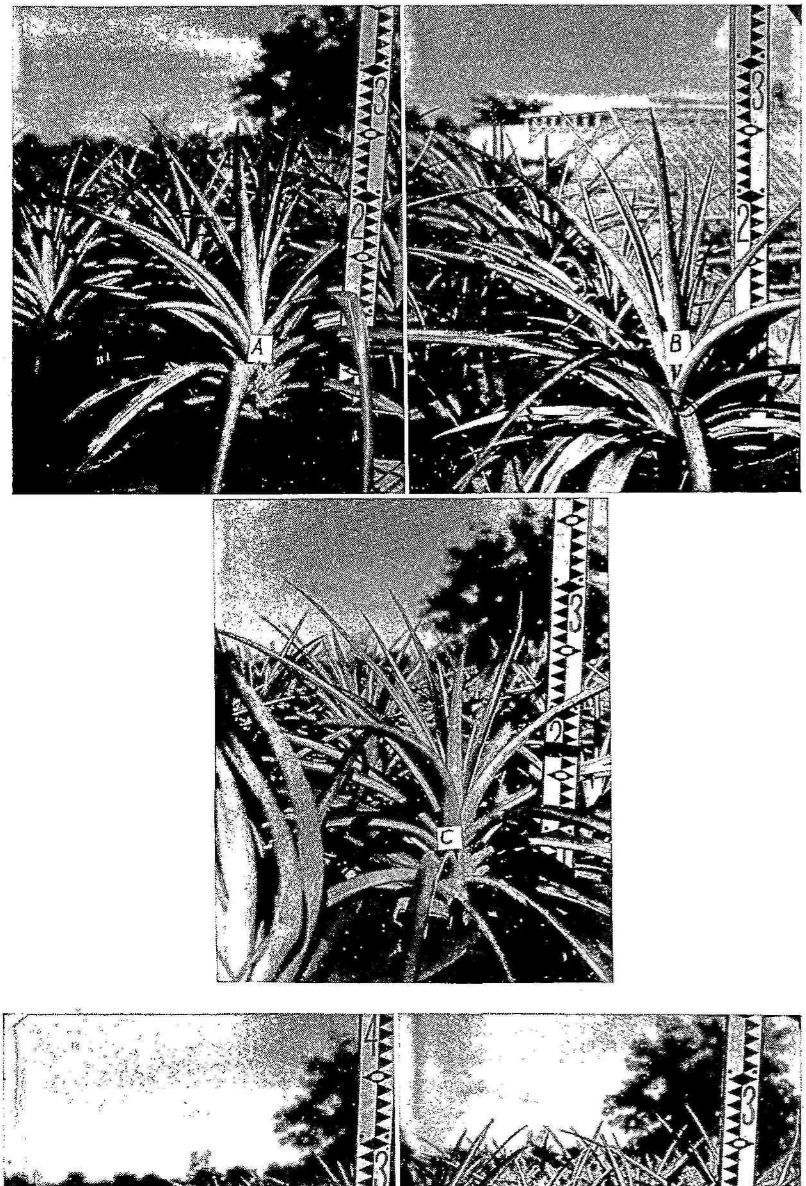


FIG. 2.

differences between the effects of the treatments on mean fruit weights. The results of the evaluation of the statistical significance of the mean fruit-weight differences that may be attributed to the various treatments tried are shown in table 1. These results indicate that the pineapple plants grown in the soil to which filter press cake had been added (treatment C), were the heaviest yielders, their yields being significantly superior at the 5-percent level to those of pineapple plants grown in soil with the pH

TABLE 1.—*Mean fruit weights of pineapple plants grown in Bayamón silty clay from Palo Blanco, Arecibo*

[Plant crop]

| Symbol | Treatments | Mean weight of fruit | Outyielded at—[1] | |
|---|---|---|---|---|
| | | | 5-percent level | 1-percent level |
| | | *Pounds* | | |
| A | Soil pH adjusted with lime to 6.2 | 3.54 | — | — |
| B | Soil pH adjusted with lime to 7.2 | 3.17 | — | — |
| C | Filter press cake mixed with soil | 4.49 | A–D | B |
| D | Ferrous sulfate spray applied to plants | 3.52 | — | — |
| E | Control—no treatment | 3.85 | — | — |

[1] Least significant difference between mean weights of fruits at the 5-percent level, 0.89 lb.; at the 1-percent level, 1.20 lbs.

TABLE 2.—*Analyses for the total sum of squared deviations for mean fruit weights of pineapple plants grown in Bayamón silty clay from Palo Blanco, Arecibo*

[Plant crop]

| Source | Degrees of freedom | Sum of squares | Mean square | *F* value[1] |
|---|---|---|---|---|
| Total | 49 | 29.6191 | | |
| Replications | 9 | 2.1907 | | |
| Treatments | 4 | 9.7195 | 2.4294 | 4.94* |
| Error | 36 | 17.7089 | .4919 | |

[1] One asterisk indicates significance at 5-percent level; two asterisks at 1-percent level in this and later tables.

adjusted with lime to 6.2 (treatment A) and to pineapple plants which received ferrous sulfate spray, treatment D (figure 3, A, C, D). These same filter-press-cake-treated plants were also significantly superior in

FIG. 2.—Vegetative growth made by pineapple plants by the end of approximately 11 months from planting: A, Soil pH adjusted with lime to 6.2; B, soil pH adjusted with lime to 7.2; C, filter press cake mixed with soil; D, ferrous sulfate spray applied to plants; and E, control—no treatment.

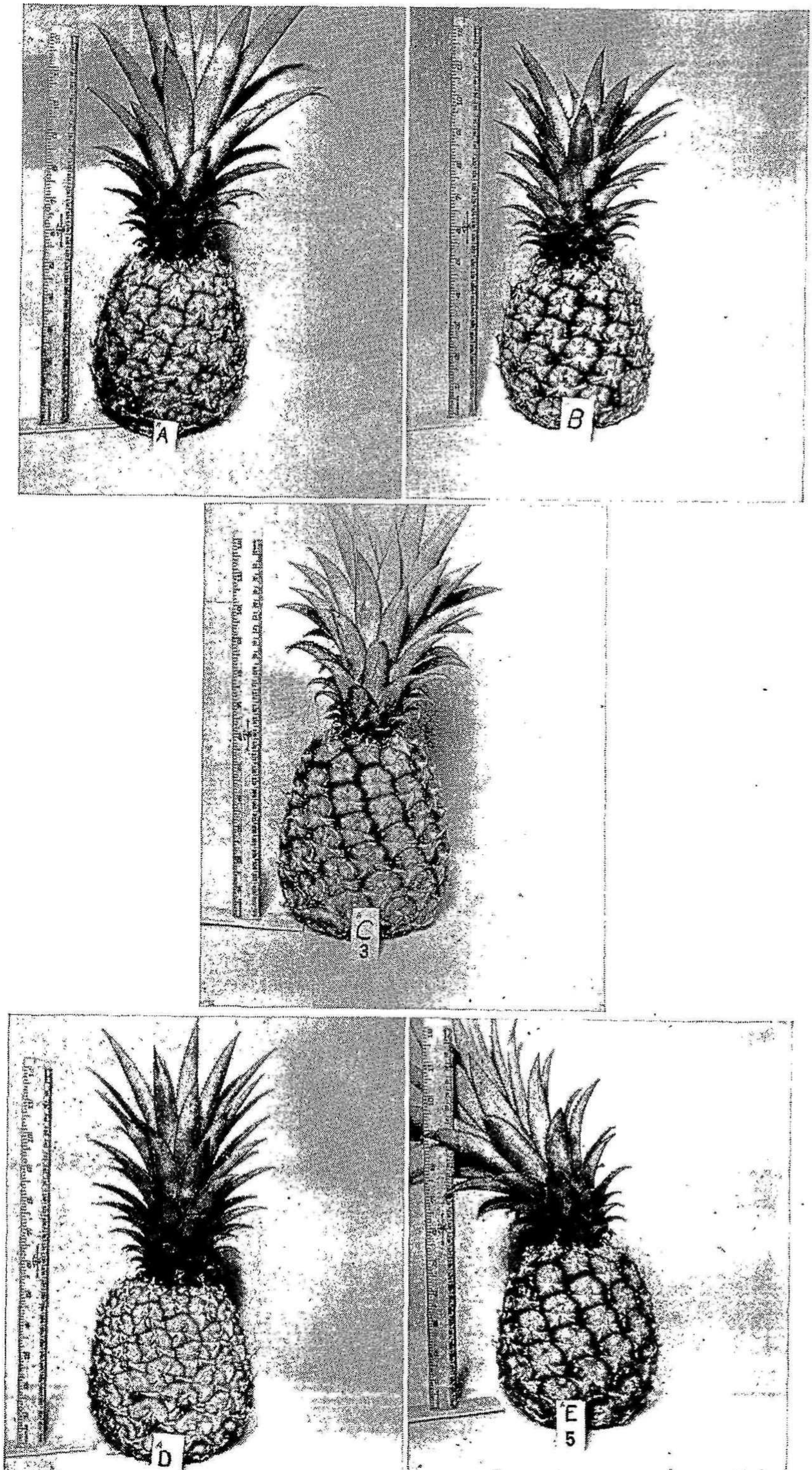


Fig. 3.

yield at the 1-percent level to the pineapple plants of treatment B, grown in soil where the pH was adjusted with lime to 7.2 (figure 3, B). It is also evident from table 1 that, except for the filter-press-cake treatment, no significant differences occurred between any of the other treatments considered in the experiment.

## Effect of Treatments on Slip Production

The results gathered on the mean number of slips from plants undergoing the various treatments are shown in table 3; table 4 presents a summary of the statistical analysis of these data. It indicates that there are significant differences between the mean number of slips produced by the plants under the different treatments. The results of the evaluation of the statistical significance of the differences in mean number of slips that may be attributed to the different treatments are presented in table 3. They indicate that the pineapple plants which developed in the soil to which filter press cake was added (treatment C) produced the greatest mean number of slips. However, they were significantly superior at the 5-percent level only to the slips produced by the plants of treatments A and B grown in soil that received lime to raise the pH to 6.2 and 7.2, respectively. There were no significant differences between the mean number of slips produced by plants that received other treatments.

TABLE 3.—*Mean number of slips and of suckers of pineapple plants grown in Bayamón silty clay from Palo Blanco, Arecibo*

[Plant crop]

| Symbol | Treatments | Mean number of slips | Outyielded at 5-percent level[1] | Mean number of suckers | Outyielded at 1-percent level[2] |
|---|---|---|---|---|---|
| A | Soil pH adjusted with lime to 6.2 | 4.2 | — | 1.6 | — |
| B | Soil pH adjusted with lime to 7.2 | 4.2 | — | 1.3 | — |
| C | Filter press cake mixed with soil | 7.8 | A–B | 3.5 | A–B–D–E |
| D | Ferrous sulfate spray applied to plants | 5.3 | — | 1.9 | — |
| E | Control—no treatment | 5.7 | — | 1.8 | — |

[1] Least significant difference between mean number of slips at the 5-percent level, 3.36.

[2] Least significant difference between mean number of suckers at the 1-percent level, .96.

FIG. 3.—Typical pineapple fruits and average weight of fruits obtained from plants subjected to the various treatments: A, Soil pH adjusted with lime to 6.2, 3.54 lbs.; B, soil pH adjusted with lime to 7.2, 3.17 lbs.; C, filter press cake mixed with soil, 4.49 lbs.; D, Ferrous sulfate spray applied to plants, 3.52 lbs.; and E, control—no treatment, 3.85 lbs.

## Effect of Treatment on Sucker Production

The results obtained on the mean number of suckers in the different treatments are reported in table 3; a summary of the statistical analysis appears in table 4. As can be seen, the *F* value for the experiment is highly significant, showing that there were highly significant differences between the mean number of suckers produced by the pineapple plants under the various treatments. As a matter of fact, the *F* value obtained for the mean number of suckers was a little over 6 times the actual *F* value required for odds of 99.1, thus underlining the effect of treatments on the production of suckers by pineapple plants. It is evident from table 3 that the filter-press-cake-treated plants (treatment C) were superior in production of

TABLE 4.—*Analyses for the total sum of squared deviations for mean number of slips and suckers of pineapple plants grown in Bayamón silty clay from Palo Blanco, Arecibo*

[Plant crop]

| Source | Degrees of freedom | Sum of squares | Mean square | *F* value |
|---|---|---|---|---|
| | | *Slips* | | |
| Total | 49 | 343.68 | | |
| Replications | 9 | 15.52 | | |
| Treatments | 4 | 87.32 | 21.83 | 3.26* |
| Error | 36 | 240.84 | 6.69 | |
| | | *Suckers* | | |
| Total | 49 | 44.98 | | |
| Replications | 9 | 4.18 | | |
| Treatments | 4 | 29.48 | 7.37 | 23.77** |
| Error | 36 | 11.32 | .31 | |

suckers to those undergoing other treatments, and in a highly significant way. This demonstrates that the filter-press-cake amendment had a beneficial effect on sucker production. There was no significant difference between the results of other treatments. The suckers of the filter-press-cake-treated plants developed much earlier than the suckers from plants that underwent other treatments.

## Effect of Soil pH on Weight of Fruits, Number of Slips, and Number of Suckers

To determine the possible effect of soil pH on fruit yields, and slip and sucker production of pineapple plants under the various treatments, a regression study was made of the above-mentioned criteria on soil pH. Soil samples were taken from each replicate of each treatment at depths of 0–3 inches and 3–6 inches, respectively; pH determinations were made using a glass electrode. Table 5 presents the results of the regression studies. It can be seen that the regressions were all significant either at the 5- or 1-percent level. They were all highly significant at the 1-percent level at the 0–3-inch soil depth. Therefore, under the conditions of this experiment, this soil depth is the better of the two studied for regression studies of the weight of fruits, number of slips, and number of suckers on soil pH. Since the regression coefficients are negative, there was an inverse relation between soil pH and the growth criteria being considered.

The regressions of weight of fruits, number of slips, and number of suckers on soil pH are shown in figure 4. To avoid plotting each fruit weight, number of slips, and number of suckers with reference to each pH

TABLE 5.—*Results of regression studies of weight of fruits, number of slips, and number of suckers on soil pH at two soil depths; experiment in Bayamón silty clay from Palo Blanco, Arecibo*

[Plant crop]

| Criteria | Regression coefficient at soil depth of— | | Percentage of sum of squares explained by regression at soil depth of— | | Number of observations |
|---|---|---|---|---|---|
| | 0–3 inches | 3–6 inches | 0–3 inches | 3–6 inches | |
| | | | *Percent* | *Percent* | |
| Weight of fruits | −0.319** | −0.310** | 21.0 | 16.0 | 50 |
| Number of slips | − .904** | − .827** | 14.0 | 10.0 | 50 |
| Number of suckers | − .470** | − .452** | 29.0 | 22.0 | 50 |

reading obtained, the pH values and the different criteria considered were grouped arbitrarily according to pH ranges and mean weight of fruits, mean number of slips, and mean number of suckers as is shown in table 6.

In figure 4 it may be clearly seen that weight of fruits, number of slips, and number of suckers produced by pineapple plants were adversely affected by increments of soil pH. In other words, increases in fruit yields as well as in slip and sucker production were inversely proportional to increments in soil pH. Thus an acid reaction of the soil medium tended to favor plant response in all respects.

## Effect of Treatments on Weight of Fruits, Number of Slips, and Number of Suckers, Eliminating Soil pH Effect

To study the effects of the different treatments divorced from their pH effect on the mean weight of fruits, mean number of slips, and mean number

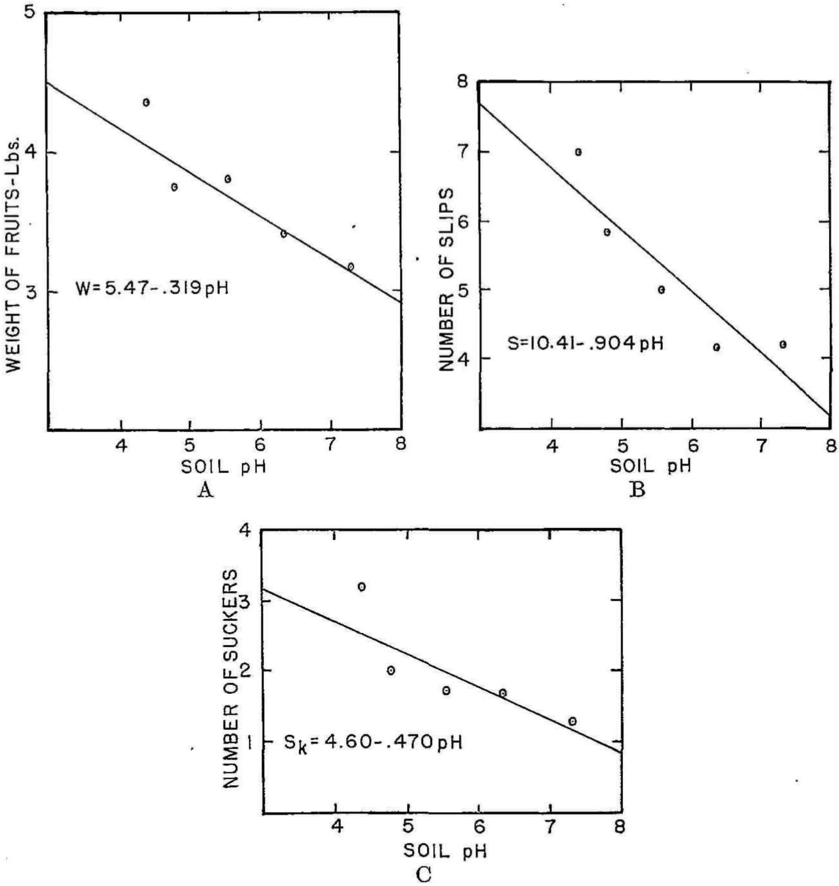


FIG. 4.—Regressions of weight of fruits (A), number of slips (B), and number of suckers (C) on soil pH at 0–3 inches soil depth; experiment in Bayamón silty clay from Palo Blanco, Arecibo.

TABLE 6.—*Summary of criteria considered in regressions of weight of fruits and numbers of slips and suckers; experiment in Bayamón silty clay from Palo Blanco, Arecibo*

[Plant crop]

| Number of plots | pH range | Mean pH | Mean yield per fruit | Mean number of slips | Mean number of suckers |
|---|---|---|---|---|---|
| | | | *Pounds* | | |
| 10 | 3.91–4.60 | 4.46 | 4.35 | 7.00 | 3.20 |
| 17 | 4.61–5.00 | 4.77 | 3.74 | 5.88 | 2.00 |
| 7 | 5.01–6.00 | 5.39 | 3.80 | 5.00 | 1.71 |
| 6 | 6.01–7.00 | 6.26 | 3.42 | 4.17 | 1.67 |
| 10 | 7.01–7.50 | 7.24 | 3.17 | 4.20 | 1.30 |

TABLE 7.—*Summary of covariance analyses for mean fruit weights of pineapple plants grown in Bayamón silty clay from Palo Blanco, Arecibo*

[Plant crop]

| Symbol | Treatments | Adjusted mean weight of plants | Deviations from control | Least significant deviation at 5-percent level |
|---|---|---|---|---|
| | | *Pounds* | *Pounds* | |
| A | Soil pH adjusted with lime to 6.2 | 3.726 | 0.036 | 1.398 |
| B | Soil pH adjusted with lime to 7.2 | 3.595 | − .095 | 2.395 |
| C | Filter press cake mixed with soil | 4.234 | .544 | .760 |
| D | Ferrous sulfate spray applied to plants | 3.350 | − .340 | .646 |
| E | Control—no treatment | 3.690 | — | — |

TABLE 8.—*Summary of covariance analyses for mean number of slips of pineapple plants grown in Bayamón silty clay from Palo Blanco, Arecibo*

[Plant crop]

| Symbol | Treatments | Adjusted mean number of slips | Deviations from control | Least significant deviation at 5-percent level |
|---|---|---|---|---|
| A | Soil pH adjusted with lime to 6.2 | 4.040 | −1.692 | 5.150 |
| B | Soil pH adjusted with lime to 7.2 | 3.939 | −1.857 | 8.824 |
| C | Filter press cake mixed with soil | 7.959 | 2.163 | 2.799 |
| D | Ferrous sulfate spray applied to plants | 5.403 | − .393 | 2.377 |
| E | Control—no treatment | 5.796 | — | — |

TABLE 9.—*Summary of covariance analyses for mean number of suckers of pineapple plants grown in Bayamón silty clay from Palo Blanco, Arecibo*

[Plant crop]

| Symbol | Treatments | Adjusted mean number of suckers | Deviations from control | Least significant deviations at— | |
|---|---|---|---|---|---|
| | | | | 5-percent level | 1-percent level |
| A | Soil pH adjusted with lime to 6.2 | 1.352 | −0.697 | 1.104 | — |
| B | Soil pH adjusted with lime to 7.2 | .624 | −1.425 | 1.893 | — |
| C | Filter press cake mixed with soil | 3.910 | 1.861 | .600 | 0.805 |
| D | Ferrous sulfate spray applied to plants | 2.105 | .116 | .510 | — |
| E | Control—no treatment | 2.049 | — | — | — |

of suckers, a covariance analysis was made eliminating the effect of variations on soil pH; tables 7, 8, and 9 present the results.

It appears from tables 7 and 8 that none of the treatments had an effect on mean weight of fruits or mean number of slips, when the effect of pH was disregarded. In other words, the possible detrimental effect that lime might have as a nutrient or otherwise, or the possible beneficial effect of filter press cake or iron spray to plants, were not evident when the pH effect was disregarded. On the other hand, table 9 indicates that when the pH effect is disregarded, filter press cake was the only factor that had a highly significant effect on the number of suckers produced by the pineapple plants undergoing this treatment. This indicated that some factor other than pH was also responsible for the high sucker production under this treatment. This point will be considered in detail in the discussion.

TABLE 10.—*Total and soluble iron and manganese content of midsection of active center leaves of pineapple plants grown in Bayamón silty clay from Palo Blanco, Arecibo*

[Plant crop]

| Symbol | Treatments | Total iron | Soluble iron | Soluble iron to total iron | Total manganese | Soluble manganese | Soluble manganese to total manganese | Ratio Fe/Mn, soluble |
|---|---|---|---|---|---|---|---|---|
| | | *P.p.m.* | *P.p.m.* | *Per cent* | *P.p.m.* | *P.p.m.* | *Per cent* | |
| A | Soil pH adjusted with lime to 6.2 | 140 | — | — | 330 | 294 | 89.09 | — |
| B | Soil pH adjusted with lime to 7.2 | 193 | 74 | 38.34 | 330 | 256 | 77.58 | 1:3.5 |
| C | Filter press cake mixed with soil | 158 | 69 | 43.67 | 270 | 189 | 70.00 | 1:2.7 |
| D | Ferrous sulfate spray applied to plants | 114 | 34 | 29.82 | 360 | 213 | 59.17 | 1:6.3 |
| E | Control—no treatment | 123 | 46 | 37.39 | 450 | 375 | 83.33 | 1:8.2 |

### Results of Chemical Analyses of Leaf Tissue Fractions

The results of quantitative analyses for total and soluble iron and manganese of the midsection fractions of active leaves of pineapple plants in the various treatments are presented in table 10. They provide no conclusive evidence of a direct relationship between the iron and manganese content of the plant tissues analyzed and yields of pineapples reported in table 1. It is of interest to note in table 10 that a relatively large proportion of the total manganese in the midsection of active leaves of pineapple plants is soluble whereas the reverse is true of the total iron therein.

## EXPERIMENT ON FAJARDO CLAY

### EXPERIMENTAL RESULTS AND STATISTICAL INTERPRETATION

### Effect of Treatments on Plant Growth

Pineapple plants which were grown in soil treated with filter press cake made more vegetative growth and were darker green than those given other treatments. The stems of these filter-press-cake-treated plants were thicker and their leaves wider and larger than those of the other plants. All the filter-press-cake-treated plants had developed suckers just before being treated with acetylene, showing earliness in this respect (figure 5). This was true also of plants similarly treated but grown in Bayamón silty clay. Pineapple plants which received lime as a soil remedial treatment were of a light-green color, which was more pronounced in those growing in soil that was limed to raise the pH to 7.2. Even the check plants looked better in all respects than the lime-treated plants. In short, these plants were the most vigorous of all and were similar to those treated with filter press cake in the experiment reported above. (Figure 6, A, C, D.)

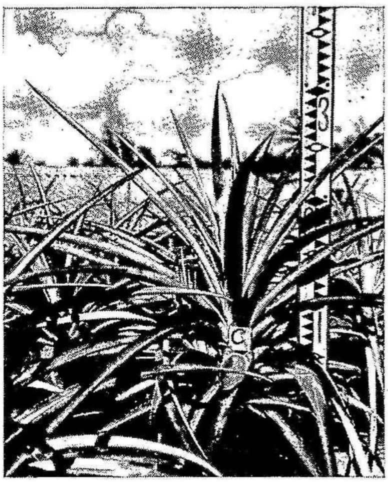

FIG. 5.—Pineapple plant grown in soil with which filter press cake had been mixed. Note developing sucker at lower left side of stem.

## Effect of Treatments on Fruit Yields

The results on the mean weight of fruits undergoing the different treatments are presented in table 11; table 12 presents the statistical analysis of this fruit data. Table 12 shows that there were highly significant differences between the mean fruit weights of plants grown under different treatments. Table 11 also shows the results of the evaluation of the statistical significance of the mean-fruit-weight differences attributable to the various treatments. It appears from these data that the pineapple plants grown in soil mixed with filter press cake (treatment C) produced the greatest mean weight of fruits, this mean weight being significantly superior at the 5-percent level to that of pineapple plants grown in limed soil to raise the pH to 6.2 (treatment A) and to the check plants of treatment E. Also the fruit yields of these filter-press-cake-treated plants were superior at the 1-percent level to the yields of plants from treatment B where the soil was limed to raise its pH to 7.2, and to those of treatment D,


FIG. 6.—Vegetative growth made by pineapple plants approximately 11 months from planting: A, Soil pH adjusted with lime to 6.2; C, filter press cake mixed with soil; and D, ferrous sulfate spray applied to plants. (Treatments B and E not shown.)

which received a ferrous sulfate spray. No significant difference was evident between the mean fruit weights of the plants in the other treatments.

Effect of Treatments on Slip Production

The data on the mean number of slips produced under the different treatments are reported in table 13; table 14 summarizes the statistical

TABLE 11.—*Mean fruit weight of pineapple plants grown in Fajardo clay from Experiment Station Farm, Río Piedras*

[Plant crop]

| Symbol | Treatments | Mean weight of fruits | Outyielded at[1] | |
|---|---|---|---|---|
| | | | 5-percent level | 1-percent level |
| | | *Pounds* | | |
| A | Soil pH adjusted with lime to 6.2 | 3.33 | — | — |
| B | Soil pH adjusted with lime to 7.2 | 3.27 | — | — |
| C | Filter press cake mixed with soil | 4.47 | A–E | B–D |
| D | Ferrous sulfate spray applied to plants | 2.94 | — | — |
| E | Control—no treatment | 3.60 | — | — |

[1] Least significant difference between mean weights of fruits at the 5-percent level, 0.86 lb.; at the 1-percent level, 1.15 lbs.

TABLE 12.—*Analyses for the total sum of squared deviations for mean fruit weight of pineapple plants grown in Fajardo clay from Experiment Station Farm, Río Piedras*

[Plant crop]

| Source | Degrees of freedom | Sum of squares | Mean squares | *F* value |
|---|---|---|---|---|
| Total | 49 | 32.5398 | | |
| Replications | 9 | 2.9297 | | |
| Treatments | 4 | 13.3720 | 3.3430 | 7.41** |
| Error | 36 | 16.2381 | .4511 | |

TABLE 13.—*Mean number of slips and of suckers of pineapple plants grown in Fajardo clay from Experiment Station Farm, Río Piedras*

[Plant crop]

| Symbol | Treatments | Mean number of slips | Outyielded at 5-percent level[1] | Mean number of suckers | Outyielded at 1-percent level[2] |
|---|---|---|---|---|---|
| A | Soil pH adjusted with lime to 6.2 | 3.6 | — | 1.7 | — |
| B | Soil pH adjusted with lime to 7.2 | 4.2 | — | 1.2 | — |
| C | Filter press cake mixed with soil | 6.2 | A | 3.1 | A–B–D–E |
| D | Ferrous sulfate spray applied to plants | 3.9 | — | 1.0 | — |
| E | Control—no treatment | 4.9 | — | 1.7 | — |

[1] Least significant difference between mean number of slips at the 5-percent level, 2.31.

[2] Least significant difference between mean number of suckers at the 1-percent level, 1.21.

analysis of these data. It is clear that the results were significant as regards slip production, since the *F* value obtained experimentally was greater than that required to give odds of 19:1. The results of the evaluation of the statistical significance of differences between the mean number of slips that may be attributed to the various treatments are reported in table 13. It is evident that the pineapple plants treated with filter press cake (treatment C) were superior in slip production to those treated otherwise, but were significantly superior only at the 5-percent level to the slips produced by pineapple plants of treatment A grown in soil that was limed to a pH of 6.2. No significant differences were observed in slip production that could be ascribed to other treatments.

TABLE 14.—*Analyses for the total sum of squared deviations for mean number of slips of pineapple plants grown in Fajardo clay from Experiment Station Farm, Río Piedras*

[Plant crop]

| Source | Degrees of freedom | Sum of squares | Mean square | $F$ value |
|---|---|---|---|---|
| Total | 49 | 204.32 | | |
| Replications | 9 | 44.72 | | |
| Treatments | 4 | 42.92 | 10.73 | 3.31* |
| Error | 36 | 116.68 | 3.24 | |

TABLE 15.—*Analyses for the total sum of squared deviations for mean number of suckers of pineapple plants grown in Fajardo clay from Experiment Station Farm, Río Piedras*

[Plant crop]

| Source | Degrees of freedom | Sum of squares | Mean square | $F$ value |
|---|---|---|---|---|
| Total | 49 | 47.62 | | |
| Replications | 9 | 2.82 | | |
| Treatments | 4 | 26.92 | 6.730 | 13.54** |
| Error | 36 | 17.88 | .497 | |

## Effect of Treatments on Sucker Production

Table 13 presents the data on the mean number of suckers of the pineapple plants from each treatment; table 15 reports a summary of the statistical analysis of these data. This summary indicates that there are highly significant differences in sucker production by the pineapple plants undergoing the different treatments. Table 13 shows the evaluation of the statistical significance of mean number of suckers as a result of the treatments. The pineapple plants grown in soil mixed with filter press cake (treatment C) again surpassed those undergoing other treatments in sucker production, and in a highly significant way. It is also evident that differences in sucker production between the plants of other treatments were not significant. Again suckers arising from the plants treated with filter press cake were considerably more developed than those of plants undergoing other treatments.

## Effect of Soil pH on Weight of Fruits, Number of Slips, and Number of Suckers

As was done in the other experiment, a regression study was made to find the possible effect of soil pH on fruit weight, and slip and sucker production. The same procedure was followed for taking soil samples at various depths and readings in the glass electrode as for the soil of the first experiment. Table 16 shows the results of these regression studies. With only one exception, which fell short of a significant value, the regression coefficients on soil pH of the three criteria considered were all significant also. As in the first experiment, the regression coefficients were negative,

TABLE 16.—*Results of regression studies of weight of fruits, number of slips, and number of suckers on soil pH at two soil depths; experiment in Fajardo clay from Experiment Station Farm, Río Piedras*

[Plant crop]

| Criteria | Regression coefficient at soil depth of— | | Percentage of sum of squares explained by regression at soil depth of— | | Number of observations |
|---|---|---|---|---|---|
| | 0–3 inches | 3–6 inches | 0–3 inches | 3–6 inches | |
| Weight of fruits......... | −0.245* | −0.317* | 12.0 | 9.0 | 50 |
| Number of slips......... | − .472 | − .905* | 7.0 | 11.0 | 50 |
| Number of suckers...... | − .346** | − .474* | 17.0 | 12.0 | 50 |

indicating that there is an inverse relation between soil pH and the criteria under consideration.

The regression of weight of fruits and number of suckers on soil pH at 0–3-inch soil depth is presented in figure 7. To avoid plotting each fruit weight and number of suckers with respect to each pH value obtained, the same procedure was followed as for the experiment already reported. The values for pH's and the various criteria considered were grouped arbitrarily according to pH ranges, mean weight of fruits, and mean number of suckers as reported in table 17.

The summary presented and figure 7 shows that, as a whole, the mean yield of fruits and the mean number of suckers produced by the pineapple plants were again adversely affected by increased soil alkalinity. Under the conditions of the experiment, increases in fruit yields and sucker production were again inversely correlated with increments in soil pH. Similar results have been obtained with respect to fruit yields and pH studies (8).

## Effect of Treatments on Weight of Fruits, Number of Slips, and Number of Suckers, Eliminating Soil pH Effect

As in the previous experiment, covariance analyses were made to study the effect of the various treatments on mean weight of fruits, mean number

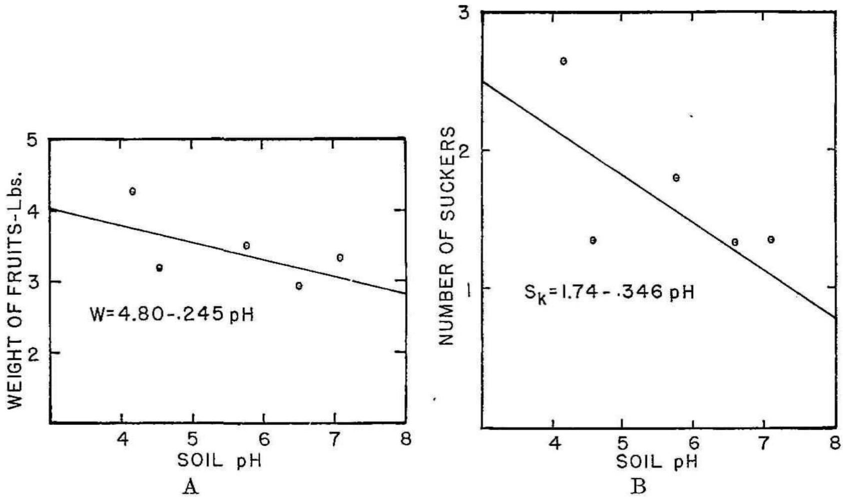


FIG. 7.—Regressions of weight of fruits (A), and number of suckers (B) on soil pH at 0–3 inches soil depth; experiment in Fajardo clay from Experiment Station Farm, Río Piedras.

TABLE 17.—*Summary of criteria considered in regressions of weight of fruits and number of suckers; experiment in Fajardo clay from Experiment Station Farm, Río Piedras*

[Plant crop]

| Number of plots | pH range | Mean pH | Mean yield per fruit | Mean number of suckers |
|---|---|---|---|---|
| | | | *Pounds* | |
| 14 | 3.81–4.40 | 4.14 | 4.25 | 2.64 |
| 17 | 4.41–5.00 | 4.57 | 3.20 | 1.35 |
| 5 | 5.01–6.10 | 5.59 | 3.53 | 1.80 |
| 6 | 6.11–6.90 | 6.51 | 2.94 | 1.33 |
| 8 | 6.91–7.32 | 7.12 | 3.37 | 1.25 |

of slips, and mean number of suckers, when the effects of soil pH were disregarded. Tables 18 and 19 report the results of these.

Contrary to expectations, it appears that the iron spray was detrimental to fruit and sucker production at the 5-percent level, when the effect of pH was ignored. In the previous experiment the iron spray had neither favorable nor unfavorable effects on the pineapple plant life cycle. None of the treatments (table 19) had any effect on slip production when pH was ignored. This is consistent with results obtained in the first experiment.

TABLE 18.—*Summary of covariance analyses for mean fruit weights of pineapple plants grown in Fajardo clay from Experiment Station Farm, Río Piedras*

[Plant crop]

| Symbol | Treatments | Adjusted mean weight of fruits | Deviations from control | Least significant deviations at— 5-percent level | Least significant deviations at— 1-percent level |
|---|---|---|---|---|---|
| | | *Pounds* | *Pounds* | | |
| A | Soil pH adjusted with lime to 6.2 | 3.827 | 0.643 | 1.066 | — |
| B | Soil pH adjusted with lime to 7.2 | 4.362 | 1.178 | 1.588 | — |
| C | Filter press cake mixed with soil | 3.759 | .575 | .646 | — |
| D | Ferrous sulfate spray applied to plants | 2.476 | −.708 | .584 | .784 |
| E | Control—no treatment | 3.184 | — | — | — |

TABLE 19.—*Summary of covariance analyses for mean number of slips and of suckers of pineapple plants grown in Fajardo clay from Experiment Station Farm, Río Piedras*

[Plant crop]

| Symbol | Treatments | Adjusted mean number of slips | Deviations from control | Least significant deviations at— 5-percent level | Least significant deviations at— 1-percent level |
|---|---|---|---|---|---|
| | *Slips* | | | | |
| A | Soil pH adjusted with lime to 6.2 | 4.196 | −0.199 | 3.000 | — |
| B | Soil pH adjusted with lime to 7.2 | 5.517 | 1.122 | 4.470 | — |
| C | Filter press cake mixed with soil | 5.349 | .954 | 1.819 | — |
| D | Ferrous sulfate spray applied to plants | 3.342 | −1.053 | 1.644 | — |
| E | Control—no treatment | 4.395 | — | — | — |
| | *Suckers* | | | | |
| A | Soil pH adjusted with lime to 6.2 | 2.008 | 0.570 | 1.164 | — |
| B | Soil pH adjusted with lime to 7.2 | 1.881 | .443 | 1.735 | — |
| C | Filter press cake mixed with soil | 2.659 | 1.221 | .706 | 0.948 |
| D | Ferrous sulfate spray applied to plants | .711 | −.727 | .638 | .856 |
| E | Control—no treatment | 1.438 | — | — | — |

From table 19 it appears again that filter press cake was the only factor producing a highly significant effect on the number of suckers produced by the pineapple plants in this treatment, which suggests that some factor other than pH was a contributing agent in promoting a better production of suckers.

## Results of Chemical Analyses of Leaf Tissue Fractions

Table 20 reports the results of quantitative analyses for total and soluble iron and manganese of the midsection of active leaves from pineapple plants under the different treatments. The data do not indicate any definite relationship between the iron and manganese content of the plant tissues analyzed and yields of pineapples. It can also be seen that a relatively higher proportion of total manganese was in the soluble form, the reverse being true for total iron.

TABLE 20.—*Total and soluble iron and manganese content of midsection of active center leaves of pineapple plants grown in Fajardo clay from Experiment Station Farm, Río Piedras*

[Plant crop]

| Symbol | Treatments | Total iron | Soluble iorn | Soluble iron to total iron | Total manganese | Soluble manganese | Soluble manganese to total manganese | Ratio Fe/Mn, soluble |
|---|---|---|---|---|---|---|---|---|
| | | *P.p.m.* | *P.p.m.* | *Percent* | *P.p.m.* | *P.p.m.* | *Percent* | |
| A | Soil pH adjusted with lime to 6.2 | 324 | 45 | 13.89 | 390 | 307 | 78.72 | 1:6.8 |
| B | Soil pH adjusted with lime to 7.2 | 271 | 148 | 54.61 | 240 | 163 | 67.92 | 1:1.10 |
| C | Filter press cake mixed with soil | 123 | 60 | 48.78 | 240 | 132 | 55.00 | 1:2.20 |
| D | Ferrous sulfate spray applied to plants | 149 | 49 | 32.89 | 120 | 71 | 59.17 | 1:1.45 |
| E | Control—no treatment | 140 | 62 | 44.29 | 180 | 109 | 60.56 | 1:1.76 |

## GENERAL DISCUSSION

The qualitative observations made on the growth of pineapple plants under the various treatments, as well as the quantitative evidence obtained on the different growth criteria considered in both pineapple experiments, revealed information of importance.

It was found in both pineapple experiments, that the plants treated with filter press cake produced more vigorous growth than plants undergoing other treatments. Moreover, they were greener in color, their leaves were wider, and their stems and flower stalks thicker than the corresponding organs of pineapple plants undergoing the other treatments, thus suggesting high yield.

With only one exception the filter-press-cake-treated plants produce significantly greater yields in both experiments than the plants undergoing other treatments. They were the largest plants of all and the ones having the thickest flower stalks. In other words, the size of plants and thickness of flower stalks were directly related to yield. It may logically be assumed that a large plant with a large, thick flower stalk is capable of yielding a larger fruit because of higher food reserves than small plants with rather small, thin flower stalks, which presumably have a lower food-storage capacity.

It was found in both experiments that pineapple plants grown in soil with which filter press cake was mixed were superior in slip production to plants undergoing other treatments. However, they were significantly superior only to the lime-treated plants, thus showing the detrimental effect of the use of lime, not only on yield production, as mentioned before, but also on slip production. This suggests that the use of lime in pineapple growing is not a wise agricultural practice under present conditions.

It was evident that the filter-press-cake-treated plants in a highly significant way surpassed those undergoing other treatments in the number of suckers produced. This was true in both experiments. It was surprising to observe that the stem offshoots of the plants undergoing this treatment began to show much earlier than those of plants under other treatments. This, of course, was advantageous since these offshoots naturally had a longer period for growth and development, and consequently were better developed to produce a good ratoon crop. Whether the factor responsible for this early appearance of suckers is nutritional, or something else still remains to be investigated. As judged from the qualitative observations made on growth and development of the plants undergoing the various treatments, filter press cake seems to hasten the growth of pineapple plants. In other words, filter press cake tends to favor complete vegetative growth of pineapple plants until they are ready for the acetylene treatment.

The results obtained in both experiments showed conclusively that increases in fruit yields and slip and sucker production were favored by an acid reaction of the soil. These criteria of growth increased as soil pH decreased. Pennock reported similar results on fruit yields and pH studies (8). The theoretical assumption that raising the soil pH slightly above 6 would control the activity of available manganese in the soil and thus favor a better iron-manganese balance (which would be reflected in the metabolism of the pineapple plants and consequently in fruit yields, etc.) was not confirmed in these studies.

The quantitative chemical data presented for both available iron and manganese, and the corresponding ratios, do not provide any clear-cut information that relates fruit yields and other growth criteria here considered to iron and manganese relationships under field conditions. Unpublished data of the writer on iron-manganese studies with pineapples under field conditions point to the possibility that factors other than iron and manganese adversely affect pineapple production, since there seems to be no interaction between lime and ferrous spray treatments in field experiments. This is in complete agreement with similar results obtained by Pennock in pineapple field studies (8). Moreover, the fact that the best yields of pineapples were obtained at relatively low soil acidity where manganese is supposed to be quite soluble (6) strengthens the assumption that factors other than iron and manganese are involved in adversely affecting pineapple production under field conditions. This does not mean that one should completely disregard the importance of the iron and manganese nutrition of pineapples, but it does show that the use of lime in pineapple growing to correct the adverse effects of iron-manganese imbalance is not a sound agricultural practice.

It was found that filter press cake decreased soil pH, lowering it to 4.42 for the Bayamón silty clay of Arecibo and to 4.11 for the Fajardo clay of Río Piedras, as compared with original values of 4.85 and 4.56, respectively, for the untreated soil of both experiments. With these pH's and a source of organic matter such as filter press cake, it is logical to assume that soil micro-organisms, principally soil fungi, were abundant, since it has been demonstrated that such soil microbes are closely associated with the decomposition of organic matter added to the soil (3, 13, 14). It is a well-known fact that organic matter improves soil texture and consequently permits better soil aeration. Since filter press cake is a source of organic matter, it may be assumed that it contributed in the better aeration of the soil, a factor that has been found (because it gives access to oxygen) to be vital for normal healthy root development and consequently for normal plant metabolism (2, 5, 11). Possibly filter press cake was also beneficial in helping prevent the leaching out of soluble nutrients added to the soil in the form of inorganic fertilizer, thus conserving nitrogen, available potash, phosphorus, and other plant nutrients for the pineapple plants.

The covariance analyses made to study the effects of treatments with soil pH effects disregarded indicated that none of them had any effect on yield or slip production in the experiment in Bayamón silty clay from Arecibo. However, in the experiment in Fajardo clay from Río Piedras, the covariance analyses did show to our surprise that the iron spray was significantly detrimental to both yield and slip production. Presumably some unknown factor or factors were responsible for the plants' reaction in this particular experiment. On the other hand, when the pH effect was disregarded, filter press cake was the only treatment which highly significantly influenced the production of suckers by pineapple plants in both experiments, thus showing that some other factor or factors played an important role in this respect.

## Conclusion

The results presented for both pineapple experiments demonstrated the outstandingly beneficial effect of filter press cake and the detrimental effect of lime applications to pineapple soils. The vigorous growth and deep green color of pineapple plants grown in soil with which filter press cake was mixed, and the significant or highly significant results obtained in yield, number of slips, and number of suckers, strengthens the belief that agricultural practices in the Island may be modified or altered so as greatly to increase pineapple production.

## Summary

This paper reports the results obtained in studies carried out to establish the relationship between iron and manganese imbalance in the soil and remedial treatments on pineapple growth, development, and production. In addition to lime carbonate, organic matter in the form of filter press cake was also tested as a soil remedial treatment. The experimental results may be summarized briefly as follows:

1. Pineapple plants grown in soil with the top 6 inches of which filter press cake had been mixed, developed vigorously and were of a dark green color. Their leaves were wider and their stems and flower stalks thicker than those of pineapple plants given other treatments.

2. Pineapple plants grown in soil treated with filter press cake produced more than plants given other treatments. With only one exception their yields were significantly or highly significantly larger than those of plants undergoing other treatments.

3. Pineapple plants grown in soil treated with filter press cake were superior in slip production to plants given other treatments, but were only significantly superior at the 5-percent level to those produced by the lime-treated plants.

4. Pineapple plants grown in soil treated with filter press cake were highly significantly superior in production of suckers to pineapple plants undergoing other treatments.

5. Regression studies revealed that fruit yields and slip and sucker production were inversely proportional to increments in soil pH. A relatively acid soil medium favored plant growth, development, and production.

6. Soil samples at 0–3 inches depth were found to be the best index for regression studies of weight of fruits and number of slips and number of suckers on soil pH.

7. Other than the soil pH, filter press cake was the only factor that had

a highly significant effect on the number of suckers produced by pineapple plants.

8. No relationship was found between the soluble iron and manganese contents of the midsection, center leaves of pineapple plants and yields.

9. The results suggest that the use of lime in pineapple growing is not a sound agricultural practice, insofar as the correction of soil iron-manganese imbalance, and its detrimental effects on the crop are concerned.

10. The results also underline the possibility that factors other than the availability of iron and manganese adversely affect pineapple production in the Island.

11. The use of filter press cake as a soil amendment in pineapple growing offers the opportunity of altering or modifying agricultural practices so as to increase pineapple production in the Island.

## Literature Cited


1. *Annual Book of Statistics of Puerto Rico*, Dept. of Agric. and Commerce, Bur. of Statistics, Investigations and Commercial Services, fiscal year 1948–1949.
2. Arrington, L. B., and Shive, J. W., Oxygen and carbon dioxide content of culture solution in relation to cation and anion nitrogen absorption by tomato plants, *Soil Sci.*, **42**(5) 341–356, November 1936.
3. Bonnet, J. A., Nitrogen transformation in the decomposition of sugar cane trash with special bearing upon Puertorican soil problems, thesis submitted to the Graduate Faculty of Rutgers University in partial fulfillment of the requirements for the degree of Master of Science, May 10, 1930.
4. Bonnet, J. A., Tirado Sulsona, P., and Abruña, F., Effect of lime-phosphorus, and green manure on sweet potatoes and corn grown in acid soils, *Jour. of Agric. Univ. P. R.*, **31**(4) 303–321, Oct. 1947.
5. Gilbert, S. G., and Shive, J. W., The significance of oxygen in nutrient substrates for plants: I, The oxygen requirement, *Soil Sci.*, **53**(2) 143–152, February 1942.
6. Hopkins, E. F., Pagán, V. and Ramírez Silva, F. J., Iron and manganese in relation to plant growth and its importance in Puerto Rico, *Jour. of Agric. Univ. P. R.*, **28**(2) 43–101, April 1944.
7. Peech, M., Determination of exchangeable bases in soils, *Ind. Eng. Chem. Anal.*, **13**(6) 436–441, June 1941.
8. Pennock, W., Field response of Red-Spanish pineapples to nitrogen, calcium, iron and soil pH, *Jour. of Agric. Univ. P. R.*, **33**(1) 1–26, January 1949.
9. Riera, A., Laboratory recommendation of lime to an acid soil checks with expected pH changes, *Jour. of Agric. Univ. P. R.*, **30**(3) 184–185, July 1946.
10. Saywell, L. G., and Cunningham, B. B., Determination of iron-colorimetric o-phenanthroline method, *Ind. and Eng. Chem.*, **9** 67–69, 1937.
11. Shive, J. W., The balance of ions and oxygen tension in nutrient substrates of plants, *Soil Sci.*, **51**(6) 445–459, June 1941.
12. Sideris, C. P., Krauss, B. H., and Young, H. Y., Assimilation of ammonium and nitrate by pineapple plants grown in nutrient solution and its effects on nitrogenous and carbohydrates constituents, *Plant Phys.*, **13** 489–527, 1938.
13. Waksman, S. A., *Principles of Soil Microbiology*, 2nd edition, Bailliere, Tindall, and Cox, London, England, 1931.
14. Waksman, S. A., and Starkey, R. L., *Soil and the Microbe*, John Wiley and Sons, Inc., New York, N. Y., 1931.