CHINESE-AMERICAN
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Plant Industry Series No. 20

# SOILS AND FERTILIZER USES IN TAIWAN REPUBLIC OF CHINA

TAIPEI, TAIWAN, CHINA

May 1961

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# FOREWORD

This report contains 18 papers presented by the Delegation of the Republic of China to the First Far East Regional Fertilizer Workshop held at Taipei, Taiwan, China, from October 24 to November 5, 1960, under the sponsorship of the International Cooperation Administration of the United States Government.

It presents briefly the agronomical and economical basis of the fertilizer usage in this island province of China, and also aspects concerning the planning, local production, importation, marketing and distribution in the fertilizer program.

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May 1961

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# THE FERTILIZER PROGRAM OF TAIWAN, CHINA

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## I. Heavy Fertilization Required by Natural Environment and Cropping System

Like all sub-tropic countries with year-round warm temperature and high annual rainfall, the soils of Taiwan are constantly subject to rapid chemical decomposition and leaching. The depletion of soil fertility on much of its cultivated land is aggravated by the highly intensive land use whereby two to three or more crops are grown and harvested each year. The basic cropping pattern of Taiwan's paddy fields is to grow two rice crops a year, one in the spring and the other in the fall. Prevailing in central and southern Taiwan and growing popular in other areas as well, however, is to grow another upland crop in the winter following the harvest of the second rice crop with little or no irrigation. Such winter crops include wheat, tobacco, flax, winter varieties of sweet potato, soybean, corn and many kinds of vegetables. Fast growing summer crop varieties, i.e. melons, vegetables and jute varieties, have been developed for planting as a summer catch crop to fill up the short interval between the harvest of the first and the transplanting of the second rice crop. An increasing number of farmers in central and southern Taiwan have gone into the growing of four crops a year on the same piece of land.

Such intensive land use under natural conditions conducive to rapid soil depletion demands constant replenishment of nutrients back to soils. It makes the upkeeping of soil productivity the foremost agricultural problem of Taiwan nowadays and ever after.

## II. Total Consumption of Fertilizers Continuously on the Increase

The annual consumption of chemical fertilizers in the best years of Taiwan before the World War II (average of 1935-39) is 599,055 m.t. In 1958, Taiwan consumed a total of 703,020 m.t. of chemical fertilizers, being 103,965 m.t. or 17.4% more than the 1935-39 average in gross tonnage. Since more concentrated fertilizers are used after the War, the increase in consumption is much more striking when expressed in terms of the weight of total plant food (N, $P_2O_5$ and $K_2O$), being 103,599 m.t. for 1935-39 average and 162,889 m.t. in 1958, or a 57.3% increase.

## Table 1.
## Fertilizer Consumption in Taiwan

Unit: m.t.

| Year | N | $P_2O_5$ | $K_2O$ | Total NPK | Total fertilizer |
|---|---|---|---|---|---|
| 1935-39, Peak (average) | 66,543 | 27,864 | 9,152 | 103,559 | 599,055 |
| 1945, Lean | 864 | 331 | 119 | 1,314 | 5,789 |
| 1950 | 48,708 | 12,790 | 1,334 | 62,832 | 289,529 |
| 1951 | 59,285 | 12,771 | 9,608 | 81,664 | 368,511 |
| 1952 | 69,488 | 22,013 | 12,368 | 103,869 | 470,439 |
| 1953 | 69,595 | 25,210 | 14,671 | 109,476 | 489,924 |
| 1954 | 82,008 | 27,330 | 16,704 | 126,043 | 575,376 |
| 1955 | 83,341 | 29,084 | 17,369 | 129,794 | 578,619 |
| 1956 | 90,769 | 30,693 | 19,487 | 140,949 | 647,535 |
| 1957 | 97,027 | 31,954 | 23,635 | 152,616 | 673,829 |
| 1958 | 102,095 | 34,072 | 26,722 | 162,889 | 703,020 |

Source of data: Plant Industry Division, JCRR

Thus in 1958, an average of 795 kg. per hectare of chemical fertilizers was applied to some 883,466 ha. of the cultivated land area of Taiwan. Calculated from the FAO data (1953-1957)*, fertilizer consumption per ha. of agricultural land in Taiwan is 123.72 kg. in terms of plant food (N, $P_2O_5$, $K_2O$). This rate compares favorably with that of the following countries:

| | | | |
|---|---|---|---|
| Netherland | 192.65 kg. | Norway | 116.36 kg. |
| Belgium | 183.16 | Denmark | 104.99 |
| Japan | 167.41 | United Kingdom | 69.71 |
| West Germany | 121.46 | | |

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*Agricultural area—"Yearbook of Food and Agricultural Statistics (Production)", 1953-1956, FAO
Fertilizer consumption—"An Annual Review of World Production and Consumption of Fertilizers", 1954-1957, FAO

However, it should be pointed out that the high rate of fertilizer consumption per hectare in Taiwan is due to the application of fertilizers successively on the 2 or 3 crops grown each year, and that the agricultural area of Taiwan is nearly 100 percent crop land, while that of European countries contains a varying portion of meadows and pastures whereon lower rates of fertilizers are usually applied.

## III. Use of Fertilizers by Different Crops

Having by far the largest acreage among all crops, rice claims the lion's share of the total fertilizer consumption. For instance, out of a total of 703,020 m.t. of fertilizers consumed in 1958, 683,961 m.t. were distributed through the regular government channel and the balance were sold by local factories directly to farmers. Of this 683,961 m.t., 500,716 m.t. or 73.2% were used on rice, 99,525 m.t. or 14.6% on sugarcane and 83,720 m.t. or 12.2% on all other crops put together.

The crops on which farmers are applying fertilizers at fairly high rates include rice, sugarcane, pineapple, jute, cotton and tobacco. For other crops, the current rate of application is yet considerably below optimum as determined by experiments. Generally speaking, the following factors pose hindrance to farmers' willingness in using fertilizers in sufficient amounts on the latter category of crops: (1) the relatively low or instable economic return from the crop concerned makes investment in fertilizer unreliable, e. g. tea, sweet potato, sugarcane for brown sugar, etc.; (2) such factors as drought, run-off, etc. make efficiency of fertilizers unreliable, e.g. peanuts and, in some areas, sweet potato, and, on slope land, banana, tea, citronella, cassava; (3) response of the crops concerned to nitrogen fertilizers is low, and farmers generally do not appreciate as well the value of phosphorous and potash fertilizers, e.g. soybean, peanuts, other beans; and (4) insufficiency in fertilizer experimentation, demonstration and extension, e.g. citronella, cassava, banana, citrus, vegetables, etc.

In these crops not receiving proper amount of fertilizers lies an immense potential for further improvement of crop production in Taiwan through better experimentation and extension on the use of fertilizers.

The optimum rate of fertilizer application and the actual rate applied in 1958 are given in Table 2.

## Table 2.
## The Quantity of NPK Fertilizers Distributed in 1958 and the Optimum Rate of Fertilizer Application for Various Crops

| Crop | Optimum rate of application (kg/ha) | | | Actual distribution record in 1958 | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Total quantity (m.t.) | | | For each ha. (kg.)[1] | | |
| | N | $P_2O_5$ | $K_2O$ | N | $P_2O_5$ | $K_2O$ | N | $P_2O_5$ | $K_2O$ |
| Rice | 80 | 40 | 40 | 70,032 | 27,152 | 14,499 | 90.0 | 34.9 | 18.6 |
| Sugarcane | 150-225 | 75 | 75 | 17,993 | 2,845 | 4,953 | 187.9 | 29.7 | 51.7 |
| Sweet potato | 30 | 25 | 50 | 907 | 333 | 1,278 | 4.0 | 1.5 | 5.6 |
| Wheat | 80 | 60 | 40 | 586 | 346 | 161 | 25.8 | 15.2 | 7.1 |
| Corn | | | | 356 | 156 | 155 | 38.4 | 16.8 | 16.7 |
| Sorghum | | | | 31 | 13 | 13 | 8.6 | 3.8 | 3.8 |
| Peanut | 10 | 30 | 40 | 4 | 8 | 12 | 0.04 | 0.07 | 0.11 |
| Soybean | 10 | 30 | 40 | 1 | 5 | 3 | 0.03 | 0.11 | 0.07 |
| Tea | 37.5-75 | 19 | ? | 884 | 243 | 200 | 18.3 | 5.0 | 4.2 |
| Banana | 150 | 150 | 225 | 1,042 | 460 | 535 | 75.3 | 33.2 | 38.6 |
| Pineapple (general) | 200 | 50 | 200 | 2,118 | 637 | 1,487 | 194.1 | 58.4 | 136.3 |
| Pineapple (TSC) | 200 | 50 | 200 | 276 | 78 | 195 | 241.3 | 67.9 | 170.8 |
| Citrus | 200 | 200 | 200 | 666 | 292 | 340 | 69.8 | 30.6 | 35.6 |
| Jute | 80 | 40 | 60 | 1,199 | 250 | 835 | 94.8 | 19.8 | 66.0 |
| Cotton | 80 | 60 | 60 | 482 | 140 | 179 | 106.3 | 31.0 | 39.5 |
| Flax | | | | 100 | 35 | 47 | 63.8 | 22.5 | 30.0 |
| Tobacco | 80 | 80 | 210 | 324[2] | 589[2] | 1,318[2] | 38.7[2] | 70.2[2] | 157.1[2] |
| Vegetables | | | | 789 | 345 | 344 | 9.0 | 4.0 | 3.9 |
| Sugarcane for brown sugar | | | | 196 | 33 | 56 | 45.3 | 7.7 | 12.9 |
| Green manure | | | | — | 66 | — | — | 0.5 | — |
| Others (for schools and other organizations) | | | | 205 | 46 | 112 | | | |
| Others (indigenous fertilizers sold to free market) | | | | 3,904 | — | — | | | |
| Total: | | | | 102,095 | 34,072 | 26,722 | | | |

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[1] Calculated by dividing the actual total distribution by the planted acreage.

[2] Not including about 300 kg. oil cakes per hectare.

## IV. Consumption of Different Nutrient Elements

Nitrogen fertilizer has always been consumed in much larger quantities than phosphorous and potash fertilizers. Calculated from the data given in Table 1, the N, $P_2O_5$ and $K_2O$ consumed in Taiwan over the years are in the following proportions:

**Table 3.**

**Consumption of Different Nutrient Elements in Taiwan**

Unit: %

| Year | N | $P_2O_5$ | $K_2O$ | Total |
|---|---|---|---|---|
| 1935-39 average | 64.3 | 26.9 | 8.8 | 100 |
| 1952 | 66.9 | 21.2 | 11.9 | 100 |
| 1958 | 62.7 | 20.9 | 16.4 | 100 |

In recent years, there is a healthy trend towards better balanced application of N-P-K. The future trend is toward a further increasing of the proportion of $K_2O$ and a lowering of that of N, though the absolute amount of nitrogen fertilizer consumed will always lead, by a wide margin, over the other two major elements. Such a trend is based on the following two considerations:

A. The response of nitrogen fertilizers is significant in Taiwan even at relatively high levels for all crops except legumes. Sugarcane, sweet potatoes, tobacco, jute, pineapple, banana and second rice crop (fall planted) show definite response to potash. However, since for a number of crops including rice and sugarcane, farmers are already using nitrogen at high levels, while the rate of application of potash on all crops is at present very low, potentially the consumption of potash will show a more rapid increase when expressed in indices.

B. A good number of important crops in Taiwan, including rice, sugarcane, sweet potato, jute, tobacco, citrus, banana and pineapple, are by nature not phosphorus feeders. Furthermore, unlike nitrogen and potash which are constantly lost from the soil through leaching, phosphorous is fixed by the soil. It is believed the phosphorus status of most parts of Taiwan has been built up over the years when phosphate fertilizers were successively applied on rice, sugarcane and some other fields. This, we believe, explains that fertilizer experiments show relatively low response towards phosphate fertilizers by this wide range of crops. However, other crops including wheat, soybean, peanut, corn, rape seed, pasture crops do respond to phosphate application. The consumption of phosphorus fertilizer, which is at present used by farmers in larger amounts in both gross tonnage and in terms of weight of $P_2O_5$, will increase at a slower rate than that of the potash fertilizer.

## V. Local Production of Chemical Fertilizers

There was a small chemical fertilizer industry in Taiwan before the World War II, producing calcium cyanamide and calcium superphosphate. The industry suffered considerable damage during the War. Since after the War, the fertilizer industry has been rehabilitated and greatly expanded. At present, Taiwan has eight factories, belonging to two corporations, both government operated, producing ammonium sulphate, calcium ammonium nitrate, calcium cyanamide, urea, liquid ammonia, nitrophosphate, calcium superphosphate and fused phosphate. In 1959, a total of 288,546 m.t. of fertilizers was produced, equalling roughly 33% of the total consumption of the same year. With new factories constructed, completed, well underway, or being actively planned, a rapid boost in local production of fertilizers will be effected in the coming five years. By 1964, Taiwan will be expected to produce domestically about 80% of the nitrogen fertilizer and 72% of the phosphorus fertilizer requirement.

The following table is indicative of the rate of recovery and expansion of the fertilizer industry in Taiwan:

**Table 4.**
**Fertilizer Production in Taiwan**

Unit: m.t.

| Year | N | $P_2O_5$ | Total gross tonnage |
|---|---|---|---|
| 1935-39 average | 1,102 | 3,854 | 26,919 |
| 1945 | — | 72 | 400 |
| 1952 | 14,789 | 13,451 | 148,531 |
| 1959 | 34,109 | 25,596 | 288,546 |
| 1960 (planned) | 52,270 | 23,140 | 325,056 |

The fertilizer industry of Taiwan, following the world trend, is going into the production of compound fertilizers or fertilizers with higher concentration at the expense of the time-honored calcium cyanamide, ammonium sulfate and calcium superphosphate. Taiwan, however, produces none and has no plan to manufacture potash fertilizers.

## VI. Experiment and Demonstration of Chemical Fertilizers

### A. Experiment

The fertilizer experiments conducted in Taiwan so far are mainly for solving practical problems in the field. They may be grouped into three broad categories:

1. Soil fertility tests for determining the relative status of N-P-K in major soil groups of Taiwan.

2. Determination of N-P-K requirement of different major crops. Those for rice, sugarcane, sweet potato, wheat, jute, tea, pineapple, banana and cotton have been completed. The work on corn, some legumes, vegetables and citrus are in progress. Based on such experimental results, recommendations on the optimum rate of fertilizer nutrients for various crops are made as shown in Table 2.

3. Experiments on response of major crops to fertilizers not used by Taiwan farmers before, such as urea, liquid ammonia, nitrophosphate, ammonium chloride, nitrochalk and fused phosphate, in comparison with those accustomed to them, such as ammonium sulfate, calcium cyanamide and calcium superphosphate. These experiments are conducted to provide reference to local fertilizer industry as to the desirability for producing various types of fertilizers in Taiwan. The proper method of application of these newer fertilizers are also studied to provide information for advising farmers on their usage as they come onto the market.

### B. Demonstration

Table 5 shows the number of localities of fertilizer demonstrations on rice crops conducted by the Taiwan Provincial Food Bureau in cooperation with the Taiwan Fertilizer Company and JCRR each year since 1951.

**Table 5.**
**Number of Rice Fertilizer Demonstration**

| Year | 1st crop | 2nd crop | Total |
|---|---|---|---|
| 1951 | 600 | 1,210 | 1,810 |
| 1952 | 1,210 | 1,210 | 2,420 |
| 1953 | 2,670 | 1,230 | 3,900 |
| 1954 | 805 | 605 | 1,410 |
| 1955 | 600 | 600 | 1,200 |
| 1956 | 664 | 664 | 1,328 |
| 1957 | 200 | 200 | 400 |
| 1958 | 600 | 600 | 1,200 |
| 1959 | 675 | 600 | 1,275 |
| Total | 8,024 | 6,919 | 14,943 |

To a smaller scale and in shorter periods, fertilizer demonstrations have been conducted for other crops including sugarcane by the Taiwan Sugar Corporation, tobacco by the Tobacco Research Institute, and wheat, peanut, soybean, sweet potato, tea, jute, pineapple, banana, etc., by the Provincial Food Bureau, JCRR, the Taiwan Fertilizer Company, the Provincial Department of Agriculture & Forestry, the Taiwan Chemical Fertilizer Field Service and various other agencies.

In addition to the fertilizer demonstrations sponsored by the Provincial Food Bureau and other government agencies, selected farmers carried on 961 field demonstrations in 216 townships on their own farms under instructions from township farm advisors of the farmers' associations during the past year. In many cases each of the demonstrators was a member of one of the 1,839 farm discussion groups, which meet once a month to discuss their own farm problems, including the use of fertilizers.

The main objective of the fertilizer demonstration for all crops has been to show farmers the effect of using fertilizers in balanced proportion of the three major elements. For rice, the effectiveness of fertilizers less favored by, e.g. calcium cyanamide, or not familiar to farmers, e.g. urea and nitrophosphate, has also been an objective of demonstration.

The result of these demonstrations may be assessed as follows:

1. The total consumption of chemical fertilizers has steadily increased.

2. There is a healthy and continuing trend towards a more balanced application of N-P-K in recent years.

3. The demonstrations have been successful in overcoming partly the farmers' dislikeness for calcium cyanamide, so that the local factories are now able to dispose this fertilizer as soon as it is produced. They have also invited the farmers' readiness in accepting urea when the local product starts to come onto the market this year at a planned annual output of 84,000 m.t.

4. Demonstrations and extension education on the use of fertilizers apparently have not been sufficient for crops other than rice, sugarcane, tobacco, jute and pineapple.

## VII. Marketing and Distribution of Fertilizers

An over-all plan on the fertilizer distribution for various crops in each year is prepared by a Fertilizer Sub-Committee under the Agricultural Planning & Coordination Committee (APCC) of the Ministry of Economic Affairs. The APCC is in charge of implementing the agricultural part of the Four-Year Plan for Economic Development in Taiwan, and the fertilizer program is an important and integral part of the Four-Year Plan. In the program, the fertilizer requirement for different crops, time of distribution and foreign exchange needed for import of fertilizers are well covered.

All the works on fertilizer distribution are administered by designated government agencies. Fertilizers allocated for sugarcane are distributed to the farmers by the government-operated Taiwan Sugar Corporation through its sugar mills. Those for all other crops are distributed by the Taiwan Provincial Food Bureau through the township farmers' associations which are farmers' own organizations. Fertilizers allocated to sugarcane growers are released entirely on a loan basis to be repaid without interest after the harvest of cane and milling of sugar. Fertilizers for rice growers are released by bartering with paddy rice for 40 percent of the fertilizers on spot and providing the remaining 60 percent on loan to be repaid with 3 percent interest in kind after harvest. Fertilizers for all crops other than rice and sugarcane are sold on cash basis only.

The fertilizers are shipped to the warehouses of the sugar mills or township farmers' associations according to detailed shipping and allocation plans. Farmers only have to travel a few kilometers from their farms to the warehouses to draw the fertilizers. The prices (or barter ratios) are fixed and pre-announced. The per hectare application rates for different crops are given. The amount of fertilizers each farmer is entitled to receive is compiled beforehand according to crop acreages registered by farmers themselves.

By and large, the existing system has worked satisfactorily in distributing some 700,000 m.t. of fertilizers in a year to some 750,000 farm households.

## VIII. Use of Organic Manures

Traditional to Chinese way of farming, a variety of organic manures is used by Taiwan farmers. In 1958, the following amounts were used:

| | |
|---|---|
| Green manure | 1,223,802 m.t. |
| Animal manure | 2,919,908 |
| Night-soil | 1,999,864 |
| Compost | 7,759,409 |
| Straw | 593,834 |
| Ash | 323,864 |
| Total: | 14,820,681 m.t. |

These manures are estimated to contain 60,853 m.t. of N, 33,674 m.t. of $P_2O_5$ and 47,859 m.t. of $K_2O$.

Since after the War, there have been a steady decrease in the acreage and production of green manure (1949 - 2,929,399 m.t., 1954 - 1,627,340 m.t., 1958 - 1,223,801 m.t.), an increase in the amount of other forms of organic manures and a small gain (about 1,000,000 m.t.) in total amount used. Raising of winter dryland crops in the paddy fields after the harvest of the second rice crop, a practice that is gaining popularity fast, has steadily replaced the acreage of the winter green manure crops. On the other hand, the ever growing population and number of hogs have increased the output of night-soil, animal manure and compost manure.

In the future, the trend is towards a continued decrease of the total green manure acreage in paddy fields as winter crops further expand. But, at the same time, a gradual increase in the acreage of green manure or leguminous cover crops among slope-land row crops may be expected as the soil conservation program gains momentum.

In order to compensate for the loss of green manure acreage to winter crops, Taiwan began to experiment the making of compost with city garbage by aeration method in 1956. The first pilot plant capable of handling 20 m.t. of garbage a day and an accompanying laboratory were built in the same year. After the pilot plant proved successful and the laboratory produced pertinent data, two more plants have been built, one in Ilan handling 24 m.t. of garbage a day and another in Kaohsiung handling 100 m.t. a day. Studies on sanitary treatment of night-soil is currently underway. Since around 45 percent of the populace of Taiwan are non-agricultural, the utilization of the city and town wastes for manuring purpose will be an important and integral part of the over-all program for improving the soil productivity of this island.

Another approach for upkeeping the soil productivity is the development of a nodule bacteria inoculation program for leguminous crops. Research was started by the Provincial College of Agriculture at Taichung in 1954; and the development has now reached the stage of field demonstration for lupine, milk vetch, peanut and soybean.

## IX. Objectives for Future Improvement

A. Completion of a detailed soil survey and establishment of a soil testing system, so that the per hectare rates of fertilizer application on various crops may be recommended on village or individual farm basis, instead of the present broad regional basis.

B. Strengthening of the practical type of experimentation, demonstration and extension on the proper usage of fertilizers on crops which are currently using little or no fertilizers.

C. Intensifying of research on crop, soil and fertilizer relationships, so as to set up a sound system of soil management for various crops, in which both objectives of maintaining permanent fertility and increasing crop response to fertilizers will be met. Priority will be laid on rice, sugarcane, tobacco, pineapple and jute on which farmers are already using a fairly large amount of fertilizers.

D. In coordination with the soil conservation program, demonstrate and extend the proper methods of applying chemical fertilizers, green manure or cover crops on crops grown on slope land, i.e. banana, pineapple, tea, citrus, citronella grass, cassava, etc.

E. Full utilization of all possible sources of organic manure for sustaining the soil productivity under the intensive cropping pattern of Taiwan, and extension of the use of lime wherever useful.

F. When (1) a large share of the total fertilizer consumption is met by local production, (2) the agricultural organizations are technically ready to recommend the fertilizer application rates to meet the needs of farmers on individual farm or village basis, (3) farmers' appreciation of the proper usage of balanced fertilizers is raised through the extension educational efforts, and (4) when other administrative considerations are in order, the eventual objective should be towards the free sale of fertilizers by the factories to farmers through the farmers' associations. This final step, however, should be taken with great caution and only when all conditions are ready for it.

# SOILS AND SOIL FERTILITY OF TAIWAN

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Taiwan, better known as Formosa to the outside world, is an island situated between latitudes 21°45' N to 25°38' N and longitudes 119°18' E to 122°6' E. It has a land area of 35,760 square kilometers. Being fusiform in outline, the island stretches from NNE to SSW, measuring about 349 km. from the northernmost boundary to the southern tip and 144 km. at its greatest width. Ever since the Japanese occupation time, quite a few soil scientists and agronomists have studied the classification and distribution of the soils of the island. The present brief report summarizes the findings of these workers and the authors' ten years of study on genesis, geography and fertility of soils of this area.

## I. Soil-Forming Factors

**Climate.** Taiwan, because of its geographic position, has an oceanic subtropical climate with a year-round growing season except on mountains above 1,200 m. in altitude, where frost and snow occur occasionally. Average January temperature in lowland ranges from 15°C in the north to 20°C in the south. The summer season lasts for six to seven months with temperature averaging 23-28°C. With the increase in elevation, temperature decreases at a rate of about 0.5°C per 100 m., however, the annual ranges of temperature between the average of warmest and coldest months are not so large in high mountains as in the low elevations.

Annual precipitation ranges from 1,600 to 1,800 mm. over the southwestern part to more than 4,000 mm. in the mountain regions. Most of the rainfall comes in summer time—May to August—as showers of the convectional and typhoon type. On the southern plains, dry spells of 3-4 months during the period from fall through spring are common, while northeastern Taiwan suffers from too much rainfall and cloudiness in winter when the northeast monsoon brings in lighter but more prolonged rains.

In addition to the irregular occurrence of typhoons, strong and steady northeast winds in winter and early spring also generate perennial problems, especially along the western coast.

**Topography**. Running lengthwise along the central portion rises a high mountain range (the Central Range) which forms the backbone of the island with peaks towering over 3,000 m. above sea level. Its eastern flank descends abruptly to a narrow longitudinal valley 150 km. long and 3-5 km. wide. Across the valley, there stands a secondary mountain range, the Coastal Range, facing the Pacific Ocean and sticking out steeply from the sea to more than 1,000 m. On the other hand, the western flank of the backbone ridge extends westward for tens of kilometers and descends less sharply through border mountains and a foothill zone, then, merges into the plains.

Coastal plains on the western side of the island extends inland for varying distances up to a maximum of 40 km. in the south, narrowing down to only one or two km. toward the north. Lying between the coastal plains and the foothills on the east, there is a series of tablelands dotted from Taipei down to the southern tip of the island.

All of the important rivers originate from the central mountains and have long, steep slopes on both sides in their upstream part. They are invariably short with rapid flows and none is navigable.

**Geology.** In the geologic sense, the island of Taiwan is rather young. The major part of the mountains is formed of sedimentary rocks with only a moderate part lying along the eastern flank of the Central Range which had been subject to different grades of metamorphism. These metamorphic rocks, chiefly schists and crystalline limestone, are believed to be Pre-Tertiary in age, the oldest geological formation of Taiwan. The central zone and western flank of the backbone ridge are composed of a thick sequence of well-cleaved, comparatively harder, Eocene black slate intercalated with grayish quartzose or schistose sandstone. Nearly all the high peaks in the Central Range are made up of this black slate. Sandstones and shales of Miocene and Pliocene ages form the bulk of the western border mountains and foothill belt as well as the Coastal Range on the eastern side. Conglomerate beds of various thickness are also present in the Plio-pleistocene formation in the foothill zone.

Tablelands are made up of thick gravel beds overlain by a lateritic clayey layer. They were formed by the coalesce and subsequent uptilting of alluvial fans along the base of foothills during the Pleistocene age.

Recent deposits occupy all the alluvial plains, fans, terraces, bottom lands and lacustrine basins.

Igneous rocks are rather rare and are represented mostly by scattered extrusive bodies together with minor amounts of dikes. The Penghu Islands (basaltic lava flows) and the Tatun Volcanic Group (andesitic lavas) in the vicinity of Taipei represent two main occurrences of igneous rocks of Taiwan.

**Vegetation.** Judging by the specific influence that it exerted upon the development and distribution of soils in Taiwan, vegetation seems to be of less importance as compared with the other three soil-forming factors: climate, parent material and relief. About 60% of the island's land area is forest-covered. Generally speaking, the flora of Taiwan may be divided into three broad zones: (1) The sub-tropical rain forest is confined to lowland and hills below 1,500 m. in elevation. It has been largely cut over for many years. Men's activities, especially the cultivation of paddy rice, play a vital role in the development of soils. Camphor, acacia and oak are the most commonly seen species and large areas of bamboo groves constitute an outstanding landscape of this zone. (2) Mixed forests of Quercus, Castanopsis, Pinus, firs, etc. cover a belt between 1,500-3,000 m. above sea level —temperate zone. Pure stands of Chamaecyparis are seen in high mountains. (3) Conifers predominate the cool zone above 3,000 m. with Abies kawakamit and Juniperus dominating. A sub-zone of shrubs and grasses may be recognized in high peaks over 3,600 m. above sea level.

## II. Major Soil Groups of Taiwan

Through years, climate and physiography, and to a lesser extent, vegetation, have interacted in Taiwan to produce four vertically distributed major soil zones. They are: Mountain stony soils, Red-Yellow Podzolic soil, Latosolic soils and Alluvial soils. Each of these zones is characterized by a definite combination of climate, relief and parent material which give them individuality. Likewise, each of the major zones consists of a number of great soil groups, of which some are widespread while others are of only minor extent or importance. But in general, Taiwan soils, with the only exception of old red earths, are thinner and less weathered than in many other countries due to their comparative youth and active erosion.

A generalized description of the more important soils is given below. However, it should be pointed out that within each great soil group, there are many transitional soils which have some of the characteristics of other related groups. The description of such transitional soils is beyond the scope of this paper.

**Mountain Stony Soils Zone.** This region covers the high mountains over 1,500 m. above sea level in the Central Range. Under coniferous or mixed forest cover and with a humid, temperate to cool climate, podzolization is generally believed to be the leading process of soil formation in this area. However, genuine Podzol profiles have not yet been found in this island. The reason may be twofold: (1) the fine-textured, base-enriched parent material hinders the process of podzolization; and (2) the active erosion prevailing on steep mountain slopes may wash off the soil almost as soon as it is formed. As a result, soils found in this region are generally young or imperfectly developed, and shallow, stony, slightly podzolized soils are the most widespread ones. Small patches of Gray-Brown Podzolic soils may occur on flat mountain tops or gentle slopes. Thay have a humus layer on the surface, a thin $A_2$, and a marked textural B horizon, but the $A_1$ horizon is generally weakly developed. Strong acid reaction prevails throughout the profile.

In areas where the dip of slaty beds approximately parellel to the dominating slopes, Mountain Humus soils characterized by a thick, very friable, blackish humus layer underlain by partly disintegrated slates are commonly seen.

**Red-Yellow Podzolic Soils Zone.** The Red-Yellow Podzolic soils zone occupies hilly region below 1,500 m. altitude. As a whole, it has a humid, subtropical to tropical environment. But both the seasonal distribution of rainfall and the nature of bedrocks differ considerably from place to place. These differences are strongly reflected in soils which may be divided into five sub-zones:

1. In areas over 800-1,000 m. above sea level, the annual precipitation, averaging about 3,000 mm., distributes more evenly throughout the year. Here intergrade types of Gray-Brown Podzolic and Red-Yellow Podzolic soils represent the mature soils. They have developed under hardwoods or mixed forests on comparatively fine-textured slates and shales. With a total solum of 70 cm. in average, these soils possess a marked textural B horizon which is reddier in color than either the Gray-Brown Podzolic soil found in high mountains or the Red-Yellow Podzolic soils in the northeastern part. The $A_2$ horizon is generally weakly expressed.

2. Northern Taiwan, especially the northeastern part, is characterized by a continuously wet or moist climate, according to Mohr's classification. Even in short dry seasons, the relative humidity seldom drops below 80%. The soil does not really dry out, or at most, only the uppermost part on bare land. Red-Yellow Podzolic profiles predominate in this region, which the Chinese pedologists

would rather prefer the term Yellow Podzolic soils or Yellow earths. Although relatively shallow in sola, commonly not more than 60 cm., these soils have a thin, grayish $A_1$ and a weakly developed but readily recognizable $A_2$, underlain by yellow plastic clay subsoils. On steep slopes, rock fragments may present in the soil profile in various quantities. Under continuous paddy rice culture, these yellow clayey soils tend to transform to profiles resembling those of Planosols within a period of 30 to 50 years.

3. Toword the south, the dry season becomes more and more pronounced and the subsoil turns more and more redder in tint. Besides, sandstones and shales of Tertiary age in southern Taiwan differ from those in northern Taiwan in that the former are softer and more basic than the latter. These differences have resulted in the presence of Red-Yellow Podzolic—Brown Forest intergrades in the soil patterns of central and southern Taiwan. In case of calcareous material such as on marl in Tainan area, Brown Forest soils are formed.

4. As mentioned above, the eastern flank of the backbone ridge is composed chiefly of schist. Climate in eastern Taiwan is somewhat intermediate between those in northern and southern Taiwan. Soils developed under such conditions are considered to be intergrades between Gray-Brown Podzolic and Red-Yellow Podzolic soils, being rich in mica flakes throughout the profile. More often than not, shattered parent rocks exist within 70 cm. from the surface, and outcrops of schist are not uncommon. In addition, shallow, strongly acid, yellow-brownish sticky clay soils develop on crystalline limestone.

5. Finally, soils of the Coastal Range are closely associated with surface geology which, in turn, governs the topography to a large extent. Brown Forest or Gray-Brown Podzolic—Brown Forest intergrades develop on soft, base-rich shale and sandstone. They are moderately deep, silt clay loam-textured soils with pH values around 6.0 and have a weakly developed textural B horizon. Some shallow ones may contain more or less rock fragments. On the other hand, andesitic agglomerate usually forms very steep bare slopes. On lower and gentler slopes, profiles resemble Ando soils are formed. They have a dark, friable and granular mineral-organic surface layer underlain by yellowish-brown, wet, sticky clay subsoils. Both surface and subsoils are moderately to strongly acid. These soils have also been found on volcanic ash material in the Tatun Volcanic Group near Taipei.

It should be pointed out that, as a rule, slightly podzolized shallow stony soils again are the most widespread soils in the hilly region of Taiwan. It is also true that on slopes where the bedrock is comparatively hard and the stratification happens to be parallel to the land surface, Mountain Humus soils exist.

**Latosolic Soils Zone.** Red Latosolic soils in this island have been found to be confined to two types of parent material: the Diluvial (Pleistocene) tableland and the basic volcanic rocks. Deep, Reddish-Brown Latosolic soils occur on Diluvial tablelands from a few tens of meters above sea level to places over 1,500 m. altitude, where the recent climate should not be pertinent for giving rise of Latosolic soils. This inconsistency with climate conditions may substantiate the hypothesis that the Reddish-Brown Latosolic soils were formed during the Pleistocene Era preserved to present. If so, they should be classified as relict soils rather than normal soil; thus, the term "Old Red Earths" has been given by some Chinese pedologists. Morphologically, they have a light grayish-red clay loam surface low in organic matter, which grades into a reddish-brown, blocky, clay subsoil, plastic when wet and hard when dry. In places, dark brownish mottlings and/or small iron concretions may be present in the subsoil.

Red Latosolic soils derived from basic volcanic materials on gentle slopes differ from those occurring on Diluvial tablelands mainly in that they are yellower, commonly reddish yellow or yellowish brown, in color and that under forest cover, an incipient, discontinuous "bleicherde" may oftentimes be recognized below the grayish yellow-brown surface. Translocation of silicate clay from the surface to the subsoil is also evident. In these aspects, the red soils developed from volcanic rocks in Taiwan should probably be considered as an intergrade type of Latosolic and Red-Yellow Podzolic soils.

Red Latosolic soils are invariably strongly acid in reaction and highly unsaturated with the only exception of those occurred on the Penghu Islands where soils are calcareous owing to the high evaporation rate over precipitation, the repeated application of coral limestones (primarily as windbreak walls) and the cyclic salt contained in winds.

When irrigated and under continuous cropping of paddy rice, the color of the soils turns gradually from red to yellow then light bluish gray with the progressive reduction and leaching of iron oxides, and finally a Gleysolic Planosol is resulted.

**Alluvial Soils Zone.** Alluvial soils, the most important agricultural soils of this island, occur on flood plains, river terraces, basins and alluvial fans. They are young soils with no or little profile development and vary from place to place. For this reason, they are the most complicated great soil groups of Taiwan with such properties as texture, depth, reaction, base status and stratifications being closely associated with the parent material as well as the position relative to river channels. Very little has been done on the classification and geographical distribution of Alluvial soils in the past. Therefore, at this time, not much can be said about these soils except some few very broadly generalized statements:

1. Soils derived from slate alluvial materials, such as those occurred along the Silo River, Ilan Chushui River and Hsiatanshui River, are moderately fine-textured, neutral or slightly acid in reaction and moderately well supplied with bases. They are the best paddy rice soils and have grayish silt loam surface underlain by olive gray, silt clay loam subsoils, soft when wet and brittle when dry. A special type of physiological disease occurred on rice which has been believed to be related to iron toxicity is reported in some poorly drained areas of these soils.

2. Soils derived from schisty alluvium are of minor importance, occurring only in the rift valley between the Central Range and the Coastal Range. They resemble the slate alluvial soils in morphology but are commonly shallower, micaceous and less acid in reaction.

3. Sandstone and shale alluvial soils are the most widespread ones under this category. As the sandstones and shales differ greatly in both chemical and physical properties, the soils formed from alluvial materials of these rocks, as may be expected, vary widely from place to place. These inherent differences were further augmented by longtime farming practices and deposits from irrigation water. But, in general, they are commonly light gray in color and sandy loam in texture. In northern Taiwan, the sandstone and shale alluvial soils is mainly used for rice production and is strongly acid in reaction. Those occurred in southern Taiwan, being chiefly cultivated to dryland crops, have a higher base status and are finer in texture than those found in the north.

4. Saline alluvial soils occur on lowlands along the western coast. Except for the presence of a rather high content of soluble salts, they resemble the corresponding inland alluvial soils in all other characteristics.

5. In the central part of the southwestern coastal plain (Chianan Plain), there exists a special type of alluvial soils (marine deposit?). They are heavy clayey soils which swell when wet and shrink and crack into hard, large columnar structures when dry. They have a neutral to slightly alkaline reaction.

Without irrigation, this type of soil is not suitable for many kinds of crops.

Besides, sandy and gravelly river wastes occupy large areas on both sides of all the big rivers as well as in the Taitung-Hwalien longitudinal valley. In western Taiwan, gravelly colluvial-alluvial soils occur in a narrow belt along the base of foothills.

## III. Fertility Characteristics of the Agricultural Soils

Red Latosolic soils and alluvial soils of different parent materials are the main agricultural soils in Taiwan cultivated for lowland rice and upland crops. To give a glimpse of the fertility of these various groups of soils, information from our recent researches are presented briefly as follows under the sub-titles of (1) texture, (2) reaction, (3) organic matter and nitrogen, (4) phosphorus, and (5) potassium:

**Texture.** The texture of soils in Taiwan is closely related to the nature of the parent rocks. The Latosolic soil developed on the diluvial tableland is usually moderately heavy, mostly clay loam in texture. The slate alluvial soils and the mudstone (calcareous silt stone—marl) alluvial soils in the southern part are probably the heaviest alluvial soils in Taiwan, ranging from loamy clay to silty clay loam. The sandstone and shale alluvial soils in the northern and central Taiwan are from sandy loam to loam. A part of the saline alluvial soil close by the sea coast is rather sandy. The soils in the eastern valley vary in their texture, but they are, for most part, loamy soils.

Generally speaking, most soils in Taiwan are of loamy texture. Sandy soils are generally confined to a limited area along the sea coast. The heavy soils of slate and mudstone parent materials seldom contain over 40% of clay particles. Therefore, soils in Taiwan, with few local exceptions, pose no much problem of poor drainage or difficulty for tillage.

Little work has been done on the mineralogical composition of the soils in Taiwan. Recently, with the techniques of X-ray and DTA, the presence of kaolinite and halloysite in the Latosolic soils and illite in the alluvial soils as the dominant clay minerals has been identified. The cation-exchange capacity of soils in Taiwan has been systematically determined recently. Soils with medium texture and organic matter content (2-3%) generally have a C.E.C. around 10 me/100 gm. Those of soils with heavier texture and/or higher organic matter may go higher, but rarely over 15 me/100 gm. The low C.E.C. of soils in Taiwan reflects its poor retaining capacity for plant nutrients.

**Reaction.** The reactions of soils in Taiwan are greatly influenced by the degree of weathering and the nature of the parent materials. The Latosolic soils are old soils which have been exposed to the sub-tropical climate for a longer time than the alluvial soils. As a zonal type under intense weathering and leaching, the clay complex is highly unsaturated with pH generally below 5.

The reactions of the alluvial soils are mainly determined by the base status of the parent materials. The sandstone and shale alluvial soils are mostly 5.5-6.0 in pH. Those of the northern part are inclined to acid side and those of the central part are more base-saturated and usually have a higher pH, frequently approaching 6.0. The mudstone alluvial soils are well base-saturated soils. Their pH values range from 6.5 up to over 7.0. The reaction of slate alluvial soils varies considerably due to the inclusion of some other parent materials. Those of the Ilan plain are quite acid, with pH below 6; those of the Pingtung plain are slightly acid, with pH between 6 to 6.5, and those of the central part is neutral, with pH above 7. The schist alluvial soils in the eastern valley are neutral in reaction. The higher salt content, predominantly sodium chloride and much less amount of sodium and magnesium sulphate, brought in from the sea water, causes the soils by the sea coast saline. The extent of saline soils in southwestern part of Taiwan is wider. With the exception of salt content, the other properties are very similar to their neighbouring soils. The pH of saline soils rarely goes up to 8. The high $CaCO_3$ content of the soil renders the process of desalinization or dealkalization not difficult.

To summarize, the reaction of alluvial soils in Taiwan varies mostly in the range of pH 5.5 to 7.5. They are quite adapted for most sub-tropical crops. Only the Latosolic soils are frequently too acid for normal growth of plant. Liming has been proved beneficial, particularly for legumes.

Agricultural soils in Taiwan are mostly cultivated for lowland rice year round or in rotation with upland crops. Soils under submerged condition seem more highly buffered in pH. On one hand, liming material added to the soils is quickly leached away under intense leaching, while on the other, residual acidity of chemical feitilizers such as ammonium sulphate is easily neutralized by the quick release of bases from soil minerals and the bases in irrigation water under submerged condition. As long as the leaching is severe and there is a good supply of bases in the soil minerals and irrigation water as usually in the case of our alluvial paddy soils, the pH of soil will remain the same for many years to come without being affected. In a long term fertilizer experiment in Taipei, a plot receiving ammonium sulphate alone continuously for thirty three years lowered its pH only by 0.3 unit, and that receiving calcium oxide only raised its pH by 0.3 unit. This explains that the effect of residual acidity or basicity of fertilizers on the reaction of lowland rice soils may not be too significant.

**Table 1.**

**The Change of pH of Soil Resulted from Continuous Application of Same Fertilizer for Thirty-three Years**

| Treatment | | % Saturation | pH |
|---|---|---|---|
| Complete inorganic fertilizer | A | 44.8 | 5.3 |
| | B | | 5.5 |
| Ammonium sulphate | A | 27.7 | 5.0 |
| | B | | 5.3 |
| Complete inorganic fertilizer & lime | A | 46.7 | 5.6 |
| | B | | 5.7 |
| No fertilizer or manure | A | 36.0 | 5.3 |
| | B | | 5.6 |

Notes: (1) A and B represent surface soil and subsoil, respectively.
(2) Each figure is the average of two replicated plots.
(3) The rates of N, $P_2O_5$ and $K_2O$ are all 95 kg/ha. per crop (two crops per year). The rate of CaO is 560 kg/ha., equivalent to 1,000 kg/ha. of $CaCO_3$ per crop.

**Organic matter and nitrogen.** Organic matter content of tropical soils is generally low. So is that of soils in Taiwan. It may be as high as 5% or as low as 1%, but generally between 2-3%.

The organic matter content in the soils of Taiwan is mainly controlled by the variation of temperature and rainfall from north to south, or from the plain to the mountainous region of higher elevation. Therefore the organic content of the soils of the Taipei area is usually over 3.5%, and decreases gradually southward to less than 1.5% in the coastal plain of Tainan. Similarly, as the temperature decreases and the rainfall increases from the plain upward to the mountainous region, the organic matter content of the soils increases accordingly. The functional relationship between organic matter content and the Lang's rain factor is very clear.

Texture is also a controlling factor of organic matter content of soils of Taiwan. Heavy texture slows down the decomposition of organic matter, and light texture hastens it. Heavy soils in Taiwan always contain more than 2.5% of organic matter with 4-5% as the upper limit at the Ilan Delta and Taipei basin, where rainfall is high, temperature low, and texture of soil comparatively heavy. On the other hand, light soils always contain less than 2% of organic matter with that of the soils of the coast of Tainan as the lower limit, where temperature is high, rainfall low, and texture of soil light.

Soil nitrogen exists mainly in organic form. Therefore the nitrogen content fluctuates with the organic matter content, mostly between 0.1-0.15%.

C/N ratios of organic matter in Taiwan range from 6 to 12, but most of them are between 8 to 10. Generally, that of the subsoil is narrower than that of the surface soil. It is interesting to note that the C/N ratio of the soil organic matter is somewhat related to the reaction of soil and the total content of organic matter. In acid soil, C/N ratio increases with the organic matter content; while in neutral soils, it decreases with the increase of organic matter.

**Phosphorus.** Data on total phosphorus in the soils of Taiwan determined by fusion method are not available. An approximation of them is the phosphorus extracted by hot hydrochloric acid of constant boiling point. The $P_2O_5$ content of the important agricultural soils is shown in Table 2.

**Table 2.**

**Hot Hydrochloric Acid Extracted $P_2O_5$ of Soils of Taiwan**

| Soil group | No. of samples | Average $P_2O_5$ (%) |
|---|---|---|
| Latosolic soils | 48 | 0.1 |
| Sandstone & shale alluvial soils | 99 | 0.08 |
| Mudstone alluvial soils | 61 | 0.11 |
| Slate alluvial soils | 28 | 0.15 |
| Saline alluvial soils | 17 | 0.15 |
| Schist alluvial soils | 14 | 0.14 |

It is seen that the calcareous soils generally have a higher total phosphorus content.

Thousands of soil samples in Taiwan had been run for "available" phosphorus with various methods. Of course, the absolute and relative values of the available phosphorus of different soils as determined by different methods are greatly diversified. Acid extractants result in the conclusion that calcareous soils are run "higher" in available phosphorus than the acid soil, but alkaline extractant such as $NaHCO_3$ results in a contrary conclusion. It suggests that any single test of available phosphorus cannot be universally applied to different soils.

Since "acid soluble" or "alkali soluble" is not synonymous with "available", the phosphorus of soils in Taiwan has recently been fractionated into the total amounts of each discrete chemical form of phosporus, namely, organic phosphorus, calcium phosphate, aluminum phosphate, iron phosphate and occluded phosphate. The results are shown in Table 3.

The total amount of phosphorus as shown in Table 3 is somewhat lower than the previously determined value (Table 2), but the relative values for different soil groups are alike.

The content of organic phosphorus in the six soil groups ranges from 22 to 173 ppm in the surface soils and from 9 to 74 ppm in the subsoils. It constitutes approximately 5-25% of the total phosphorus in the surface soil and less than 10% in the subsoil. Apparently this value is closely correlated with the content of organic matter of the respective soil. The soils in the northern part of Taiwan are higher in organic matter and hence also higher in the content of organic phosphorus. The lower content of organic phosphorus in the subsoils also reflects their low content of organic matter.

The content of occluded phosphate is approximately 100 ppm in all the soils, and constitutes 11-35.9% and 16.6-57.7% of the total phosphorus of the surface soil and subsoil, respectively.

The distribution of the other three forms of inorganic phosphate in the soil is rather characteristic of the soil groups, and can be grouped into three distribution patterns as follows:

1. Iron phosphate dominant pattern, to which the Latosolic soils belong.

2. Calcium phosphate dominant pattern, to which the soils with slight acid to neutral reactions belong, including mudstone alluvial soils, saline alluvial soils, slate alluvial soils and schist alluvial soils.

3. Iron and calcium phosphates dominant pattern, to which the acid sandstone and shale alluvial soils belong.

Each form should be available to plants to a certain extent. With a specified crop, soil and soil condition, one or more forms might be the most important source of available phosphorus. Our limited data on soils of Taiwan indicate that aluminum-bound phosphorus is the main source of available phosphorus for both upland and lowland crops, iron-bound phosphorus is also a main source for lowland rice, and calcium phosphate, though abundant, may not be the main source of available phosphorus due to the fact that most of it is existing in the coarse fraction of the soil.

### Table 3.
### Average Amount of Soil Phosphorus Fractions of the Main Agricultural Soils of Taiwan

| Soil group | pH range | Phosphorus (ppm) in form of | | | | | | % Occluded P in total P | % Organic P in total P |
|---|---|---|---|---|---|---|---|---|---|
| | | Ca-phos. | Al-phos. | Fe-phos. | Occluded phos. | Organic phos. | Total P | | |
| Latosolic soils | A 5.0-5.5 | 24 | 38 | 82 | 114 | 91 | 349 | 33.7 | 26.0 |
| | B 5.5-6.5 | 18 | 12 | 43 | 131 | 19 | 223 | 57.7 | 8.4 |
| Sandstone and shale alluvial soils | A 5.0-6.3 | 80 | 25 | 95 | 81 | 72 | 354 | 23.7 | 21.4 |
| | B 5.1-7.0 | 87 | 20 | 81 | 126 | 42 | 357 | 36.3 | 12.5 |
| Mudstone alluvial soils | A 6.8-7.7 | 118 | 23 | 47 | 121 | 39 | 347 | 35.9 | 11.2 |
| | B 7.0-7.8 | 129 | 9 | 27 | 116 | 20 | 301 | 40.1 | 6.8 |
| Saline alluvial soils | A 7.8-7.9 | 302 | 25 | 46 | 106 | 22 | 499 | 21.5 | 4.3 |
| | B 8.0-8.5 | 240 | 11 | 27 | 112 | 9 | 399 | 30.5 | 2.1 |
| Slate alluvial soils | A 5.4-7.8 | 268 | 48 | 77 | 104 | 93 | 589 | 17.7 | 16.4 |
| | B 6.2-8.0 | 258 | 32 | 57 | 115 | 47 | 508 | 23.7 | 9.2 |
| Schist alluvial soils | A 5.5-7.8 | 446 | 36 | 47 | 86 | 173 | 787 | 11.0 | 23.4 |
| | B 6.9-8.1 | 412 | 31 | 76 | 107 | 74 | 700 | 16.6 | 9.6 |

Note: A and B represent surface soil and subsoil, respectively.

**Potash.** Like phosphorus, data on the total content of potassium in the soils of Taiwan are not yet available. The contents determined by the extraction of hot hydrochloric acid are listed in Table 4. This may stand for the relative potentialities of the potassium supply of different soil groups.

**Table 4.**
**Hydrochloric Acid Soluble Potassium in Soils of Taiwan**

| Soil group | No. of samples | pH | $K_2O$ (%) |
|---|---|---|---|
| Latosolic soils | 48 | 4.5—5.5 | 0.17 |
| Sandstone & shale alluvial soils | 99 | 5.0—6.0 | 0.15 |
| Mudstone alluvial soils | 61 | 6.0—7.0 | 0.18 |
| Slate alluvial soils | 28 | 5.5—7.0 | 0.58 |
| Saline alluvial soils | 27 | 7.5—8.0 | 0.22 |
| Schist alluvial soils | 8 | 7.0—7.5 | 0.10 |

As many soil samples had been run for "available" potassium by various methods as for phosphorus. The results from various workers by different methods, though not in agreement with one another, show a rather consistent trend of the relative magnitude of various soil groups. This is because of the fact that the available potash determined by different methods all mainly represent the amount of exchangeable potassium.

Recently determined values of the exchangeable and fixed potassium of representative soils of Taiwan are shown in Table 5.

Together with the review of data of previous work, the potassium status of the main agricultural soils in Taiwan may be summarized as follows:

1. Most of the soils in Taiwan contain about 50-100 ppm of exchangeable potassium. The Latosolic soils tend to be lower and the mudstone alluvial soils and the schist alluvial soils tend to be higher, with the sandstone and shale alluvial soils as the intermediate. The exchangeable potassium of the saline soil is exceptionally high with more than 100 ppm.

2. The amount of the exchangeable potassium in Taiwan soils is in general higher in surface soils than in subsoils, probably due to the recent application of fertilizers.

3. The conventionally termed available potassium is largely exchangeable potassium. Therefore the content of available potassium in the soils is about at the same order of the exchangeable potassium.

### Table 5.
### Exchangeable and Non-exchangeable Potassium in Soils of Taiwan

| Soil group | Soil[1] layer | pH (average) | Average amount of exchangeable K (ppm) | Average amount of non-exchangable K (ppm) |
|---|---|---|---|---|
| Latosolic solis | A | 5.3 | 82 | 77 |
| | B | 5.8 | 57 | 113 |
| Sandstone & shale alluvial solis (Taipei) | A | 5.3 | 66 | 195 |
| | B | 6.0 | 50 | 229 |
| Sandstone & shale alluvial soils (Hsinchu) | A | 6.4 | 60 | 328 |
| | B | 6.8 | 38 | 268 |
| Mudstone alluvial soils (Tainan, Kaohsiung) | A | 7.2 | 73 | 334 |
| | B | 7.5 | 44 | 348 |
| Saline alluvial soils (Yunlin, Tainan) | A | 7.8 | 118 | 370 |
| | B | 8.3 | 91 | 340 |
| Slate alluvial soils (Ilan) | A | 5.7 | 53 | 188 |
| | B | 6.3 | 51 | 191 |
| Slate alluvial soils (Pingtung) | A | 6.4 | 66 | 158 |
| | B | 6.9 | 40 | 199 |
| Slate alluvial soils (Changhwa) | A | 6.6 | 73 | 221 |
| | B | 7.2 | 27 | 267 |
| Schist alluvial soils (Eastern Taiwan) | A | 7.0 | 77 | 523 |
| | B | 7.4 | 80 | 372 |

[1] A and B represent surface soil and subsoil, respectively.

4. The non-exchangeable potassium in the soils of Taiwan is several times that of exchangeable potassium. The Latosolic soils contain about 100 ppm, the sandstone and shale alluvial soils and the slate alluvial soils contain about 100-200 ppm, the mudstone alluvial soils and the schist alluvial soils contain over 200 ppm, occasionally over 300 ppm.

5. The content of non-exchangeable potassium in subsoils is higher than that in the surface soils.

6. The strong acid-soluble potassium in the soils is mostly in the range of 0.1-0.2%, but that of the slate alluvial soils is as high as 0.58%, most of which is in mineral form not extractable by sulfuric acid as revealed by subsequent study.

Fixation of potassium by the various soil groups has been studied under different moisture conditions. A part of the representative figures are presented in Table 6.

## Table 6.

## Fixation of Added K in Soils

| K applied (ppm) | Moisture condition | K (ppm) fixed by soils | | | | |
|---|---|---|---|---|---|---|
| | | Latosolic soils (Taoyuan) | Latosolic soils (Chungli) | Sandstone and shale alluvial soils (Taichung) | Slate alluvial soils (Yuanlin) | Mudstone alluvial soils (Hsinying) |
| 200 | Contiunous F.M.C. | -16 | 18 | 25 | 76 | 77 |
| | Continuous flooding | - 2 | 25 | 52 | 70 | 72 |
| | Alternate flooding and F.M.C. | -13 | 2 | 26 | 61 | 81 |
| | Alternate flooding and air dry | 0 | 2 | 31 | 71 | 84 |
| 400 | Continuous F.M.C. | -36 | -23 | 7 | 119 | 97 |
| | Continuous flooding | -14 | 11 | 67 | 121 | 119 |
| | Alternate flooding and F.M.C. | -19 | 1 | 88 | 122 | 129 |
| | Alternate flooding and air dry | -23 | 11 | 99 | 207 | 233 |

Note: F.M.C. designates field moisture capacity.

The data show that the added potassium is little fixed by Latosolic soils and acid sandstone and shale alluvial soils with pH around 5 (Tables 6 and 7), appreciably fixed by the acid sandstone and shale alluvial soils with pH around 6, and greatly fixed by calcareous mudstone and slate alluvial soils. Flooding the soil does not effect the fixation to any appreciable degree, but alternate flooding and drying to air dry condition greatly increases it.

## Table 7.

## Accumulation of Exchangeable and Non-exchangeable Potassium in the Soils of Long Term Fertility Experiment Plots

| Treatment | Soil layer[1] | Exchangeable K (ppm) | Non-exchangeable K (ppm) |
|---|---|---|---|
| Complete inorganic fertilizers and lime | A | 39 | 142 |
| | B | 51 | 149 |
| Complete inorganic fertilizers | A | 47 | 138 |
| | B | 39 | 161 |
| Potassium sulphate only | A | 90 | 120 |
| | B | 74 | 135 |
| Ammonium sulphate only | A | 47 | 122 |
| | B | 55 | 120 |
| No manure | A | 47 | 106 |
| | B | 51 | 118 |

[1] A and B represent surface soils and subsoils, respectively.

The accumulation of potassium in the sandstone and shale alluvial soils with pH 5.2 was studied in long term fertility experiment plots and it was found that, out of the 1,829 ppm of potassium applied in thirty-three years, only very little had been fixed.

Our limited data suggest that, under flooding condition, the rice plant can absorb a larger percentage of its total absorbed potassium from the non-exchangeable potassium, or the rate of replenishment from non-exchangeable potassium to exchangeable potassium is quicker in submerged soil than in upland soil.

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# FERTILIZER EXPERIMENTS IN TAIWAN

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Fertilizer experiments of various crops in Taiwan include those on the optimum rate, relative availability of fertilizers and methods of application. Specific emphasis is, however, placed on the optimum rate of application. Methods of application attracted the interest of agriculturists only fairly recently. In these experiments, the related factors, such as soils, climate, kinds of crops, crop rotation system and the prices of fertilizers with respect to those of the agricultural products are all considered.

## I. Crops

The economic values of the most important crops in Taiwan' are shown in Table 1. They are paddy rice, sweet potato, sugarcane, peanut, tobacco, soybean, tea, banana, pineapple, wheat, citrus and jute. With the exceptions of peanut, soybean and citrus for which relatively less fertilizer experiments have been car-

**Table 1.**
**Economic Value of the Main Crops in Taiwan (1958)**

| Crop | Percentage to total value of agricultural production | Percentage to total value of crop production |
|---|---|---|
| Rice | 40.774 | 50.968 |
| Sweet potato | 9.126 | 11.408 |
| Sugarcane | 7.901 | 9.876 |
| Peanut | 3.283 | 4.104 |
| Tobacco | 1.733 | 2.166 |
| Soybean | 1.577 | 1.971 |
| Tea | 1.501 | 1.808 |
| Banana | 1.085 | 1.356 |
| Pineapple | 0.938 | 1.173 |
| Wheat | 0.895 | 1.119 |
| Citrus | 0.844 | 1.055 |
| Jute | 0.696 | 0.870 |

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ried out, noteworthy results have been derived from the experiments on the fertilization of the other nine crops. Out of the nine crops, more systematic and large scaled experiments have been carried out for rice, sugarcane and tobacco, as rice is the first important staple crop in Taiwan and sugarcane and tobacco are the two major agricultural enterprises undertaken by the government with the research work on them performed by the Sugar Experiment Station of the Tawan Sugar Corporation and Tobacco Research Institute of the Taiwan Tobacco & Wine Monopoly Bureau.

## II. Soils

Due to the great variation of soils in Taiwan, fertilizer experiments for various crops are carried out on representative soils. Generally speaking, nitrogen is deficient for all crops and all soils, but the responses of crops to phosphorus and potassium are different from soil to soil. From 1930 to 1942, 118 fertilizer experiments on rice had been conducted at various localities in Taiwan. The experimental results indicated that there was a wide variation in the response of rice to $P_2O_5$ and $K_2O$ (Table 2).

**Table 2.**

**Percentage Increase of Rice Grain Due to Application of N, $P_2O_5$ or $K_2O$ (1930-42)**

| Soil | N | | $P_2O_5$ | | $K_2O$ | |
|---|---|---|---|---|---|---|
| | 1st crop | 2nd crop | 1st crop | 2nd crop | 1st crop | 2nd crop |
| Sandstone & shale alluvial soils | 28.835 | 20.525 | 4.285 | 5.717 | 2.080 | 2.667 |
| Lateritic soils | 21.667 | 19.378 | 12.013 | 9.778 | 10.685 | 12.490 |
| Slate alluvial soils | 24.548 | 16.258 | 5.498 | 3.758 | 2.340 | 4.958 |

According to a review of the fertilizer requirements of sugarcane in the past fifty years, the response of sugarcane to nitrogen is invariably significant on all soils. Deficiency of phosphorus mostly occurs on Lateritic soils. Response of sugarcane to potash varies greatly. For example, there is almost no response at all on saline soil, but the response is even higher than that to nitrogen on Lateritic soils and on the slate alluvial soils along the Peitou River. Application rates varying from zero to 300 kg. per hectare of $K_2O$ were recommended.

Liming experiments has also been carried out for several crops. Sugarcane responds to lime significantly on Lateritic soils without exception. Rice also responds to lime on acid soils, particularly when the fertility level is low or only organic manure is applied. In the case of rice, an application of three tons of quick lime may bring an increase in yield by 20%.

Experiments on the responses of crops to minor elements are also carried out for a few kinds of crops. No deficiency of minor elements for sugarcane has been observed so far. Deficiency of magnesium for tobacco has been reported, but further proof is necessary. Boron deficiency has definitely been proved for cultivation of sugar beet in Taiwan. Foliar application of manganese on citrus has been reported advantageous.

## III. Climate

The effect of climate on the response of crops to fertilizers may be illustrated by the experiment on sugarcane conducted at seven places in northern Taiwan during the years of 1943-1944 and 1944-1945. In 1943-1944, application of $K_2O$ on sugarcane would increase a yield by 16.17%, while in 1944-1945, the increase was only 5.17%. This is largely due to the difference in climatic condition. It is for this reason that fertilizer experiments are always repeated year after year in Taiwan.

## IV. Rates of Application

The recommended rates of application of the three elements on the various crops in Taiwan are based on the physical response of crops to fertilizers and the relative prices of fertilizers to agricultural products. The recommended rates of fertilizers for the main crops are listed in Table 3.

**Table 3.**
**Rates of Fertilizers for Main Crops in Taiwan**

kg/ha

| Crop | N | $P_2O_5$ | $K_2O$ |
|---|---|---|---|
| Rice | 60—120 | 35— 80 | 35— 80 |
| Wheat | 60—100 | 20—120 | 20— 60 |
| Sweet potato | 30— 90 | 25— 50 | 120—200 |
| Sugarcane | 150—226 | 40— 75 | 50—150 |
| Peanut, soybean | 20 | 40— 60 | 40— 60 |
| Jute | 80—120 | 20— 60 | 80—180 |
| Tobacco | 50 | 60 | 150 |
| Citrus | 40—280 | 40—280 | 30—280 |
| Pineapple | 200—560 | 50—140 | 200—560 |

The fertilizers experimented for recommending the rates of their application are mostly ammonium sulphate, calcium superphospate and potassium chloride. It is of no doubt that some adjustments must be made when different types of fertilizers are practically applied to the fields on different types of soils. The wide range of recommended rate of each element is due to many variable factors such as soils, irrigation, rotation system, number of stands and age of the trees (citrus and tea).

## V. Kinds of Fertilizers

The supply of plant nutrients in organic manure is far from being sufficient to meet the requirements of the crops. Large amounts of chemical fertilizers are therefore necessary for better yields.

The fertilizing value of organic manure has been studied through a series of field experiments. According to the results of experiments on green manures conducted for seven years, all but sesbania (*Sesbania roxburghii*) are better than ammonium sulphate. The author has carried out an experiment to compare the relative values of compost and ammonium sulphate for rice and wheat in a period of seven years. In all but one year the compost is better than ammonium sulphate, though, statistically insignificant. In sugarcane experiment, the value of N in green manure is only equivalent to 53% of that in chemical fertilizer in Tainan, and to 77% in Huwei.

Many fertilizer experiments to study the relative effects of different sources of nitrogen fertilizers had been carried out for rice. Ammonium sulphate is the best of all. Ammonium chloride has approximately the same value. Calcium cyanamide and urea are also comparable to ammonium sulphate, if properly applied. Nitrochalk and ammonium nitrate have been proved inferior to the above mentioned ones, particularly for lowland rice. For wheat, ammonium sulphate, ammonium chloride, urea and calcium cyanamide seem to have the same effect according to experiments. For sugarcane, the form of nitrogenous fertilizer does not show any different effect. The nitrogenous fertilizers used in sugarcane experiments are ammonium solution, nitrochalk, ammonium sulphate and urea. Calcium cyanamide seems to be better than ammonium sulphate on Lateritic soils. The most important nitrogenous fertilizers for tobacco were traditionally soybean cake, cotten seed cake, rape seed cake, etc. Recently, ammonium sulphate, ammonium phosphate, nitrophosphate, nitrochalk and urea have been used for comparative study in experiment. It is found that urea seems to be the best of all. Its consumption will be increased in the future.

The relative availability of water soluble, citrate soluble and citrate insoluble phosphates to rice and wheat has been studied through field and pot experiments.

It is found that calcium superphosphate is always the best one on soils of all reactions. However, fused phosphate and phosphatic rock are fairly available on strongly acid soils. For sugarcane, calcium superphosphate and fused phosphate do not show much difference in availability. The fertilizers practically allocated to sugarcane is calcium superphosphate. The availability of different phosphates is somewhat influenced by the kinds of nitrogenous fertilizers used with the phosphates. In a wheat experiment, fused phosphate showed a better effect with ammonium sulphate, while superphosphate showed a better effect with calcium cyanamide.

In earlier years, potassium sulphate was used on tobacco, and potassium chloride on all other crops. With exception of tobacco, both potassium sulphate and chloride almost have the similar effect on most crops, while chloride is cheaper than sulphate. Recent fertilizer experiments with pineapple indicated the superiority of sulphate over chloride. As a consequence, sulphate has been allocated to pineapple growers instead of the previously allocated chloride.

## VI. Method of Application

Very few data on the placement and time of fertilizer application, nor on the absorption of plant nutrients in the different growing stages of crops, are available in Taiwan. From experience rather than from experiment, phosphatic and potash fertilizers are usually applied as base dressing and nitrogenous fertilizers as both base and top dressing. For densely grown crops, fertilizers are broadcasted. For row crops, fertilizers are applied in rows, bands or hills; but nothing about the proper distance or depth is known.

Recently, foliar application of fertilizers either in liquid or solid form has been studied with regard to sugarcane, citrus, tobacco, pineapple and vegetables. Foliar application of fertilizers on pineapple is being widely practised by pineapple growers in Taiwan.

Liquid fertilizers have been proved successful for tobacco in experiment. Experimental data indicate that 60 kg/ha. of nitrogenous fertilizer in liquid form is equal to 90 kg/ha. in solid form.

Potassium fertilizer was usually applied as base dressing for rice. To boost its fertilizing value, split application is now under experimentation. Fertilizer experiments in coordination with rice varieties, cultural methods and crop rotation systems are in progress. Experiment on the varietal tolerance to heavy nitrogen application, fertilizer experiment of rice nursery, experiment on increased rates of fertilizer application and dense population of rice, etc., are also underway.

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# FERTILIZERS AND MANURES OF RICE IN TAIWAN

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## I. Introduction

In Taiwan, fertilizers and manures are very important to rice growing. There is a very close relationship between the rice production and the consumption of fertilizers. The acreage of rice, the consumption of chemical fertilizers for rice, the total rice production, and the unit area yield of brown rice in 1947 and 1958 are shown as follows:

**Table 1.**
**Rice Production & Fertilizer Consumption in 1947 & 1958**

| Crop | 1947 | | | | 1958 | | | |
|---|---|---|---|---|---|---|---|---|
| | Acreage (ha.) | Consumption of chemical fertilizers (m/t) | Brown rice production (m/t) | Unit area yield (kg./ha.) | Acreage (ha.) | Consumption of chemical fertilizers (m/t) | Brown rice production (m/t) | Unit area yield (kg./ha.) |
| 1st crop | 287,395 | 20,208 | 471,419 | 1,640 | 344,032 | 239,179 | 934,027 | 2,715 |
| 2nd crop | 390,162 | 39,238 | 527,593 | 1,352 | 434,157 | 261,537 | 960,100 | 2,211 |
| Total | 677,557 | 59,446 | 999,012 | | 778,189 | 500,716 | 1,894,127 | |

It is obvious from the above table that rice production increases with the consumption of chemical fertilizers. In 1947, the average rate of application of chemical fertilizers for rice was 70 kilograms per hectare for the first crop and 100 kilograms per hectare for the second crop. In 1958, 695 kilograms per hectare were used for the first crop and 602 kilograms for the second crop. To compare the yield of unit area of 1958 with that of 1947, an increase of 66% in the first crop and 64% in the second crop was obtained due to the increased rate of chemical fertilizers used.

## II. Response of Rice to N, P and K Fertilizers in Taiwan

From 1930 to 1942, there were 549 NPK field experiments of rice conducted at 118 localities on the whole island. In these experiments, ammonium sulphate, calcium superphosphate and potassium sulphate were used as fertilizers. The response of rice to NPK fertilizers is shown in Table 2.

**Table 2.**

**Average Response of Rice Grain to NPK Fertilizers, 1930-1942**

(Unit: kg./ha.)

| Element applied (kg./ha.) | First crop (256 field experiments) | | | Second crop (293 field experiments) | | |
|---|---|---|---|---|---|---|
| | Nitrogen | Phosphate | Potash | Nitrogen | Phosphate | Potash |
| 0 | 2,848 | 3,512 | 3,632 | 2,578 | 2,968 | 2,985 |
| 40 | + 443 | + 156 | + 84 | + 309 | + 113 | + 109 |
| 80 | + 871 | + 207 | + 87 | + 558 | + 168 | + 151 |
| 120 | + 1,041 | + 226 | + 91 | + 737 | + 213 | + 161 |
| 160 | + 1,075 | | | + 795 | | |

In 1953 and 1955, 173 NPK fertilizer experiments of rice with 3×3×3 confounding factorial design were carried out at various localities of Taiwan. Ammonium sulphate, calcium superphosphate and potassium chloride were used as fertilizers. The responses of rice grain to NPK fertilizers are shown in Table 3.

**Table 3.**

**Average Response of Rice Grain to NPK Fertilizers, 1953 & 1955**

(Unit: kg./ha.)

| Element applied (kg./ha.) | First crop (82 field experiments) | | | Second crop (91 field experiments) | | |
|---|---|---|---|---|---|---|
| | Nitrogen | Phosphate | Potash | Nitrogen | Phosphate | Potash |
| 0 | 2,579 | 2,992 | 3,254 | 2,603 | 2,985 | 2,993 |
| 60 | + 879 | + 126 | + 54 | + 542 | + 111 | + 112 |
| 120 | + 1,280 | + 169 | + 74 | + 868 | + 174 | + 139 |

The above two tables indicate that the soils of this island are definitely deficient in nitrogen. The phosphoric acid deficiency comes next. The potash deficiency is the least. The response of rice to nitrogen is more significant in the first crop than in the second crop, the response of rice to phosphate shows about the same degree for the two crops, and that to potash is less in the first crop than in the second crop. These phenomena are true with both the native and Ponlai varieties of rice.

Application of nitrogenous fertilizer will increase the yield of rice grain by 34-50% for the first crop and 21-33% for the second crop. Application of phosphate or potash will cause an increase of yield by 2-6%.

## III. Response of Rice to NPK Fertilizers on the Main Soil Groups of Taiwan

For finding the response of rice to NPK fertilizers on the different main soil groups, the results of the above mentioned field experiments are grouped according to the various main soil groups on which the experiments were conducted. The results are shown in Tables 4 and 5.

**Table 4.**

**Response of Rice Grain to NPK on the Main Soil Groups of Taiwan, 1930-1942**

(Unit: kg./ha.)

| Soil group | N, $P_2O_5$ or $K_2O$ applied | First crop N | First crop $P_2O_5$ | First crop $K_2O$ | Second crop N | Second crop $P_2O_5$ | Second crop $K_2O$ |
|---|---|---|---|---|---|---|---|
| Red and yellow earths | | (11 field experiments) | | | (11 field experiments) | | |
| | 0 | 2,442 | 2,882 | 2,917 | 2,407 | 2,698 | 2,575 |
| | 40 | + 487 | + 289 | + 212 | + 289 | + 201 | + 227 |
| | 80 | + 744 | + 304 | + 265 | + 521 | + 230 | + 353 |
| | 120 | + 701 | + 326 | + 359 | + 493 | + 226 | + 319 |
| | 160 | + 664 | | | + 448 | | |
| Slate alluvial soils | | (19 field experiments) | | | (20 field experiments) | | |
| | 0 | 2,924 | 3,591 | 3,592 | 2,714 | 3,033 | 2,986 |
| | 40 | + 384 | + 97 | + 107 | + 291 | + 96 | + 121 |
| | 80 | + 824 | + 157 | + 171 | + 488 | + 169 | + 216 |
| | 120 | + 1,023 | + 227 | + 89 | + 673 | + 176 | + 188 |
| | 160 | + 1,126 | | | + 809 | | |
| Sandstone and shale alluvial soils | | (57 field experiments) | | | (63 field experiments) | | |
| | 0 | 2,915 | 3,610 | 3,753 | 2,652 | 3,072 | 3,116 |
| | 40 | + 497 | + 149 | + 78 | + 334 | + 142 | + 77 |
| | 80 | + 918 | + 223 | + 63 | + 602 | + 182 | + 139 |
| | 120 | + 1,018 | + 182 | + 91 | + 774 | + 192 | + 134 |
| | 160 | + 1,097 | | | + 808 | | |
| Schist alluvial soils | | (8 field experiments) | | | (7 field experiments) | | |
| | 0 | 2,396 | 3,072 | 3,247 | 2,529 | 2,916 | 2,831 |
| | 40 | + 358 | + 38 | + 223 | + 295 | − 14 | + 201 |
| | 80 | + 862 | + 186 | + 11 | + 415 | + 28 | + 113 |
| | 120 | + 997 | + 139 | + 67 | + 681 | + 176 | + 250 |
| | 160 | + 1,003 | | | + 596 | | |

Earlier experiments in 1930-1942 indicated that rice responded to nitrogen greatly on all soil groups. The response is higher for the first crop than the second crop, also higher for the fertile soils than the less fertile soils. The responses of rice to phosphorus and potash are all low, probably below the statistically significant level. The response to phosphorus is almost same for both the first and

### Table 5.

### Response of Rice Grain to NPK on the Main Soil Groups of Taiwan, 1953 & 1955

| Soil group | N, $P_2O_5$ or $K_2O$ applied (kg./ha.) | First crop (kg./ha.) | | | Second crop (kg./ha.) | | |
|---|---|---|---|---|---|---|---|
| | | N | $P_2O_5$ | $K_2O$ | N | $P_2O_5$ | $K_2O$ |
| Red and yellow earths | | (17 field experiments) | | | (18 field experiments) | | |
| | 0 | 2,716 | 3,404 | 3,372 | 2,774 | 3,311 | 3,261 |
| | 60 | + 981 | + 137 | + 182 | + 759 | + 113 | + 198 |
| | 120 | + 1,401 | + 181 | + 230 | + 1,107 | + 151 | + 210 |
| Slate alluvial soils | | (22 field experiments) | | | (22 field experiments) | | |
| | 0 | 2,458 | 3,115 | 3,155 | 2,477 | 2,789 | 2,821 |
| | 60 | + 894 | + 45 | + 53 | + 498 | + 147 | + 132 |
| | 120 | + 1,265 | + 138 | + 18 | + 779 | + 253 | + 138 |
| Sandstone and shale alluvial soils | | (38 field experiments) | | | (44 field experiments) | | |
| | 0 | 2,919 | 3,510 | 3,582 | 2,730 | 3,094 | 3,135 |
| | 60 | + 831 | + 118 | + 5 | + 512 | + 114 | + 61 |
| | 120 | + 1,200 | + 146 | + 34 | + 860 | + 163 | + 98 |
| Schist alluvial soils | | (4 field experiments) | | | (3 field experiments) | | |
| | 0 | 1,779 | 2,647 | 2,786 | 1,687 | 2,029 | 2,030 |
| | 60 | + 1,011 | + 97 | − 107 | + 308 | − 6 | + 103 |
| | 120 | + 1,818 | + 127 | − 85 | + 822 | + 271 | + 159 |

second crops, but that to potash is obviously higher for the second crop than the first crop. The response to phosphorus and potash seems higher on red soils than on other soil groups. Experiments conducted in 1953 and 1955 do not change the picture much, except that the response to phosphorus on red soils is no better than that on other soil groups, probably due the accumulation of the phosphatic fertilizers applied.

## IV. Percentage of Experiments Showing Significant Response to NPK Fertilizers

From 1953 to 1955, 173 NPK fertilizer experiments were conducted adopting 3×3×3 confounding design. The percentage of experiments showing statistically significant response to individual elements is shown in Table 6.

### Table 6.

### Percentage of Experiments Showing Significant Response to Individual Elements

| Response | First crop | | | | | | Second crop | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | N | | $P_2O_5$ | | $K_2O$ | | N | | $P_2O_5$ | | $K_2O$ | |
| | 60 kg./ha. | 120 kg./ha. | 60 kg./ha. | 120 kg./ha. | 60 kg./ha. | 120 kg./ha. | 60 kg./ha. | 120 kg./ha. | 60 kg./ha. | 120 kg./ha. | 60 kg./ha. | 120 kg./ha. |
| Positive | 95 | 94 | 21 | 22 | 13 | 17 | 77 | 85 | 20 | 31 | 29 | 35 |
| Negative | 0 | 0 | 0 | 1 | 1 | 4 | 0 | 3 | 3 | 1 | 1 | 0 |

The figures shown in the above table are the percentage of experiments showing response to N, $P_2O_5$, or $K_2O$ at 5% and 1% significant levels.

Assuming that the locations of experiments are selected at random, the results at 120 kg./ha. of N and 60 kg./ha. each of $P_2O_5$ and $K_2O$ in the above table indicate:

A. About 95% of paddy soils of Taiwan responds to nitrogen in the first crop and 85% of paddy soils in the second crop.

B. About 20% of paddy soils responds to phosphorus in both the first and second crops.

C. About 15% of paddy soils in the first crop and 30% in the second crop respond to potash.

The average interaction between each two elements of NPK is shown in Table 7.

**Table 7.**

**The Interaction (kg./ha.) of NP, NK and PK**

| Crop | NP | NK | PK |
|---|---|---|---|
| 1st crop | + 2 | + 7 | + 5 |
| 2nd crop | − 55 | + 39 | + 9 |

From the above table, it is obvious that no significant interaction is existing between any two elements of N, P and K.

## V. Recommendation and Allocation of Fertilizers on the Paddy Soils of Taiwan

According to the results of NPK field experiments conducted from 1930 to 1942 and other related data, ten regions for fertilizer recommendation were classified. The average increment of rice grain from per kilogram of N, $P_2O_5$ or $K_2O$ per hectare in the various regions of Taiwan are shown in Table 8.

**Table 8.**

**Increment of Rice Grain from Per Kilogram of Element Per Hectare in the Various Regions of Taiwan, 1930-1942**

(Unit: kg./ha.)

| Regions | Properties of soils | Crop | N | | | | $P_2O_5$ | | | $K_2O$ | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | I | II | III | IV | I | II | III | I | II | III |
| Ilan | Slate alluvial soils<br>Clay loam<br>pH 5.5-6.0<br>Organic matter 2.5-3.5% | 1st | 7.3 | 2.2 | -8.7 | -4.0 | 0.5 | 2.3 | 0.3 | 4.2 | 3.2 | 1.5 |
| | | 2nd | 5.5 | 6.5 | 1.9 | 1.7 | 3.7 | 1.0 | 0.8 | 6.9 | 1.7 | 0.2 |

(continued)

| Regions | Properties of soils | Crop | N | | | | $P_2O_5$ | | | $K_2O$ | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | I | II | III | IV | I | II | III | I | II | III |
| East Taiwan | Schist alluvial soils<br>Clay loam<br>pH 6.0-8.0<br>Organic matter around 2.5% | 1st | 5.4 | 11.6 | 5.6 | 3.3 | 1.3 | 3.3 | 0.3 | 0.7 | -2.6 | -4.0 |
| | | 2nd | 6.0 | 2.8 | 7.3 | 3.8 | 0.5 | 0.5 | 3.3 | 3.4 | 1.3 | -0.9 |
| Taipei | Sandstone and shale alluvial soils<br>Clay loam<br>pH 4.5-5.5<br>Organic matter around 3.5% | 1st | 10.3 | 8.8 | 1.4 | -0.7 | 6.7 | 0.3 | 0.4 | 2.2 | 0.5 | 0.1 |
| | | 2nd | 6.1 | 7.7 | 1.7 | -0.3 | 3.8 | 2.1 | -1.0 | 0.7 | 2.2 | -0.5 |
| Taoyuan | Deluvium<br>Clay loam<br>pH 4.0-5.5<br>Organic matter 2.5-3.5% | 1st | 13.4 | 7.5 | -0.9 | -0.9 | 5.9 | 3.0 | -0.7 | 9.6 | 1.5 | 3.0 |
| | | 2nd | 7.1 | 7.1 | -0.9 | -1.7 | 5.0 | 1.4 | -0.8 | 6.6 | 3.6 | -1.5 |
| Hsinchu & Miaoli | Sandstone and shale alluvial soils<br>Loam<br>pH 5.0-6.0<br>Organic matter 1.5-2.5% | 1st | 15.5 | 10.6 | 4.8 | 0.4 | 2.4 | -0.3 | 0.3 | 0.2 | -0.5 | 0.9 |
| | | 2nd | 7.6 | 6.0 | 4.4 | -0.2 | 1.6 | -0.2 | -0.1 | 2.6 | 0.3 | -0.1 |
| Taichung | Sandstone and shale alluvial soils<br>Loam<br>pH 6.0-6.6<br>Organic matter 1.5-2.5% | 1st | 16.3 | 13.3 | 6.2 | -1.4 | 10.2 | 3.1 | 0.5 | 2.0 | 0.1 | 2.8 |
| | | 2nd | 9.8 | 9.2 | 5.1 | 2.5 | 4.5 | 0.7 | 0.8 | 3.2 | 2.6 | 2.8 |
| Chuhui | Slate alluvial soils<br>Clay loam<br>pH 6.6-7.5<br>Organic matter 1.5-2.5% | 1st | 13.5 | 10.9 | 11.9 | 4.4 | 3.1 | -0.6 | 2.6 | -1.4 | -0.6 | -2.5 |
| | | 2nd | 9.4 | 3.3 | 2.4 | 2.4 | 1.5 | 1.9 | 0.3 | 4.0 | 3.1 | 1.5 |
| Saline and alkaline soil region | Sandstone and shale alluvial soils<br>Sandy loam<br>pH 7.5-8.0<br>Organic matter 1.0-1.5% | 1st | — | — | — | — | — | — | — | — | — | — |
| | | 2nd | 11.3 | 16.2 | 11.8 | 7.2 | 12.9 | 5.2 | 4.5 | -1.8 | -0.1 | -0.5 |
| Chiayi & Tainan | Sandstone and shale alluvial soils<br>Clay loam<br>pH 6.0-7.5<br>Organic matter 1.0-1.5% | 1st | — | — | — | — | — | — | — | — | — | — |
| | | 2nd | 7.4 | 4.0 | 7.4 | 2.6 | 2.4 | 1.8 | 1.7 | 1.4 | 1.9 | 2.0 |
| Kaohsiung & Pingtung | Slate alluvial soils<br>Clay loam<br>pH 5.5-7.0<br>Organic matter 1-2% | 1st | 9.5 | 13.6 | 8.2 | 2.1 | 5.2 | 1.0 | 4.2 | 2.3 | 1.3 | -1.6 |
| | | 2nd | 5.1 | 5.7 | 0.1 | 0.2 | 1.3 | 3.8 | 0.4 | 0.8 | 3.7 | -2.1 |

Remarks: I Kg. of rice grain increased by per kg. of element at 40 kg./ha. rate;
II Kg. of rice grain increased by per kg. of element at 80 kg./ha. rate;
III Kg. of rice grain increased by per kg. of element at 120 kg./ha. rate;
VI Kg. of rice grain increased by per kg. of element at 160 kg./ha. rate.

From the increment of rice from per kilogram of element in the ten regions, a recommendation on fertilizer application for the two crops of rice is made for those regions.

## Table 9.
## Recommendation on Fertilizers for Rice

(Unit: kg./ha.)

| Region | N | $P_2O_5$ | $K_2O$ |
|---|---|---|---|
| Ilan | 60 | 40 | 40 |
| East Taiwan | 80 | 40 | 40 |
| Taipei | 80 | 40 | 40 |
| Taoyuan | 80 | 60 | 60 |
| Hsinchu and Miaoli | 100 | 40 | 40 |
| Taichung | 120 | 60 | 40 |
| Muddy river valley | 100 | 40 | 40 |
| Saline soil | 100 | 80 | 0 |
| Chiayi and Tainan | 80 | 40 | 40 |
| Kaohsiung and Pingtung | 100 | 40 | 40 |
| Average (whole Province) | 90 | 48 | 38 |

The actually allocated rate of fertilizers for rice in 1959 is shown in Table 10.

## Table 10.
## Average Allocated Amount of Fertilizers for Rice in 1959

(Unit: kg./ha.)

| Food area | First crop | | | Second crop | | |
|---|---|---|---|---|---|---|
| | N | $P_2O_5$ | $K_2O$ | N | $P_2O_5$ | $K_2O$ |
| Taipei | 74 | 31 | 16 | 74 | 23 | 22 |
| Hsinchu | 97 | 39 | 26 | 93 | 34 | 28 |
| Taichung | 116 | 41 | 29 | 114 | 38 | 29 |
| Tainan | 112 | 36 | 20 | 106 | 35 | 26 |
| Kaohsiung | 112 | 43 | 24 | 94 | 32 | 30 |
| East Taiwan | 84 | 29 | 12 | 84 | 25 | 24 |
| Average | 99 | 37 | 21 | 96 | 31 | 27 |

It is seen that the allocated amount of N is over the recommended amount, while that of $P_2O_5$ and $K_2O$ is below the recommended amount.

## VI. Comparison of Different Types of Fertilizers

### A. Comparison of Nitrogenous Fertilizers

From 1952 to 1955, there conducted a good number of field experiments at various localities to compare the effect of nitrogenous fertilizers on rice with ammonium sulphate, ammonium chloride, urea, calcium ammonium nitrate and ammonium nitrate. Taking the availability of ammonium sulphate at the rate of 80 kg. of nitrogen per hectare as 100, the relative availabilities of the other four fertilizers were calculated in Table 11.

### Table 11.
### Relative Availabilities of Ammonium Sulphate, Ammonium Chloride, Urea, Calcium Ammonium Nitrate and Ammonium Nitrate to Paddy Rice in Taiwan

(Unit: %)

| Type of fertilizer | First crop | | Second crod | |
|---|---|---|---|---|
| | Rice grain | Rice straw | Rice grain | Rice straw |
| Ammonium sulphate | 100 | 100 | 100 | 100 |
| Ammonium chloride | 96 | 98 | 98 | 104 |
| Urea | 94 | 94 | 95 | 94 |
| Calcium Ammonium nitrate | 88 | 85 | 88 | 93 |
| Ammonium nitrate | 70 | 66 | 81 | 82 |

Obviously, ammonium sulphate is the best fertilizer for rice growing, but the differences in effects among the ammonium sulphate, ammonium chloride and urea are not quite significant for both crops. The effects of ammonium sulphate, ammonium chloride and urea are all significantly better than that of ammonium nitrate and calcium ammonium nitrate.

The effect of calcium cyanamide on rice has been compared with that of ammonium sulphate from past field trials and demonstrations. The results are shown in Table 12.

### Table 12.
### Comparison of Effects of Calcium Cyanamide and Ammonium Sulphate on Rice

| pH value of soils | Rate of nitrogen (kg./ha.) | Crop | No. of experiments | Effect of calcium cyanamide | | | |
|---|---|---|---|---|---|---|---|
| | | | | Being batter than or equal to ammonium sulphate | | Being poorer than ammonium sulphate | |
| | | | | No. of expts. | % | No. of expts. | % |
| < 6.0 | 80 | 1st crop | 19 | 15 | 79 | 4 | 21 |
| | | 2nd crop | 19 | 8 | 42 | 11 | 58 |
| | 120 | 1st crop | 10 | 8 | 80 | 2 | 20 |
| | | 2nd crop | 10 | 7 | 70 | 3 | 30 |
| > 6.0 | 80 | 1st crop | 6 | 3 | 50 | 3 | 50 |
| | | 2nd crop | 8 | 3 | 38 | 5 | 62 |
| | 120 | 1st crop | 5 | 2 | 40 | 3 | 60 |
| | | 2nd crop | 5 | 2 | 40 | 3 | 60 |

Table 12 shows that, on acid soils, calcium cyanamide is significantly better than ammonium sulphate. On neutral and alkaline soils, calcium cyanamide is a little inferior to ammonium sulphate, particularly for the second crop and with a high rate of application.

## B. Comparison of Phosphatic Fertilizers

In 1952, pot experiments with rice as a indicator crop were carried out on four main soil groups of Taiwan to study the availability of calcium superphosphate, fused phosphate and rock phosphate (Reno). The results are shown in Table 13.

**Table 13.**

**Comparison of the Fertilizing Value of Superphosphate, Fused Phosphate and Rock Phosphate on the Rice Grain**

(gm./pot of dry wt.)

| Soils | First crop | | | | | | Second crop | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Calcium superphosphate | | Fused phosphate | | Rock phosphate | | Calcium superphosphate | | Fused phosphate | | Rock phosphate | |
| | Yield gm./pot | Index % | Yield gm./pot | Index % | Yield gm./pot | Index % | Yield gm./pot | Index % | Yield gm./pot | Index % | Yield gm./pot | Index % |
| Sandstone & shale alluvial soils | 18.6 | 100 | 17.4 | 94 | 18.1 | 97 | 22.9 | 100 | 23.3 | 102 | 22.2 | 97 |
| Lateritic soils | 14.6 | 100 | 14.4 | 99 | 14.5 | 99 | 18.4 | 100 | 17.3 | 93 | 17.0 | 93 |
| Slate alluvial soils | 11.8 | 100 | 10.7 | 91 | 10.7 | 91 | 14.8 | 100 | 14.7 | 99 | 8.0 | 54 |
| Mudstone alluvial soils | 22.4 | 100 | 20.6 | 92 | 20.4 | 91 | 23.9 | 100 | 14.7 | 62 | 5.1 | 21 |

Remark: Rate of $P_2O_5$ is 120 kg./ha.

From the figures in the above table, no matter what kinds of soils they are, the availability of superphosphate is the greatest, that of fused phosphate is the intermediate, and that of rock phosphate is the least, particularly on the slate alluvial soils and clay pan alluvial soils in the second crop.

From 1952 to 1953, four field experiments of three kinds of phosphates were carried out on the red earth of Taoyuan. The results are shown in Table 14.

The difference in response of rice to calcium superphosphate and fused phosphate on the red earth is not significant, but both are significantly better than rock phosphate in the first crop of 1952.

### Table 14.

### Relative Availabilities of Three Kinds of Phosphates to Rice Grain on Red Earth

| Type of fertilizer | 1952 ($P_2O_5$ 120 kg./ha.) | | | | 1953 ($P_2O_5$ 60 kg./ha.) | | | |
|---|---|---|---|---|---|---|---|---|
| | 1st crop | | 2nd crop | | 1st crop | | 2nd crop | |
| | Yield kg./ha. | Index % | Yield kg./ha. | Index % | Yield kg./ha. | Index % | Yield kg./ha. | Index % |
| Calcium superphosphate | 4,187 | 100 | 4,811 | 100 | 4,356 | 100 | 3,479 | 100 |
| Fused phosphate | 4,072 | 97 | 4,628 | 96 | 4,187 | 96 | 3,494 | 100 |
| Rock phosphate | 3,752 | 90 | 4,675 | 97 | 4,030 | 93 | 3,359 | 97 |
| Non-phosphate | 3,530 | 84 | 4,459 | 93 | 3,597 | 83 | 3,095 | 89 |

## VII. Organic Manure on Rice

In 1952, a comprehensive survey of fertilizer use was made by the Provincial Food Bureau. In this survey a total of 27,589 rice farmers in 284 townships were asked to report the actual amount of fertilizer and manure used on their first and second crops of rice. The information collected is summarized in Table 15.

### Table 15.

### Fertilizer and Manure on Rice in Taiwan, 1952

| Type | First crop | | | | | | Second crop | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | N | | $P_2O_5$ | | $K_2O$ | | N | | $P_2O_5$ | | $K_2O$ | |
| | kg./ha. | % | kg./ha. | % | kg./ha. | % | kg./ha. | % | kg./ha. | % | kg./ha. | % |
| Chemical fertilizer | 65 | 60 | 24 | 48 | 10 | 18 | 66 | 65 | 24 | 55 | 10 | 22 |
| Manure[1] | 44 | 40 | 26 | 52 | 44 | 82 | 35 | 35 | 20 | 45 | 35 | 78 |
| Total | 109 | 100 | 50 | 100 | 54 | 100 | 101 | 100 | 44 | 100 | 45 | 100 |

[1] Including compost, green manure, night-soil and animal excrete.

It is clear from the above data that about one-third of the total nitrogen, half of the total $P_2O_5$, and four-fifths of the total $K_2O$ of rice come from the manure.

### A. The Effect of Organic Manure

In 1954, ninety-five NPK field experiments with or without manure were carried out at various localities over the whole island to study the effect of manure on the yield of rice. The results are shown in Table 16.

### Table 16.

### Response of Rice Grain to Chemical Fertilizers With and Without Manure Present

| Crop | Manure | No. of experiments | Nitrogen (kg./ha.) |  | Phosphate (kg./ha.) |  | Potash (kg./ha.) |  |
|---|---|---|---|---|---|---|---|---|
|  |  |  | Response | Mean yield without nitogen | Response | Mean yield without phosphate | Response | Mean yield without potash |
| 1st crop | Absent | 49 | + 1,295 | 3,106 | + 147 | 4,401 | + 77 | 4,548 |
|  | Present | 49 | + 1,134 | 3,427 | + 147 | 4,561 | + 106 | 4,708 |
|  | Difference |  | — 161 | + 321 | 0 | + 160 | + 29 | + 160 |
| 2nd crop | Absent | 46 | + 571 | 2,650 | + 137 | 3,221 | + 191 | 3,358 |
|  | Present | 46 | + 548 | 2,923 | + 114 | 3,271 | + 182 | 3,585 |
|  | Difference |  | — 23 | + 273 | — 23 | + 250 | — 9 | + 227 |

Remarks: Rate of manure: 6 m.t./ha.;
Rate of nitrogen: 120 kg./ha. in the 1st crop and 80 kg./ha. in the 2nd crop;
Rate of $P_2O_5$ and $K_2O$: 60 kg./ha. each for both 1st and 2nd crops.

The data indicate that rice responds to the nitrogen, $P_2O_5$ and $K_2O$ contained in the local manure for the both first and second crops. In the first crop, the response to nitrogen is greater than that to $P_2O_5$ and $K_2O$. In the second crop, the response to the three elements in manure is about of the same order. As a consequence, with the presence of organic manure, the response of rice to the chemical fertilizers is accordingly decreased for both the first and second crops.

## B. Effect of Organic Manure Versus Chemical Fertilizers on Rice

The data from a long-term experiment conducted from 1926 to 1957 as shown in Table 17 reveal the effect of organic manure and chemical fertilizers compared at the rate of 95 kilograms of nitrogen.

### Table 17.

### Comparison of Response of Rice to Organic Manure and NPK Fertilizers

(Unit: kg./ha.)

| Fertilizer or manure | First crop |  | Second crop |  |
|---|---|---|---|---|
|  | Response | Average yield | Response | Average yield |
| Ammonium sulphate, superphosphate and potassium chloride | + 1,230 | 2,795 | + 734 | 2,429 |
| Stable manure | + 1,598 | 3,163 | + 1,112 | 2,807 |
| Green manure | + 1,392 | 2,957 | + 866 | 2,561 |
| No fertilizers and manure |  | 1,565 |  | 1,695 |

Obviously, the effect of continuous application of organic manure is better than chemical fertilizers, even though more $P_2O_5$ and $K_2O$ were supplied in the later case.

## VIII. Methods of Application of Fertilizers on Paddy Soils of Taiwan

Experiments have been conducted to study the proper method of applying some nitrogenous fertilizers on rice.

A. Ammonium nitrate which is not an ideal nitrogenous carrier for rice was found to be more effective as a top-dressing.

B. For the method of application of urea, seven field experiments were conducted at various localities for both first and second crops of rice in 1955. According to the results of experiments, deep placement and top-dressing are found significantly more effective in increasing the yield of rice. Most of the urea applied on the soils of the experimental localities will decompose within 3 to 5 days, and evaporation of ammonia by the application of urea is very significant as compared with ammonium sulphate. When urea is to be used as base manure on paddy soils, complete mixing with surface soil is advisable. On the soils of light texture, field should be drained before application; and flooding after 3 to 4 days seems to be more profitable.

C. As regard to the use of calcium cyanamide in the paddy field, many papers have been published. Some of the highlights are as follows:

1. Mixing calcium cyanamide with ammonium sulphate cannot enforce their effect on each other, but mixing with soybean cake seems to be advantageous.

2. Calcium cyanamide mixed with compost seems to be effective in promoting the decomposition of organic matter and consequently increasing the availability of nitrogen.

3. A mixture of calcium cyanamide with compost prepared five days before transplanting causes no harm to the crop, even if it is applied on the same day of transplanting, and the effect is better than applied separately.

4. Under the climatic condition of Taiwan, application of 80 kg./ha. of nitrogen in the form of calcium cyanamide on the same day of transplanting would cause a serious injury to the crop, application at four days before transplanting would cause little harmful results, and application at six to eight days before transplanting causes no harm at all.

5. Calcium cyanamide may be used as top-dressing, if it is mixed with soils in advance. The longer is the time of mixing before application, the better is the result. The proportion of calcium cyanamide to soil is not a critical point.

D. The effect of ammonia solution on rice is comparable to that of ammonium sulphate, if it is mixed with the soil right after the application. Large loss of nitrogen was found to occur, should it be left in the flooding water.

## IX. Summary

According to the response of rice to NPK fertilizers in 722 field experiments in Taiwan, the soils of this island are definitely deficient in nitrogen. The phosphorus deficiency comes next, and that of potash the least.

About 95% of paddy soils in Taiwan will respond to nitrogen in the first crop and 85% in the second crop. About 20% of paddy soils will respond to phosphorus for both the first and second crops. About 15% of paddy soils in the first crop and about 30% in the second crop are responsive to potash.

Application of nitrogenous fertilizer will positively increase the yield of rice grain by 34-50% for the first crop, and 21-33% for the second crop. Application of phosphorus and potash will bring an increase of yield by only 2-6%.

All main soil groups are deficient in nitrogen, particularly in the first crop. The deficient status of phosphorus and potash of different soil groups are variable. Generally, the red and yellow earths are more deficient in phosphorus and potash than other soil groups.

No significant interaction was found between any two elements of NPK fertilizers.

Due to the differences in properties and characteristics of the soils in Taiwan, a scheme for application of fertilizers has been mapped out, based upon the status of soil fertility at various localities. The recommended rate of nitrogen is very close to the allocated rate, but the allocated rates of $P_2O_5$ and $K_2O$ are below the recommended rates.

From the comparisons of the effects of different kinds of nitrogenous fertilizers on rice, it was found that ammonium sulphate is the best one for rice growing. However, the difference in effect of the ammonium sulphate, ammonium chloride and urea is not significant. Obviously, ammonium nitrate and calcium ammonium nitrate are not suitable as a fertilizer on the paddy soils except when used as a top-dressing. Calcium cyanamide is a good source of nitrogen, if used properly.

The rice responds only slightly to organic manure, therefore its response to chemical fertilizers is slightly decreased when organic manure is used.

The effects of continuous application of organic manures on rice yield are better than that of the chemical fertilizers of NPK only with equal rate of nitrogen. Results from experiments on the proper methods of application of calcium cyanamide, ammonium nitrate, urea and ammonia solution on the paddy soils are summarized in the paper.

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# RESPONSE OF RICE TO LIME IN TAIWAN

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Acid soils cover a large area in Taiwan. The response of lowland rice to lime on acid soils in Taiwan has been studied in a great many field experiments. Although considerable amount of data has been accumulated, interpreted and published, the problem is still remaining at a research stage.

In this paper the results of several series of experiments and demonstrations are presented in a summarized form.

## I. Response of Rice to Lime

Eight field tests on the response of rice to lime were conducted in 1947-1948 on two kinds of acid soils. Five of them were conducted on an alluvial soil derived from sandstone and shale weathering materials, and the remaining three on a Latosolic soil of diluvial deposit. The experimental results regarding the direct and residual effects on the yield of rice and pH of soil may be summarized as follows:

### A. Results on the Alluvial Soil

1. On the alluvial soil, when sufficient chemical fertilizers were applied, 3,000 kg/ha of agricultural lime increased 576 kg/ha of grain or 17% over the yield of the unlimed plot; while 6,000 kg/ha of lime increased 651 kg/ha of grain or 19% over the yield of the unlimed plot.

2. It was found that the residual effect of 3,000 kg/ha of lime applied on the first crop was equivalent to about 1,000 kg/ha on the second crop, and that of 6,000 kg/ha was equivalent to about 2,000 kg/ha., respectively, both rates being not able to increase the yield of rice significantly. However, 4,000 kg/ha of lime applied on the second crop increased 409 kg/ha of grain corresponding to 24% of the yield of unlimed plot.

3. 3,000 kg/ha and 6,000 kg/ha of lime applied on the plots without chemical fer-

tilizers increased 392 kg/ha and 576 kg/ha of grain corresponding to 19% and 28% of the yield of unlimed plot, respectively. The residual effect of 3,000 kg/ha of lime applied on the first crop increased 147 kg/ha of grain of the second crop or 11% over the yield of the unlimed plot and that of 6,000 kg/ha of lime increased 319 kg/ha of grain or 23% over the yield of the unlimed plot, respectively.

### B. Results on the Latosolic Soil

1. On the Latosolic soil with sufficient chemical fertilizers, 1,000 kg/ha, 4,000 kg/ha and 6,000 kg/ha of lime increased 465 kg/ha, 944 kg/ha and 1,095 kg/ha of grain, or 17%, 36% and 42% over the yield of the unlimed plot. The residual effects on the second crop of rice of the latter two rates increased 411 kg/ha and 504 kg/ha of grain or 19% and 23% over the yield of the unlimed plot, respectively.

2. 2,000 kg/ha and 4,000 kg/ha of lime on the Latosolic soil with sufficient chemical fertilizers for the second crop increased 240 kg/ha and 165 kg/ha of grain or 11% and 8% over the yield of the unlimed plot.

It is concluded from the above two series of experiments that the yield of rice responds to the lime more apparently on the first crop than on the second crop, on the Latosolic soil more than on the alluvial soil, and on the unmanured soils more than on the manured soils.

## II. Response of Rice to Lime as Influenced by Soil Fertility Level

Experiments to study the effect of lime on the yield of rice as influenced by the fertility level of soils were conducted in 1949 at ten localities, namely, Taipei, Hsichih, Hsintien, Hsinchu, Miaoli, Taoyuan, Taoyuan Agricultural Vocational School, Pateh, Chungli and Hukow. The soils of the former seven localities are alluvial soils of sandstone and shale materials and those of the latter three ones are Latosolic soils on the diluvial deposit. Their reactions are from very acid to slightly acid with pH values ranging from 4.5 to 6.3. Each experiment consists of two series, one with chemical fertilizers at the rate of 80 kg each of N, $P_2O_5$ and $K_2O$ per hectare, and the other with compost manure at the rate of 10,000-15,000 kg per hectare. Four lime levels were used in both series alike, namely, 0, 1, 2 and 3 tons per hectare, respectively. In addition to field experiments, soils were sampled from the experimental fields for chemical and physical studies. The results may be summarized as follows:

A. In the chemical fertilizer series, the results at Taipei, Hsichih, Taoyuan and Hsintien showed significant response of rice grain to lime. In the compost manure series, the results at Taipei, Pateh, Hsichih, Taoyuan, Taoyuan Agricultural Vocational School, Chungli and Hsintien showed significant response of rice grain to lime.

B. In the chemical fertilizer series, the average increase of rice grain is about 9% by 1 ton of lime per hectare, 10% by 2 tons of lime per hectare and 23% by 3 tons of lime per hectare. In the compost manure series, the average increase of rice grain at the same three lime levels is 8%, 17% and 21%, respectively. The response of rice to lime is shown more apparently in compost manure series than in the chemical fertilizer series.

C. The application of 1-3 tons of lime per hectare raises the pH values of all the soils to slightly acid and neutral, but the plots receiving 1-2 tons of lime restore to their original pH after one cropping season due to the intense leaching of calcium under the flooding condition. It seems that liming at moderate rate continuously or rather intermittently is not likely to cause any danger of overliming in paddy field.

D. Lime tends to decompose the soil organic matter. The tendency is more apparent with the application of compost manure; but, even with compost manure, the loss of organic matter is very little, mostly from 0.2% to 0.3%. It is thought that, under proper soil management with annual addition of organic manure, lime would not lower the organic matter level of the soil to such an extent as to deteriorate the soil productivity as generally believed.

E. Lime greatly increases the amount of available phosphorus of the soils. After one cropping season, however, the available phosphorus again decreases with the lowering of pH values.

F. The effect of lime on the available potash of the soils was not clear in these experiments.

G. The repsonse of rice to lime seems directly related with the general fertility of the soils. On fertile soils or soils receiving sufficient plant nuterints such as chemical fertilizers, rice does not respond to the lime so much as that on the infertile soils or soils receiving only some compost manure.

H. Soils of low pH values are generally poor soils. Therefore rice usually responds to lime on acid soils. But there is no direct relationship existing between the pH values of the soils and the response of rice to lime.

I. The cause of increase of rice yield by liming may be attributed to (1) the supply of available calcium, (2) the increase in available phosphorus, and (3) the decomposition of organic matter, hence the release of available nitrogen and phosphorus.

## III. Response of Rice to Lime as Shown by Demonstrations

More than two hundred field experimental plots in a simple design for demonstration purpose were laid out in 1950 and 1951 on the acid soils of the northern part of Taiwan, including Latosolic soils, Yellow earths and acid alluvial soils with their pH ranging from 4.0 to 6.0.

It is shown that, in more than 95% of the experiments, the yield of rice grain responds to the application of 3 tons of lime per hectare as base dressing, and in about 50% of the experiments, the increase is over 10%, which is taken arbitrarily as being significant.

The application of 3 tons of lime per hectare as top dressing is less effective than as base dressing. Only in one-fourth of the experiments, the increase of yield is above 10%.

## IV. Method of Application of Lime to Rice

Experiments on lime requirement for rice were carried out at five localities representing three kinds of the most important acid soils in Taiwan in a period of three years from 1950 to 1953. The three acid soils are Latosolic soil, Yellow earth and the acid sandstone and shale alluvial soil. The pH values are all below 5.5. In the experiments, rate of lime, method of continuous and intermittent application, and basic and top application are included for comparing their relative effect on the yield of rice. The pH values of the soils at the three localities after the harvesting of each crop in a course of two or three years were determined so as to interpret the crop response to lime in terms of soil pH. The results may be summarized as follows:

A. Yield of rice grain responds to lime more significantly in the first crop than in the second crop. In the first crop an increase of rice grain of more than 20% is frequently obtained, but in the second crop there is only an increase of about 10%.

B. The lime applied one or half year ago may show its residual effect on the succeeding crop. The effect is also more significant for the first crop than for the second crop.

C. Comparing the effect of continuous application of lime to both the first and second crops with that of application of lime to first crop only, the response of rice to lime is in general alike in first crop. In the second crop, the unlimed plot is no worse or even better than the limed plot. The tendency is more pronounced in the second and third years.

D. In the first year, the response of rice grain to lime increases with the rate of lime applied; but this difference diminishes in the later years.

E. Continuous application of lime at a rate of 3 ton/ha for four consecutive crops will bring the pH of soil to 7.2-7.5. Further application will no more raise the pH. It seems that the loss and gain of lime in soil under such condition are equilibrated.

F. Leaching of lime in flooding soil seems very quick. Suspension of liming for one crop will materially cause a drop of pH after liming for one or even several crops. However, intermittent application of lime may still bring up the pH of soils gradually in course of years, presumably to 7.2-7.5 eventually, as years pass on.

G. Liming the soil when its pH is already above 6.5 seems detrimental to the rice for second crop, but not so for the first crop.

H. With proper rate of lime, top dressing indicates a better result in a larger number of experiments.

## V. Conclusion

For effective use of lime on acid paddy soils, the following points are recommended:

A. The yield of rice responds to lime more significantly on the first crop than on the second crop, on the poor soils than on the fertile soils, and on the unmanured soils than on the manured soils.

B. For the Latosolic soils, Yellow earth and acid sandstone and shale alluvial-soils with pH below 5.5, a rate of 2-3 ton/ha of lime (CaO) is desirable.

C. Lime should be intermittently applied to first crop, but not to second crop.

D. When the pH of soil has raised above 6.5, application of lime should be suspended for one or more crops.

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# FERTILIZERS OF SUGARCANE

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## I. Natural Sugarcane Districts in Taiwan

As it is known, the effects of fertilizers are governed by many natural, artificial and other known or unknown factors. The known factors are mostly concerned with soil, kind and variety of plants, length of vegetation period, cultural practices and so forth. The unknown factors should never be over-looked by an agriculturist if successful work is to be achieved. These known and unknown factors prevailing in a field interweave together to impose particular resultant influence upon the action of fertilizers on plants. The variation of a single factor may affect the function of other factors, or, to a greater degree, the whole resultant influence of the multiple factors. Such factors differ from place to place at the same time and from time to time at the same place. As a result, the fertilization problem becomes an exceedingly complicated and staggering one. It cannot be clearly elucidated, unless the most important factors concerned have been thoroughly studied.

Climate and soil are the two most important factors that constitute the natural environment for sugarcane. The author and his co-workers[7] have converted the voluminous data on climate and soils of different sugarcane districts in Taiwan into a brief and lucid form, upon which a classification of natural sugarcane districts is made, so as to facilitate the practical application of these data to the investigation of the fertilization problem of sugarcane in Taiwan.

According to this scheme of classification, there are seven main natural sugarcane districts classified according to climate, as shown in Fig. 1. For the sake of brevity and lucidity, the soils are classified into nine categories, though there have been more than one hundred series of soils classified according to the usual method. These nine categories of soils serve as the basis for the classification of the sub-districts, which are of such a large number that they cannot possibly be shown in Fig. 1.

## A. The Climatic Districts or the Main Districts

In general, the ideal meteorological conditions of sugarcane are: the annual mean temperature should be 25-27°C, the atmospheric humidity high and the sunlight intense. The annual rainfall should be 1,500-2,000 mm., 2/3 to 3/4 of which should fall during the grand vegetation period. Weekly rainfall of 50-75 mm. should be considered as adequate. Strong wind, torrential rain or long drought are unfavorable. Unfortunately all of these are not the cases in Taiwan as can be noted from Tables 1 and 2 as well as the following description of the seven main districts:

1. Southern Highest-temperature-and-highest-rainfall District (District 1): This district is found in the southern part of this island with an average annual mean temperature of 24.9°C, the highest of all main districts. There is only one month, in which the monthly mean temperature drops below 20°C. Sugarcane can grow almost without retardation throughout the whole year. The average annual total rainfall is 2,475.3 mm., only next to main District 7 being very heavy in May-September and very scanty in October-April. The most serious limiting factor for the growth of sugarcane in this main district is rainfall in the dry season. Irrigation water is available in many places of this district, but such lands are always planted to paddy rice. This district is free from the attack of winter monsoon.

2. Southern High-temperature-and-high-rainfall District (District 2): This district lies on the Western Plain south to the Tseng-wen River with an average annual mean temperature of 24.4°C, and annual mean rainfall of 2,079.0 mm., next to those of District 1. Its monthly mean temperature drops a little below 20.0°C in December, January and February. During this period the growth of cane is somewhat retarded. The northeastern monsoon loses its fierceness here. From May to September, the monthly mean rainfall ranges between 180-570 mm., being more in June, July and August, and below 50 mm. from October to March.

3. Eastern High-temperature-and-less-frequent-rainfall District (District 3): This district is found on the plain of the southern end of the narrow Eastern Valley. With an average annual mean temperature of 24.0°C, its monthly mean temperature in January and February falls a little below 20.0°C. The annual mean rainfall is 1,798 mm., distributed more evenly than in main District 2.

The northeastern monsoon sweeps this district in winter but not so strongly as it does in District 5.

4. Eastern Subnormal-temperature-and-frequent-rainfall District (District 4): The average annual mean temperature of this district is 22.6°C, the lowest among the seven main districts. The monthly mean temperature from December to March is below 20.0°C. The average annual mean rainfall is 2,157 mm., distributed more evenly throughout the year. Deficiency in sunshine in this district affects the growth of sugarcane very much.

5. Western Coastal Monsoon District (District 5): This district stretches along the western coast, from the Ta-chia River in the north to the Tseng-wen River in the south. The average annual mean temperature rises southward, the average value of four different localities in this district being 22.9°C, similar to that of District 4. The monthly mean temperature is below 20.0°C in December to March. The average annual mean rainfall is 1,518.5 mm., the lowest among the seven main districts. The monthly mean rainfall in October to March is about or below 50 mm. Irrigation is scarce here. From October to March blows the strong northeastern monsoon at a speed of about 10 meters per second. The sunlight is veiled by the dusty atmosphere and the cane leaves either wither or are torn into stripes severely. The more remote is the place from the coast, the milder is the monsoon.

6. Middle and Southern Normal-temperature-and-normal-rainfall District (District 6): This district lies between main District 5 and the Central Mountain Range with an average annual mean temperature of 23.1°C lower than those of the high-temperature districts and higher than those of Districts 4 and 5. The average monthly mean temperature drops below 20.0°C in December to March. The average annual mean rainfall is 1,929.0 mm., less than those in the high-rainfall districts. Its monthly mean rainfall from October to February is about or below 50 mm. It is only a little affected by the monsoon.

7. Middle and Southern Normal-temperature-and-highest-rainfall District (District 7): This district is located on the slopy land or valleys amidst the mountains, east to District 6, but with a little higher average monthly mean temperature from November to May but lower from June to September. It falls below 20.0°C from December to February. The average annual mean rainfall is 2,592.5 mm., the highest among the seven main districts. From October to February the monthly mean rainfall is deficient, similar to those of District 6, but in summer months it is higher.

### Table 1.
### Monthly and Annual Mean Temperature (°C) in Taiwan Natural Sugarcane Districts

| District | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | Annual mean temperature |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| District 1 | 19.4 | 20.1 | 22.5 | 25.1 | 27.6 | 27.9 | 28.2 | 28.1 | 28.0 | 26.8 | 23.9 | 20.6 | 24.9 |
| District 2 | 18.1 | 18.7 | 21.2 | 24.6 | 27.4 | 28.2 | 28.7 | 28.4 | 27.5 | 26.2 | 23.3 | 19.8 | 24.4 |
| District 3 | 18.9 | 19.5 | 21.1 | 23.5 | 26.0 | 27.5 | 28.2 | 28.0 | 27.0 | 25.0 | 22.7 | 20.2 | 24.0 |
| District 4 | 16.9 | 17.2 | 18.9 | 21.6 | 24.6 | 26.7 | 27.8 | 27.4 | 26.3 | 23.7 | 21.2 | 18.4 | 22.6 |
| District 5 | 16.2 | 16.4 | 18.8 | 22.4 | 25.8 | 27.3 | 28.2 | 28.0 | 27.5 | 24.7 | 21.4 | 18.1 | 22.9 |
| District 6 | 16.4 | 16.8 | 19.4 | 22.7 | 25.6 | 27.6 | 28.0 | 28.0 | 27.6 | 25.2 | 22.1 | 18.3 | 23.1 |
| District 7 | 17.1 | 18.0 | 20.2 | 23.5 | 26.2 | 27.1 | 27.5 | 26.9 | 26.7 | 25.1 | 22.3 | 18.8 | 23.3 |

### Table 2.
### Monthly and Annual Mean Rainfall (mm.) in Taiwan Natural Sugarcane Districts

| District | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| District 1 | 10.8 | 27.5 | 42.5 | 65.5 | 204.3 | 479.5 | 693.5 | 577.2 | 274.5 | 63.8 | 18.7 | 17.5 | 2,475.3 |
| District 2 | 11.0 | 26.5 | 45.5 | 70.5 | 193.0 | 454.0 | 564.2 | 446.0 | 189.5 | 44.8 | 12.5 | 21.5 | 2,079.0 |
| District 3 | 31 | 41 | 60 | 72 | 144 | 357 | 220 | 278 | 304 | 171 | 78 | 42 | 1,798.0 |
| District 4 | 61.5 | 81.5 | 108.0 | 128.5 | 210.5 | 255.0 | 247.0 | 255.0 | 367.5 | 224.5 | 134.5 | 83.5 | 2,157.0 |
| District 5 | 31.8 | 50.2 | 85.3 | 96.5 | 179.7 | 348.5 | 266.0 | 290.2 | 103.0 | 26.5 | 10.8 | 30.0 | 1,518.5 |
| District 6 | 22.9 | 43.7 | 80.1 | 92.4 | 178.1 | 416.3 | 451.9 | 392.4 | 169.7 | 32.3 | 14.9 | 34.3 | 1,929.0 |
| District 7 | 23.5 | 48.5 | 85.5 | 106.0 | 248.0 | 521 | 613 | 580.5 | 265.0 | 55.0 | 13.0 | 33.5 | 2,592.5 |

## B. The Soil Districts or the Sub-districts

Within each main district there are several sub-districts, classified according to the types of soils. Each type of soil may be found in two or more main districts.

The most productive soils for sugarcane derive their origin from basic igneous rocks, as can be evidenced by the fact found in Java,[6] South Africa[1] and Hawaii.[15] The author has found that the yield of sugar per ha. per month of a shallow and stony basic lava soil at Olaa, Hawaii, is about 0.73 m.t. whereas that of the similar soil of slate origin at Nanchow, Taiwan, is only 0.46 m.t. in spite of the fact that the climatic condition of the latter is much superior. Besides, a productive soil for sugarcane must be flat, deep, heavy, neutral in reaction, irrigable, of good drainage and free from harmful substances, such as abnormally high content of soluble salt, and not rocky, etc. It is evident from the following description that the sugarcane soils in Taiwan are far from being ideal.

1. Red earth: Under the prevailing subtropical climate in Taiwan, the principal soil forming process is laterization. As the rain factor does not exceed 75, no true Laterite exists. The soils found on the Yueh-mei, Ta-tu, Pa-kua and Kan-chueh tablelands are old and have all developed into red earth. Its characteristics are red color, sourness, low $SiO_2/R_2O_3$ of its clay, low cation exchange capacity, low content of plant nutrients, low content of organic matter, stable soil aggregate and shallowness. Besides, irrigation is always void on such soils. The yield of sugarcane is always low. They are always clayey loam, but those types which have developed from sandstones are always sandy. This kind of soil is found in all of the main districts.

2. Slate alluvial soil: The slate alluvial soil of the Muddy River Plain is found in Districts 5 and 6. Its texture is generally light and reaction slightly alkaline due to calcareous origin. Near the coast it always contains soluble salts.

In District 1 there are some kinds of slate alluvial soil with analogous properties. On the alluvial fan of the Central Mountain Range the soil contains a large percentage of slate stones, each weighing a few hundred grams to several tens of kilograms. It is an important sugarcane soil in the south, though the yield of cane per unit area is low.

3. Inland mudstone-sandstone alluvial soil: South to the Muddy River Plain till the Kan-san Plain, the soils derive their origin from mudstone and sandstone, the former being clayey and the latter sandy. They are also found sporadically in many regions. Not infrequently these two soils superimpose each other in a soil profile and in many cases they are mixed together to form a medium-textured soil. Mudstone and sandstone are always calcareous on the mountain; but, when they reach the plain, leaching and growth of plant have lowered their pH to various degrees. This soil is found in Districts 2, 3 and 6.

4. Coastal mudstone-sandstone alluvial soil: This soil is found in the southern half of District 5. It is without exception calcareous and alkaline and always contains soluble salt derived from the sea, other properties being anologous to the soil as described in the last paragraph. This soil is young and its history of being cultivated short.

5. Coral limestone alluvial soil: This soil is found sporadically at the foot of several coral limestone hills in District 2. Its texture is heavy and reaction

alkaline. Small lime concretions are always found throughout the whole profile or only in subsoil.

6. Crystalline limestone and schist alluvial soil: This soil is found in District 4 and has been brought down by torrential rain from the central mountain. Its texture is always light. Its layer is shallow and always underlain by gravels. Erosion is a serious problem here.

7. Slate-schist alluvial soil: This soil, found in District 3, is generally loamy or clay-loamy in texture and slightly acidic in reaction.

8. Slate-mudstone-sandstone alluvial soil: This soil, found in the Ta-tu and Ta-chia River basin, is medium in texture and slightly acidic to alkaline in reaction.

9. Sandstone residual soil: Found in District 7, this soil derives its origin from the loose sandstone underneath. It is light in texture, yellow or light yellow in color, neutral to slightly acidic in reaction, easily eroded. Its properties resemble those of the alluvial soil of the same parent material on the plain.

## II. Organic Manure and Crop Rotation

In Taiwan, sugarcane is planted on the farms owned by the Taiwan Sugar Corporation (hereinafter abbreviated as TSC-farm) and on the farms of farmers, who conclude contract with the Taiwan Sugar Corporation and supply sugarcane to and obtain financial and technical aids as well as fertilizer loan from the latter.

We promote the practice of "harmonic fertilization" in Taiwan sugarcane agriculture. According to this practice both balanced supply of plant nutrients and improvement of soil properties have been taken as our dual goals. This is reflected in our schemes of crop rotation, in which green manure crop has always been emphasized.

In Taiwan sugarcane fields, three kinds of green manure plants are most popularly grown, namely, Sesbania sesban, Mucuna capitata and Crotalaria juncea. Sesbania sesban is grown where drainage is poor, soil heavy or saline. Mucuna capitata develops best on sandy land or dryland. Due to its rapid growth in the warmer months and its high yield, Crotalaria juncea is favored on flat and deep soil of adequate drainage.

On TSC-farms, the most popular system of crop rotation is green manure plant—autumn plant cane—first ratooned cane. Sometimes, second ratooned cane and, in rare cases, third ratooned cane is planted in succession to the first and second ratooned, respectively. In saline soil district, the scheme, i.e. Sesbania sesban

—paddy rice—paddy autumn sugarcane—first ratooned cane, is now widely being made use of. Paddy rice is inserted herein for the purpose of leaching away the soluble salt and replacing the exchangeable sodium with calcium and magnesium liberated from alkaline earth carbonate, present everywhere in the soil by the secretion of $H^+$ ion of the rice root, as proposed by the author.[14] Recently, soybean and peanut are interplanted between sugarcane rows of autumn plant cane as a result of the finding of the fact by field experiment of the author and his co-workers[14] that the yield of sugarcane is not thereby affected if adequate fertilization is amalgamated in the farm practice.

On the contracted farms, the systems of crop rotation are diversified. Sesbania sesban—paddy rice—autumn plant cane—first ratooned cane or miscellaneous crops is one among the most popular ones. Between the cane rows of autumn paddy sugarcane and autumn plant sugarcane, peanut, sweet potato, etc. are interplanted almost without exception.

These green manure plants are sown in February and March. In previous time, Crotalaria juncea was sown both on the ridges and in the ditches of the field, so as to increase the yield. Sometimes, Crotalaria juncea is sown together with the Sesbania sesban. Since the former grows better in dry climate and the latter in wet, the yield of green manure is not much affected by the fluctuation of precipitation and the harvest is more assured. Another practice, called regeneration, is always done unto Crotalaria juncea. When the hemp reaches about 3.5 ft. high 70 days after the seed is sown, the upper part of the hemp will be cut leaving the lower part about 1-1.5 ft. high with 6-7 pieces of green leaves. Several days afterwards, more new branches and leaves will come out. By doing so, the yield of the green manure could be made 5,000-10,000 kg/ha. higher. These methods are too laborious and cannot be very well done when the sugarcane field is mechanized, so all have been abandoned. The present method of land preparation for green manure plant does not involve construction of ridges and ditches, and the seed is drilled on the flat land. The yield is about 20-30 metric tons of green mass per ha. It is plowed into the soil about two weeks before the preparation of land for sugarcane.

The sugarcane farmers always hold the proverb, "luxuriant sugarcane keeps pace with heavy green manure". The field experimental result obtained at this station by Shine[8] shows the advantageous effect of green manure upon sugarcane best. The different treatments were made at the very plots for two successive crops of autumn plant cane. The third crop was a first ratooned cane, in which green manure was omitted, so that the residual effect of green manure of the two preceding crops could be measured. The result is given in Table 3.

**Table 3.**
**Sugar Yield in Kg/ha. of Different Treatments on Three Crops**
**1955/56, 1957/58 and 1958/59**

| Treatment | 1955/56 | | 1957/58 | | 1958/59 | |
|---|---|---|---|---|---|---|
| | Sugar yield | Index | Sugar yield | Index | Sugar yield | Index |
| 20 m.t. green manure+100 kg. N as $(NH_4)_2SO_4$ | 21,254 | 111.5** | 18,232 | 122.3** | 18,945 | 116.2** |
| 30 m.t. green manure+100 kg. N as $(NH_4)_2SO_4$ | 22,106 | 116.0** | 18,877 | 126.7** | 19,492 | 119.6** |
| 40 m.t. green manure+100 kg. N as $(NH_4)_2SO_4$ | 22,005 | 115.5** | 18,823 | 126.3** | 20,277 | 124.4** |
| 100 kg. N as $(NH_4)_2SO_4$ | 19,057 | 100.0 | 14,903 | 100.0 | 16,301 | 100.0 |
| 125 kg. N as $(NH_4)_2SO_4$ | 20,668 | 108.5* | 16,796 | 112.7** | 18,949 | 116.2** |
| 150 kg. N as $(NH_4)_2SO_4$ | 21,713 | 113.9** | 17,292 | 116.0** | 19,817 | 121.6** |
| 175 kg. N as $(NH_4)_2SO_4$ | 21,976 | 115.3** | 17,432 | 117.0** | 20,614 | 126.5** |
| 200 kg. N as $(NH_4)_2SO_4$ | 22,974 | 120.6** | 17,747 | 119.1** | 20,929 | 128.4** |
| Least significant difference | | | | | | |
| 5% | 1,512 | 7.9 | 1,627 | 10.9 | 1,537 | 9.4 |
| 1% | 2,040 | 10.7 | 2,195 | 14.7 | 2,074 | 12.7 |

*Significant at 5% level.
**Significant at 1% level.

From Table 3, it can be seen that cane yields were increased by either the application of green manure or chemical nitrogen in all of the three crop years. Especially in crop year 1957/58, higher response was obtained by green manure application than by chemical nitrogen, e.g. the sugar yield of green manure plot was 3-7% higher than that of the chemical nitrogen. The application of green manure between 20 to 40 tons per ha. saved 38.85 to 62.78 kg. of chemical nitrogen per ha. in 1955/56, and 60.89 to 85.62 kg. per ha. in 1957/58. The latter was 36.5-56.7% higher than the former, the average being 41.4%. In 1958/59, however, the residual effect of green manure applied in the previous two crop years was equivalent to 33.40-60.07 kg. of chemical nitrogen per ha. As a matter of fact, the yield-promoting effect of green manure should not be ascribed to its nitrogen content alone. The chemical and physical properties of the soil might have been improved too.

Aside from green manure, our sugarcane farmers are fond of farmyard manure. The enormous yield of 25-40 tons of sugar per ha. (the average of Taiwan is about 10 tons per ha.) of contest field is claimed to be largely indebted to the application of hogs' manure. With this in view, Taiwan Sugar Corporation has started a plan to raise several thousand hogs on its farms, the largest scale of its kind ever seen in the world's agriculture.

Bagasse and cane trash are incorporated with filtered cake, spent wash of the alcohol distilleries, etc. and piled up to induce biological action and then applied to the field. But in many places these materials are incorporated together and applied to the field as such, giving no inferior effect upon cane growth and, but saving much labor and time.

After sugarcane has been harvested, the trash is left in the field. It is incorporated into the soil during land preparation for green manure plant or during the earth-in process in the ratooned field, so as to enrich the soil with organic matter.

In previous years, molasses was applied as such into the soil. It showed excellent effect on sandstone soil and red earth, not only due to its potash content bus also to some unknown factor.

## III. Chemical Fertilizers

### A. Basic Grades of NPKCa Requirement of the Different Natural Sugarcane Districts in Taiwan

The amount of plant nutrients extracted by one crop of sugarcane is noteworthy. It varies, however, according to the yield, the climate, the soil, the dose and kind of fertilizer and manure applied, the variety of sugarcane, and so forth. Field experiments carried out at this station years ago gave, for example, the following amounts per ha. for POJ 2725 grown for about eighteen months, the yield of stalks being 144,026 kg., that of green leaves 9,150 kg., and that of dead leaves 6,326 kg. Other examples may be found in the treatise "Botany of Sugarcane" written by Dillewijn.[5]

**Table 4.**

**Nutrients Extracted by One Crop of Sugarcane (kg/ha.)**

| Treatments | Whole plant | Stalk | Green leaves | Dead leaves |
|---|---|---|---|---|
| N | 126.4 | 64.0 | 32.8 | 29.8 |
| $P_2O_5$ | 78.0 | 57.0 | 11.4 | 9.6 |
| $K_2O$ | 245.2 | 152.6 | 65.6 | 27.0 |
| CaO | 181.0 | 75.6 | 30.8 | 74.6 |
| MgO | 138.8 | 71.2 | 17.0 | 50.6 |
| $SiO_2$ | 664.0 | 161.2 | 145.2 | 357.6 |

Accordingly, sugarcane requires a lot of fertilizer and, in addition, fertilizer cost constitutes a substantial fraction of the total production cost of sugarcane, for example, about 40% for autumn plant cane and 50% for ratooned cane on this island. Therefore, fertilizer dosage is one of the most important items, which need careful investigation in sugarcane agriculture.

The effect of fertilizer is governed not only by any single factor, but by a combination of natural, artificial as well as other known or unknown factors. Such a combination varies with place and time. In order to reveal the effect of fertilizer in a given combination of factors, the most reliable method is to conduct long-term field experiment with the very combination. By doing so the resultant influence of the different known and unknown factors can be measured, and the requirement of fertilizer can be determined reliably. The fertilizer dosage of sugarcane on this island is mainly decided by field experimental results.

The magnitude of profit induced by the application of fertilizer has been taken as the measure for adopting fertilizer dosage. Many investigators use percentage of yield increase caused by the application of fertilizer as a measure of the magnitude of profit of the fertilizer applied. The defect of this method may be illustrated in this way. The sugar yield per ha. of two pieces of sugarcane field without application of N are 10 and 6 tons, respectively. The application of 150 kg. of nitrogen per ha. raises the sugar yield of both fields 50% higher, whereas the increase of sugar yield or the profit induced by the application of 150 kg. of nitrogen are substantially different between the two fields. Consequently, the author employs the "production increment" as a measure of the magnitude of the profit of fertilizer application. By production increment it is meant the number of kg. of sugar yield increased by the application of one kg. of plant nutrient. For example, the sugar yield of one plot applied with 150 kg. of N/ha. is 700 kg/ha. more than that of another plot which has not received any N. The production increment of N, in this case, expressed as "150-0", is 6 kg. of sugar per kg. of N. For another example, the sugar yield of one plot, having received 150 kg. of N is 600 kg/ha. more than that of another plot having received 75 kg. of N/ha. The production increment of N, in this case, expressed as "150-75", is 8 kg. of sugar per kg. of N. Of course, the kind of fertilizer must be specified here, since it affects the production increment. Beside production increment, the current prices of both sugar and fertilizer must be taken into consideration in adopting fertilizer dosage. More than one thousand of field experiments have been installed at different strategic points in the different natural sugarcane districts in Taiwan toward this end. A specimen of the field experimental results is shown in Table 5.

In Taiwan, the response of sugarcane to the application of N is exhibited in all of the natural sugarcane districts. It is therefore, logical to regard N as the most

## Table 5.

## Yield Increment from Each Additional Unit Application of NPK Fertilizers for Autumn Planted Sugarcane in Taiwan

| Fertilizer applied (kg/ha) | | Lateritic soils | | Slate alluvial soils | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Red earth | | Mei River area | Peidou River area | | Huwei River area | | Hsia-Dann-Shui River area | | Tungkang River area | |
| | | Ave. of 32 crop years (kg/kg) | Significant expt. (%) | Ave. of 2 crop years (kg/kg) | Ave. of 16 crop years (kg/kg) | Significant expt. (%) | Ave. of 15 crop years (kg/kg) | Significant expt. (%) | Ave. of 9 crop years (kg/kg) | Significant expt. (%) | Ave. of 51 crop years (kg/kg) | Significant expt. (%) |
| N | 75— 0 | 12.56 | 50 | 13.88 | 9.26 | 33 | 20.77 | 55 | 36.91 | 83 | 32.28 | 92 |
| | 150— 75 | 8.22 | 48 | — | 7.62 | 50 | 2.99 | 27 | 31.42 | 100 | 21.34 | 83 |
| | 150— 0 | 8.70 | 61 | 16.70 | 6.68 | 33 | 11.93 | 45 | 34.35 | 100 | 27.84 | 86 |
| | 225—150 | 6.21 | 31 | 10.13 | 1.80 | 33 | 1.80 | 15 | 8.36 | 50 | 6.91 | 57 |
| $P_2O_5$ | 75— 0 | 3.64 | 31 | — | 2.33 | 13 | — | — | 16.22 | 50 | 4.61 | 36 |
| | 150— 75 | 3.88 | 36 | — | 1.31 | 8 | — | — | 4.08 | 17 | 1.77 | 25 |
| | 150— 0 | 3.12 | 45 | — | — | — | — | — | 8.26 | 50 | 1.03 | 14 |
| $K_2O$ | 75— 0 | 21.53 | 77 | 54.18 | 12.72 | 75 | 3.04 | 25 | 3.92 | 22 | 9.39 | 43 |
| | 150— 75 | 9.27 | 49 | — | 4.25 | 33 | 0.73 | 10 | 9.90 | 13 | 3.07 | 25 |
| | 150— 0 | 14.10 | 81 | 31.76 | 9.41 | 83 | 0.53 | 10 | 2.93 | 25 | 4.93 | 43 |

(continued on next row)

| Fertilizer applied (kg/ha) | | Inland sandstone alluvial soils | | | | Coastal mudstone-sandstone alluvial soils | | Coral limestone alluvial soils | | Crystalline limestone-schist alluvial soils | | Slate-schist alluvial soils | Sandstone residual soils |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Heavier types | | Lighter types | | | | | | | | | |
| | | Ave. of 30 crop years (kg/kg) | Significant expt. (%) | Ave. of 17 crop years (kg/kg) | Significant expt. (%) | Ave. of 14 crop years (kg/kg) | Significant experiment (%) | Ave. of 14 crop years (kg/kg) | Significant experiment (%) | Ave. of 6 crop years (kg/kg) | Significant experiment (%) | Ave. of 6 crop years (kg/kg) | Ave. of 7 crop years (kg/kg) |
| N | 75— 0 | 22.11 | 58 | 27.11 | 66 | 7.57 | 31 | 42.80 | 100 | 10.05 | 0 | 33.38 | 21.06 |
| | 150— 75 | 16.5 | 89 | 7.51 | 42 | 8.93 | 46 | 21.01 | 91 | 10.55 | 50 | 29.83 | 13.67 |
| | 150— 0 | 21.48 | 84 | 14.52 | 59 | 12.07 | 46 | 30.10 | 100 | 11.45 | 50 | 5.92 | 21.57 |
| | 225—150 | 3.42 | 27 | 3.83 | 42 | 2.48 | 13 | 5.44 | 43 | 2.08 | 0 | — | 12.04 |
| $P_2O_5$ | 75— 0 | 0.20 | 0.3 | 2.84 | 18 | 1.60 | 13 | 10.48 | 36 | 2.08 | 17 | 11.95 | 3.24 |
| | 150— 75 | — | — | — | — | 0.86 | 8 | 0.37 | 9 | — | — | 3.50 | 4.23 |
| | 150— 0 | 0.70 | 1 | 0.97 | 18 | 1.64 | 23 | 3.74 | 55 | — | — | — | 3.01 |
| $K_2O$ | 75— 0 | 6.76 | 34 | 3.51 | 23 | — | — | 9.57 | 35 | 5.23 | 33 | 27.83 | 4.95 |
| | 150— 75 | 3.87 | 15 | — | — | 0.75 | 8 | 2.44 | 36 | — | — | 9.10 | 1.76 |
| | 150— 0 | 7.37 | 60 | 3.43 | 36 | 0.41 | 8 | 6.86 | 55 | 4.12 | 33 | — | 5.68 |

important fertilizer in Taiwan sugarcane fields. From the nutrient uptake curve, shown in Fig. 2, it is known that most nitrogen is absorbed in winter and spring. Table 1 shows that the temperatures of all of the natural sugarcane districts are about the same in summer and autumn, but differ much from one another in winter and spring, which, as anticipated, would exert a profound influence upon the nitrogen uptake or the effect of nitrogen fertilizer. This anticipation coincides with the fact. In District 1, where the winter temperature is far above the physiological zero point of sugarcane, i.e. 15.50°C, the sugarcane grows almost without retardation throughout the cool season. In Table 5, the production increments as well as the percentages of significant experiments are prominently high at Tungkang and Hsia-dann-shui. The production increments of 225-150 are still as high as 8.36 and 6.94 respectively. The production increments of N of coral limestone soil and slate-schist soil of Districts 2 and 3 are about as high as those of District 1. On coastal mudstone-sandstone soils and Peidou slate soil of District 5, where the winter and early spring temperature is low and the growth of sugarcane is retarded for 4-5 months, the effect of N is particularly low. On the limestone-schist soil of District 4, the winter and early spring temperature is low and it is rainy throughout the year, and, as a result, the sunshine is scarce, the effect of N is not great too. Those districts, whose winter temperature lies between these two extremes, have their production increments of N between the two extremes. Exceptions are the experiments conducted on red earth and sandstone residual soil, which do not lie in Districts 2 and 3, but at high elevation in Districts 5, 6 and 7. Here, perhaps, other factor, e.g. soil, overweighs temperature in importance.

In Taiwan sugarcane fields, the effect of potash surpasses that of phosphate. On red earth and Peidou slate soil, the response of sugarcane to potash application is even greater than that to nitrogen application. The more intensively the soil has been leached, the more potash is needed. The red earth is of early Quaternary formation and is the oldest soil among the Taiwan sugarcane fields. It is beyond doubt that it needs potash most. The Peidou slate soil and coral limestone soil are also deficient in potash. Both soils are calcareous and low in exchangeable and non-exchangeable potash. Other soils do not exhibit potash deficiency so much as Peidou does. This is perhaps due to the different composition of the slate. Mudstone soil is rich in colloidal matter hence large in cation exchange capacity. The less degree of potassium saturation makes the plant unable to absorb it freely. As a result, many mudstone soils show high potash content upon chemical analysis but exhibit good response to potash application. The soils along the sea coast are always young and have not been leached much and still retain much potash bestowed from the sea. They do not show any response to potash. The requirement of potash of other soils lies between these two extremes.

In all sugarcane producing countries of the world, the response of sugarcane to phosphate application is never very attractive, except in Vietnam and Thailand, so far as the author knows. The same is true with Taiwan, where the greatest response to phosphate has been detected on red earth, Hsia-dann-shui slate soil and coral limestone soil, the respective sugar production increments for the 150-0 treatment being only 3.12, 8.26 and 3.74, which are quite low as compared with those of nitrogen and potash (see Table 5). On red earth it has been observed that the more phosphate is applied, the greater is the sugar production increment; in other words, the law of diminishing returns does not hold true here. This may be explained by the high $PO_4$-fixing power of red earth, which must be saturated to a certain extent before an appreciable amount of phosphate applied can be utilized by the sugarcane. Other soils are only weakly responsive to phosphate.

The sugarcane of the different treatments in the experiments has been analyzed for its sugar content. It is found that N lowers the sugar content and $K_2O$ raises it, while phosphate does not exert any influence in this respect.

The zonal soils in Taiwan are red earth and yellow earth, which are mostly found on high elevations and have become acidic due to long exposure to the subtropical climate. As stated above, the red earth is an important sugarcane soil, while the latter not. The properties of the young alluvial soils are dominated by their respective parent materials. The old slate as well as mudstone alluvial soils are sometimes acidic. On account of its low buffer capacity the pH of the sandstone alluvial soil, which is widely found in southern Taiwan, drops down most rapidly.[9]

Long-term field experiments have been installed on several red earths and old leached sandstone alluvial soils to investigate the effect and economy of liming.[13] The lime requirement was found by means of Jensen's and Comber's methods and the liming material used was burnt lime. It is found that the yield of the leguminous green manure plant was boosted up very much higher—sometimes one-fold—than the check, and the yield of sugarcane boosted up about 20% higher. The effect remains remarkable in the fourth crop of sugarcane.

Now this practice has been spread to every piece of acidic soil of the TSC-farms. The farmers who objected to use it one decade ago have begun to accept it too.

As mentioned above, the response of sugarcane to fertilizer application is governed by so many factors, such as climate, soil, length of vegetation period, method of planting, varieties of sugarcane, irrigation and drainage conditions, kinds of fertilizer, method of fertilizer application, method of land preparation, field management, the simultaneous application of organic manure, and other known factors. Besides, there are many unknown factors, which might play more important roles than the known factors do. Therefore, in the field experiments installed in the different natural sugarcane districts, the following items are fixed: 1) For acidic soils, calcium cyanamide, nitrochalk, ammonium sulfate, for neutral and alkaline soils, ammonium sulfate and nitrochalk are used as the N-fertilizers, while calcium superphosphate and potassium chloride are used as the P- and K-fertilizers. 2) Only autumn plant cane is tested. 3) The sugarcane varieties adopted are predominantly F108, POJ 2883, F 134 and NCO 310, which do not differ very much in response to fertilizer. 4) No organic manure is applied. 5) Other cultural practices are done according to those ordinarily done on the very farm, where the experiment is conducted.

The adoption of fertilizer dosage is made according to the production increment obtained in the long-term field experiment and the current prices of fertilizer and sugar, so that the economical use of fertilizer may be justified. These dosages are called the "basic grades of NPKCa-requirement" of the different natural sugarcane districts, the general scheme of which may be seen in Table 6. If the sugarcane variety or any other item in the practice were changed to others than those used in the experiment, another design of experiment should be installed to find out whether and how big an addition or a substration should be made to the basic grade, so that harmonic fertilization may be well kept. For example, if 30 m.t. per hectare of C. juncea is plowed under, a reduction of 40 kg. of chemical N, as found by the experiment, should be made, while the dosages of phosphate and potash are kept unchanged, since they are extracted from the soil and reduced dosage would mean too much depletion.

In Table 6, V means 300 kg. per ha., IV 225 kg., III 150 kg., II 75 kg. and I nil for the N, $P_2O_5$ and $K_2O$ requirement. For the lime, IV means absolute necessity, unless it has been limed before, III most likely necessity, II doubtful necessity and I no necessity. The lime requirement, however, must be determined by means of chemical method.

The chemical analysis of soil for the so-called available phosphate and potash has been extensively investigated and some correlation has been obtained between the analytical figures and the crop response. But for sugarcane agriculture

## Table 6.

## Basic Grades of NPKCa Requirement of the Different Natural Sugarcane Districts in Taiwan

| Main districts | Sub-districts | N | $P_2O_5$ | $K_2O$ | CaO |
|---|---|---|---|---|---|
| District 1 | (1) Slate alluvial soils | | | | |
| | a. Hsia-dann-shui slate soil | V− | III | III | I |
| | b. Tung-kang slate soil | V− | II | III | II |
| | c. Slate soil at foot of Central Mt. Range | IV | II | III | II |
| | (2 Red earth | V− | III+ | V− | IV |
| | (3) Sandstone residual soils | | | | |
| | a. Flat type | V− | III | III | III |
| | b. Sloping type | IV | II | II | III |
| District 2 | (1) Inland mudstone-sandstone alluvial soils | | | | |
| | a. Heavier type | V− | II | III+ | II |
| | b. Lighter type | V− | II | III | III |
| | (2) Coral limestone alluvial soils | | | | |
| | a. Chiaotou district | V− | III | III | I |
| | b. Hsiao-kang district | V− | II | II | I |
| District 3 | (1) Slate-schist alluvial soils | IV+ | II | II | II |
| | (2) Lateritic soils | IV+ | II | V− | IV |
| | (3) Mudstone residual soil | IV+ | II− | II | II |
| District 4 | (1) Crystalline limestone and schist alluvial soils | III+ | II | III | I |
| District 5 | (1) Red earth | IV+ | III+ | V− | IV |
| | (2) Slate alluvial soils | | | | |
| | a. Peidou slate soil | III+ | I+ | IV | I |
| | i) Slate soil | III | I | I | I |
| | ii) Slate soil newly reclaimed | III+ | I | II | I |
| | b. Huwei slate soil | III+ | I+ | II+ | I |
| | i) Slate soil | III | I | I | I |
| | ii) Slate soil newly reclaimed | III+ | I | II | I |
| | (3) Coastal mudstone-sandstone alluvial soils | III+ | II+ | II− | I |
| | a. Slate soil | III | I | I | I |
| | b. Slate soil newly reclaimed | III | I | I | I |
| | (4) Slate-mudstone-sandstone alluvial soils | III+ | II | III | I |
| | a. Slate soil | III | I | I | I |
| | b. Slate soil newly reclaimed | III+ | I | II | I |
| District 6 | (1) Slate alluvial soils | | | | |
| | a. Peidou slate soil | IV | II | IV | I |
| | b. Huwei slate soil | IV | II | II | II |
| | (2) Inland mudstone-sandstone alluvial soils | | | | |
| | a. Heavier type | IV | II− | III+ | II |
| | b. Lighter type | IV | II | III | III |
| | (3) Slate-mudstone-sandstone alluvial soils | IV | II | III | II |
| | (4) Red earth | IV+ | III | V− | IV |
| District 7 | (1) Sandstone residual soil | | | | |
| | a. Flat type | V− | III | III | II |
| | b. Sloping type | IV | II | II | II |
| | (2) Red earth | IV+ | III+ | V− | IV |

this method is far from being satisfactory.

The leaf diagnosis method for determining fertilizer requirement has also been investigated for many years. This method is refuted by the fact that the nutrient content of plant tissue is not only governed by the nutrient content of the soil, no matter it is total or "available", but also by climate, soil moisture and many other known and unknown factors, which might be more important than the former. As a result, the nutrient content of any tissue of sugarcane undergoes change throughout the whole vegetation period. It also changes with the ratio of the amounts of different nutrients present in the soil. These phenomena cause the difference in nutrient content of any tissue of sugarcane of the same crop year in the same field. For the same fertilizer treatment on the same soil the nutrient content of any tissue of sugarcane is also subject to the change of crop years. The limiting value found from the nutrient content of leaves or sheaths and results of field experiments change from year to year, soil to soil, sugarcane variety to sugarcane variety, etc. Moreover, the application of nitrogen affects the potash content of the leaves and sheaths and vice versa. As a result, the analytical data on the plant tissue does not deserve to serve as reliable instruction for the fertilization plan.

### B. Mode of Fertilizer Application

Calcium cyanamide, ammonium sulphate, nitrochalk, urea, nitrogen solution, superphosphate, fused phosphate, potassium chloride, diammonium phosphate, nitrophos are the major chemical fertilizers used in recent years. For autumn plant cane the nitrogen fertilizer is drilled into the planting ditches or alongside the cane rows once as basic fertilizer and twice as side dressings, the first about 2-3 months after planting, the second in February or March of the following year. Though many experimental results have proved that one dressing at the early growing period of the cane produces the same effect as split dressings do, yet we always practise split dressings as to beware of the danger of leaching off of the fertilizer by accidental torrential rains. For the same reasons, the potash fertilizer is applied once as basic and once as side dressing. The phosphate, however, is always used once for all as basic fertilizer, since no appreciable loss of phosphate is anticipated even in the event of torrential rain.

On the TSC-farms the fertilizer application is undertaken by tractors. On the contracted farms, a ditch is dug by an ox-plow, and then the fertilizer is dropped in by hand, and subsequently the ditch is covered by the plow again.

The liming materials used are predominantly burnt lime and filtered cake of the carbonation process. To lime both the subsoil and the surface soil is recommended. If the source of lime is limited, the subsoil should be limited first so as to bring out the greatest effect. In this case the lime is incorporated with the soil in the planting ditches, at least two weeks before the seed cuttings are sown. At that interval the soil must be kept adequately wet, so that the lime could be neutralized and not do any harm to the cane cuttings. Alternately, it may be applied, in case of necessity, into the ditches of the field, after the last earth-in is done. The surface soil is limed by broadcasting the lime material on the surface of the soil and then incorporating into it, before the land is prepared for green manure plant or sugarcane.

## IV. Liquid Fertilizers

### A. Liquid Nitrogenous Fertilizer

The field experiments on aqua ammonia were begun in 1949 with the purposes of comparing its effect with that of solid fertilizers and of determining its right placement in soils of different texture. They had been carried on in the successive years and the results showed no significant difference between the effect of aqua ammonia and solid fertilizer and that in the sandy soil and the clayey loam placement of aqua ammonia at 10 cm. below the soil surface exhibited significantly inferior results to that at 20 cm., on account of the escape of free ammonia. Aqua ammonia should be used 3-4 times in sandy soil and sandy loam soil and twice in loamy soil. Many regional tests conducted in the later years showed no significant difference between the yield in plots with aqua ammonia on the one hand and that with solid nitrogenous fertilizer plots on the other. Nitrogen solution No. 4, i.e. ammonium-nitrate-ammonia solution, containing 11.65% $NH_4$-N, 11.65% $NO_3$-N, 13.70% free $NH_3$-N and thus a total of 37% N, began to come into field experiments in 1952 and anhydrous ammonia in 1953.[12] Each form is satisfactory when properly used. The fact that these materials are all liquid makes it easy for them to be applied at the desired depth and time.

On TSC-farms liquid nitrogenous fertilizer is applied exclusively by tractors. The fertilizer tank with necessary fittings such as pressure gauge, safety valve, etc. is mounted in the front of the tractor. The fertilizer flows through a rubber tubing and a plastic hose pump connected to the power-take-off of the tractor into the ditches dug by spring teeth or similar implements, and subsequently covered by discs or the like attached to the very tractor. One tractor is able to work 4 ha. per day.

On farms where no tractor is available, another type of implement, called an ammonia-plow, designed by Takasaka, driven by an ox or a water buffalo may be used to apply liquid fertilizer. The fertilizer tank may be carried either on the farmer's back or on the buffalo's back. The fertilizer flows through a rubber tubing fastened to the rear part of the plow, thence through a flowmeter it flows into the ditch dug by the knives and consequently covered by the two mouldboards of the plow. Each plow can work 1.5 ha. per day.

Now, ammonium-nitrate-ammonia solution has been extended on TSC-farms. It is passed from the Kaohsiung Ammonium Sulphate Factory through an aluminum pipeline system, 1,600 m. in length and 10.3 cm. in diameter, to Li-tze-Ney, the southernmost depot of the Taiwan Sugar Corporation's railroad, where it is fed into four 150 m.t. storage tanks. In time of necessity the fertilizer solution is run by gravity into tank cars, each holding 12 m.t. driven by locomotive to different farms and again pumped into 15-40 m.t. field storage tanks. Finally, it is transported by small transport tank cars to the field, where it is fed into tractor tanks for direct application.

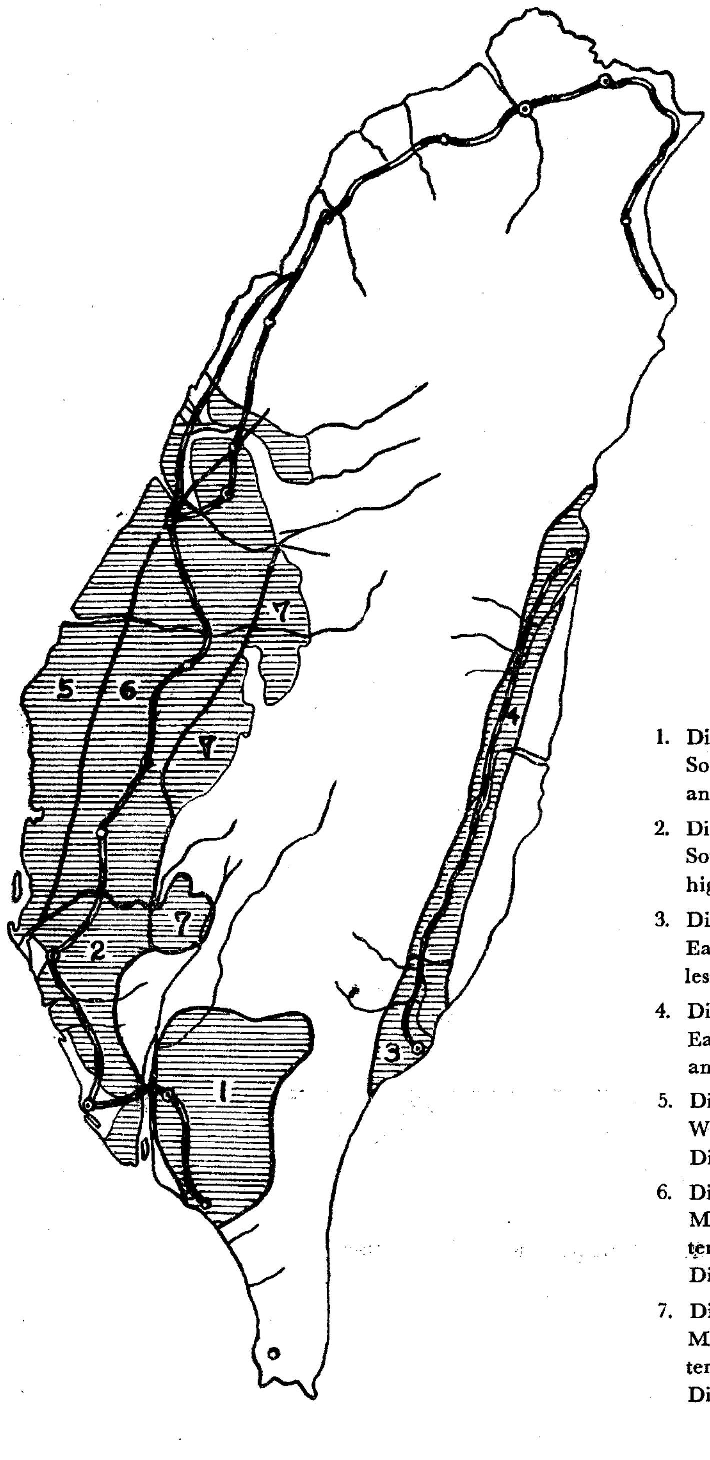
### B. Ammoniated Spent Wash Concentrate

Spent wash is the residual liquid disposed during alcohol distillation. With 8-12 Bx it contains 0.11-0.28% N, 0.05-0.14% $P_2O_5$ and 0.3-0.9% $K_2O$, the fluctuation of the latter depends upon the amount of potash in the soils, which impart the spent wash with the said nutrient through cane and molasses. To dispose spent wash into the river is always objected by the people who use the river water for drinking or industrial purpose. To use it for irrigation is always limited by the condition that there is not always in the vicinity of the alcohol plant sufficient area of field which could receive all of it and the soil there might not need that much nutrient carried with it. As spent wash contains a lot of salts, too heavy application of it always induces salt damage to the plant. To transport it to greater distance through ditches or by means of cars is uneconomical. In view of these difficulties, the exhaust steam of the sugar mill is passed into the evaporators containing spent wash and led the resultant vapor into the third evaporator of the cane juice. For each metric ton of spent wash concentrate (Bx 60) made, about 170 kg. of bagasse are required for fuel. This product is cheap and concentrated enough to be transported through long distance for being applied as fertilizer. This practice has been made in several sugar mills in Taiwan.

In view of the N and K requirement of Taiwan sugarcane soils, the N content of the spent wash concentrate is far too low as compared with the K. Therefore, the author[12] has derived the practice of passing ammonia into it, and, by so doing, its nitrogen content could be raised to any desirable level, the highest obtained being 24%. Thus the nutrient content of the fertilizer has become so high that transportation cost is reduced to the minimum. The application of it does not require supplementary addition of solid fertilizers in case where the soil does not require phosphate. This product is called ammoniated spent wash concentrate. Field experiments showed that it increased the yield of sugar 6-7% higher than chemical fertilizer, containing the same amount of plant nutrients, on several kinds of soils. Whether its superior effect was due to the minor elements or the organic matter or other ingredients contained therein remains to be investigated.

Fig. 1.

Map of Climatic Districts
of Taiwan Sugarcane Belt



**Legend**

1. District 1—
   Southern Highest-temperature-and-highest-rainfall District.
2. District 2—
   Southern High-temperature-and-high-rainfall District.
3. District 3—
   Eastern High-temperature-and-less-frequent-rainfall District.
4. District 4—
   Eastern Subnormal-temperature-and-frequent-rainfall District.
5. District 5—
   Western Coastal Monsoon District.
6. District 6—
   Middle and Southern Normal-temperature-and-normal-rainfall District.
7. District 7—
   Middle and Southern Normal-temperature-and-highest-rainfall District.

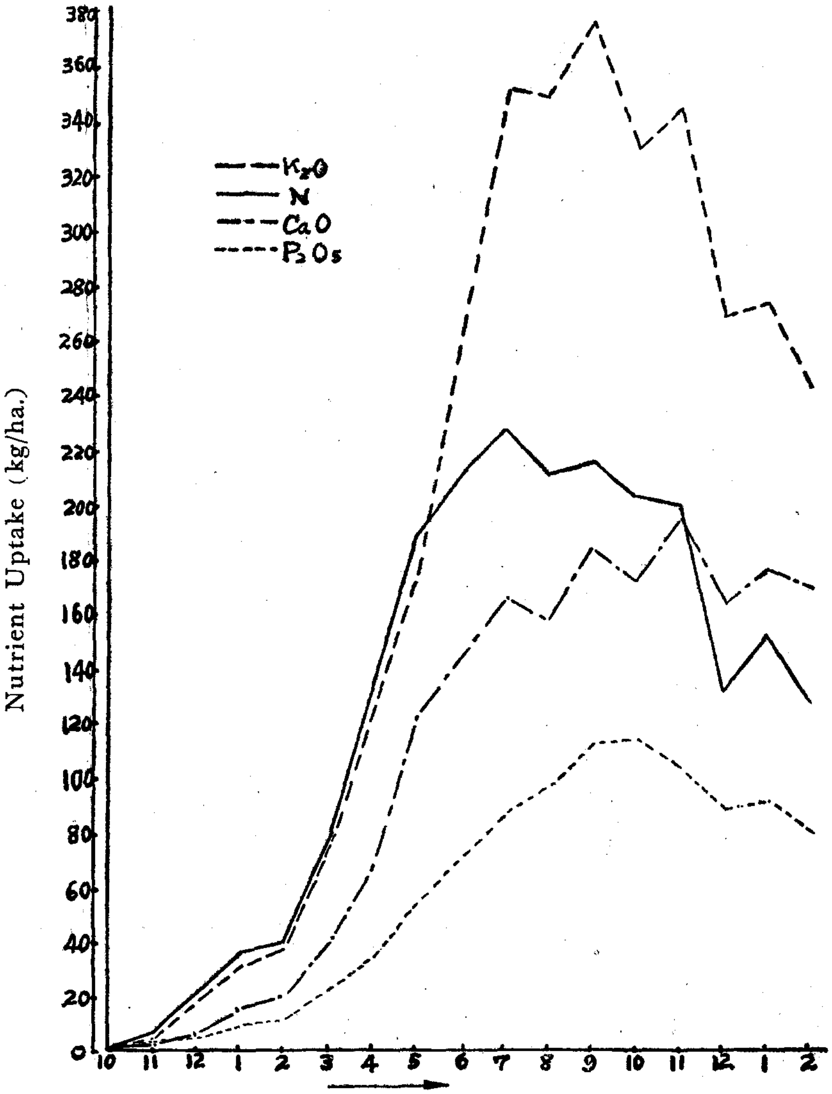


Fig. 2. Nutrients Uptake of Sugarcane, POJ 2725

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# RESPONSE OF JUTE TO FERTILIZERS

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According to 1959 statistics, the acreage of jute in Taiwan is 17,816 hectares, and the annual production of retted jute is 24,099 metric tons. Therefore, the average yield of retted jute per hectare is 1,352 kilograms. Chiayi, Tainan and Yunlin are the three major jute-producing areas.

Nutritional and fertilizer studies on jute were carried out in the past years with relatively more work done on fertilizer experiments. Out of the three major plant nutrient elements, potassium has attracted more interest. It is probably due to the facts that jute rarely responds to phosphorus and that the strikingly good effect of nitrogen on jute growth is already well known.

## I. Absorption of Three Elements by Jute

The amounts of three elements absorbed by jute have been studied in several experiments. Table 1 shows the data from two most recent ones which may represent the picture of absorption (2, 3). Samples for analysis were collected from the plot which received the best rate of fertilizers as revealed by its highest yield among all plots under experiment.

The percentage of three elements in the tissue of jute as shown in the two sets of samples is in agreement to each other. Potassium is the highest, nitrogen the next, and phosphorus the least. The nitrogen content in tissue in the experiment conducted at Changhua is appreciably lower than that of the experiment conducted at Taichung. This is most possibly due to the lower rate of nitrogen used in the Changhua experiment. This point can be further clarified in Table 2.

In another experiment conducted also at Taichung, the rates of nitrogen and

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* Affiliated into the Taiwan Provincial Chung Hsin University upon its founding in July 1961.

potassium varied with the fixed rate of phosphorus. The yield of jute fiber and the percentage of nutrients in the tissue are presented in Table 2 (3).

## Table 1.

## Percentage of Nutrients in Tissue and Total Amounts Absorbed

| Experiment location | Rate of fertilizers ($N-P_2O_5-K_2O$) (kg/ha) | Yield of retted jute (kg/ha) | Element | Percentage of nutrients in tissue (%) | | | Total amount of elements absorbed (kg/ha) |
|---|---|---|---|---|---|---|---|
| | | | | Crude jute | Peeled stock | Stock | |
| Taichung | 120-60-240 | 5,622 | N | 0.506 | 0.582 | 0.558 | 151.50 |
| | | | $P_2O_5$ | 0.326 | 0.166 | 0.217 | 57.73 |
| | | | $K_2O$ | 1.360 | 1.058 | 1.154 | 310.64 |
| Changhua | 60-60-150[1] | 3,544 | N | 0.254 | 0.376 | 0.338 | 62.55 |
| | | | $P_2O_5$ | 0.364 | 0.214 | 0.261 | 48.37 |
| | | | $K_2O$ | 1.456 | 0.904 | 1.077 | 199.11 |

[1] 10,000 kg/ha of compost were applied in addition to the chemical fertilizers.

## Table 2.

## Yield and Percentage of N and $K_2O$ in Tissue as Influenced by Fertilizer Rate

| Rate of fertilizer (kg/ha) | | | Yield of fine fiber | | N in tissue (%) | | $K_2O$ in tissue (%) | |
|---|---|---|---|---|---|---|---|---|
| $P_2O_5$ | N | $K_2O$ | kg/ha | Index | Crude jute | Peeled stock | Crude jute | Peeled stock |
| 60 | 60 | 0 | 2,705 | 100 | 0.164 | 0.235 | 0.766 | 0.557 |
| | | 60 | 3,063 | 113 | 0.173 | 0.252 | 1.193 | 0.802 |
| | | 120 | 3,832 | 141 | 0.149 | 0.154 | 1.460 | 0.836 |
| | | 180 | 3,665 | 135 | 0.132 | 0.167 | 1.552 | 1.148 |
| | | 240 | 4,227 | 150 | 0.134 | 0.138 | 1.702 | 1.154 |
| | 120 | 0 | 3,832 | 100 | 0.452 | 0.460 | 1.042 | 0.772 |
| | | 60 | 4,380 | 114 | 0.246 | 0.383 | 1.103 | 0.778 |
| | | 120 | 4,588 | 119 | 0.531 | 0.512 | 1.205 | 0.907 |
| | | 180 | 5,334 | 139 | 0.553 | 0.663 | 1.334 | 0.930 |
| | | 240 | 5,662 | 146 | 0.506 | 0.582 | 1.360 | 1.058 |

## II. Excellent Effect of Potassium on Jute

Potassium has many favorable effects in particular on jute. The following are some of the most apparent advantages as observed from a number of field experiments and demonstrations:

A. Deficiency of potassium represses the vigor of growth, postpones the growing period, hastens flowering, and consequently decreases the yield. In an experiment conducted at Tienwei, the potassium treated plot blossomed about one week earlier than the non-treated plot (2).

B. With sufficient rate of potassium, the height of jute stock can be appreciably increased. For example, the stock of the potassium treated field is, in average, about 10 cm higher than that of the non-treated one as revealed from the average of 20 demonstration fields conducted in 1958 and 1959 (1) (Table 3).

C. Potassium may increase the weight of unit length (cm) of jute stock. According to the data (4) from 10 demonstrations, the index of the weight of unit length at $K_2O$ rates of 0, 40, 80 and 120 kg/ha are 100, 104, 106 and 107, respectively (Table 3).

D. Potassium may increase the percentage of retted jute. This may be illustrated by the results of 49 demonstrations conducted in 5 years by the Tainan Fiber Crops Experiment Station (4) (Table 3).

**Table 3.**

**Height, Weight of Unit Length of Stock and Percentage of Retted Jute as Influenced by $K_2O$ Rate**

| Rate of $K_2O$ (kg/ha) | Height of jute stock (20 demonstrations) | | Weight of unit length (cm) of scratched jute (10 demonstrations) | | Percentage of retted jute (49 demonstrations) | |
|---|---|---|---|---|---|---|
| | cm | Index | kg/ha[1] | Index | % | Index |
| 0 | 340.9 | 100 | 75.36 | 100 | 10.42 | 100 |
| 40 | 343.0 | 100.62 | 78.65 | 104.36 | 10.65 | 102.21 |
| 80 | 347.2 | 101.85 | 79.75 | 105.83 | 10.83 | 103.93 |
| 120 | 351.4 | 103.08 | 80.32 | 106.58 | 10.95 | 105.09 |

$\frac{\text{Average weight per plant (kg)}}{\text{Average length per plant (cm)}}$ × Number of plants per hectare.

E. Potassium may increase the resistance of jute to insects and diseases. This may be well expressed by the experimental data of 1949 (5) of the Taiwan Agricultural Research Institute (Table 4).

### Table 4.

### Disease and Potassium Rate for Jute

| Rate of $K_2O$ (kg/ha) | Variety | | | |
|---|---|---|---|---|
| | White dew | | Sinfong green | |
| | Yield of retted jute (kg/ha) | Diseased plant (%) | Yield of retted jute (kg/ha) | Diseased plant (%) |
| 0 | 724.0 | 41 | 1,010.4 | 24 |
| 80 | 1,326.4 | 10 | 1,378.4 | 7 |
| 140 | 1,503.4 | 4 | 1,583.4 | 4 |
| 200 | 1,493.0 | 4 | 1,837.6 | 1 |

The use of potassium may greatly subdue the prevalence of Anthrax and nematodes that have been reported in Taipei and Chiayi(7).

## III. Response to Fertilizers

According to the data of fertilizer experiments on jute (1) by the Taiwan Agricultural Research Institute, jute responds to nitrogen most significantly, to potash less significantly, and to phosphorus relatively insignificantly (Table 5).

### Table 5.

### Response of Jute to Fertilizers

| Nitrogen | | | Phosphate | | | Potash | | |
|---|---|---|---|---|---|---|---|---|
| N applied (kg/ha) | Yield of crude jute | | $P_2O_5$ applied (kg/ha) | Yield of crude jute | | $K_2O$ applied (kg/ha) | Yield of crude jute | |
| | kg/ha | Index | | kg/ha | Index | | kg/ha | Index |
| 0 | 2,420 | 100 | 0 | 3,543 | 100 | 0 | 3,094 | 100 |
| 40 | 3,372 | 139 | 40 | 3,749 | 106 | 60 | 3,936 | 123 |
| 80 | 3,936 | 163 | 80 | 3,936 | 111 | 120 | 3,843 | 124 |
| 120 | 3,786 | 156 | 120 | 3,841 | 108 | 180 | 4,215 | 136 |
| 160 | 3,955 | 163 | — | — | — | 240 | 4,406 | 142 |

Based on the price of fine fiber of 1954 and the response of jute to fertilizers, the optimum rates of the three elements for different regions (1) had been recommended as shown in Table 6. According to the experimental result of the Provincial College of Agriculture, however, the recommended rates of N, $P_2O_5$ and $K_2O$ may be increased to 120-60-180 kg/ha for the Taichung region.

## Table 6.

### Optimum Rates of Three Elements in Different Regions

(Unit: kg/ha)

| Region | N | $P_2O_5$ | $K_2O$ |
|---|---|---|---|
| Chunan | 80 | 40 | 180 |
| Taichung | 120 | 20 | 80 |
| Chiayi | 80 | 40 | 120 |
| Tainan | 100 | 40 | 80 |
| Taitung | 80 | 40 | 140 |

The Tainan Fiber Crops Experiment Station has laid out ten demonstrations to show the effect of potash on jute since 1944. The average results are shown in Table 7.

## Table 7.

### Average Yield of Fine Fiber in Demonstration Fields

| Rate of $K_2O$ (kg/ha) | 1955 | | 1956 | | 1958 | | 1959 | | Average | |
|---|---|---|---|---|---|---|---|---|---|---|
| | kg/ha | Index | kg/ha | Index | kg/ha | Index | kg/ha | Index | kg/ha | Index |
| 0 | 2,510 | 100 | 2,260 | 100 | 2,378 | 100 | 2,688 | 100 | 2,459 | 100 |
| 40 | 2,753 | 110 | 2,484 | 110 | 2,500 | 105 | 2,813 | 105 | 2,638 | 107 |
| 80 | 2,837 | 113 | 2,437 | 108 | 2,596 | 109 | 2,892 | 108 | 2,690 | 109 |
| 120 | 2,944 | 117 | 2,762 | 122 | 2,736 | 115 | 2,904 | 108 | 2,837 | 115 |

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# EXPERIMENTS AND RECOMMENDATIONS ON FERTILIZERS FOR PINEAPPLE IN TAIWAN

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## I. Introduction

Pineapple is a crop known to require great amounts of inorganic nutrients for its normal growth. In Taiwan, it is most extensively grown on well-drained diluvial terraces, where soils are lateritic, and on gently-sloping portions of colluvial or alluvial lands at the skirts of terraces or hills, where soils are sandy and oftentimes gravelly, with rapid to medium permeability. All such soils are strongly leached, strongly to moderately acid in reaction, and poor in available nutrients. This is why the use of fertilizers has become one of the most dominant factors deciding the yield of pineapple fruits in Taiwan.

Since no visual symptoms of minor element deficiencies for pineapples have been observed in Taiwan (except iron chlorosis observed occasionally in the high pH soils), the studies in pineapple fertilizers have so far been confined to those of the three major nutrients, i. e., nitrogen, phosphorus and potassium.

A few fertilizer trials were conducted during the pre-war years at the Tashu Pineapple Nursery, Chiayi Agricultural Experiment Station and Laopei Pineapple Plantation.[29, 30, 32] Preliminary in nature as these experiments were, they proved the importance of adequate fertilization in the pineapple culture in Taiwan.

Okuyama, in his treatise on pineapple fertilization,[9] recommended the annual rates of 200, 120 and 160 kg. of N, $P_2O_5$ and $K_2O$, respectively, for 20,000 plants per hectare. Watanabe recommended the annual rates of 250, 125 and 250 kg. of N, $P_2O_5$ and $K_2O$ for 30,000 plants per hectare.[31] Experiments at the Tashu Nursery revealed that the combination of 200 kg. N, 100 kg. $P_2O_5$ and 283 kg. $K_2O$ could result in the highest yield.[29]

In 1953, Chu[6] presented a dissertation based on experimental data from various pineapple growing areas of the world, and concluded that in Taiwan the annual rates of N, $P_2O_5$ and $K_2O$ should range from 80, 40 and 80 kg., as minimum, to 250, 125 and 250 kg., as maximum.

In a 3×3×3 factorial NPK experiment carried out in 1950 at the Fengshan Tropical Horticultural Experiment Station, Pan[10] pointed out the importance of applying nitrogen and potash simultaneously from the standpoints of growth, yield and fruit quality. She recommended a ratio of 200-50-200 in kg. per 25,000 plants of N, $P_2O_5$ and $K_2O$ as the medium annual rates.

Chu, working at the Taiwan Provincial College of Agriculture, Taichung, reported the effects of the three essential elements on the fruit setting of pineapple in 1955. According to his results, potash and nitrogen, especially the former, were very effective in increasing the fruitage, while phosphate was much poorer in effect and even significantly detrimental to the setting of fruits if applied in combination with potash.[5] Fertilizer experiments have taken more intensive forms since 1953 when the Touliu Pineapple Experiment Station was founded by the Taiwan Pineapple Corporation. Basic problems of growth, fruits and plant nutritions have been studied in relation to soil fertility, nitrogen, phosphate and potash fertilizers, methods of fertilizer placement, nutrient interactions, spacing-fertilizer combinations, and so on. Recently the potassium requirement of pineapples is being investigated by the Station in relation to the soil potassium status in various districts of the Island.

Working at the Touliu Station on these fertilizer problems, the author first proved the practicability of dense planting up to the neighbourhood of 44,000 plants per hectare (theoretical density) under conditions where the amounts of fertilizers are increased in parallel with the increment in plant number.[13] Other experiments revealed that the nitrogen and potash requirements of pineapples varied with soil properties, year of planting and mulching and other conditions of management. Phosphate was not effective in increasing the fruit yield, and is, therefore, regarded to be not indispensable to pineapple growing under the conditions encountered.

It is felt that the fertilizer rates should be expressed on crop basis rather than on annual basis, and on plant basis rather than on area basis, because the annual rate itself changes with the stage of growth, and the number of plants per hectare is by no means a constant one. The author has recommended a ratio of 15-3-15 in grams per plant of N-$P_2O_5$-$K_2O$ for the plant crop (i.e. 2 years), and another ratio of 6.5-1.3-5.2 or 6.5-0-5.2 in grams per sucker for each ratoon crop (i.e. 1 year) for the average soil conditions in Taiwan which are characterized by low organic matter content and poor potassium status.[12] Emphasis is to be laid on the fact that such recommendations are only a guide to reasonable rates, and the correct and most profitable rates are to be found through constant observation of the growing plants.

Experimental results cited in the following are sorted according to individual fertilizer elements. All seedlings used are of the collar-of-slip type, Smooth Cayenne variety, and planted either in August or September.

## II. Nitrogen Effect

### A. Growth and Yield of Fruits

Nitrogen in the form of ammonium sulphate bears a most remarkable influence on the yield of pineapple fruits both in plant and ratoon-crop. It increases the number and size of leaves (width, length and thickness). The leaf color is especially sensitive to the increment of nitrogen application, and changes from greenish yellow to darker colors in the order of yellowish green, light green, green and dark green, with the increase in the rate of nitrogen. It was found that at any time during the growth period no farther significant increase in growth was obtained by applying extra amounts of nitrogen whenever the leaf color was just green or darker, but significant improvement in growth was obtained, provided that the leaf color was lighter.[14, 24]

Correlation of growth with the analysis of basal tissue of semi-matured leaves in one experiment has shown the critical concentration of leaf nitrogen to be around 1.4% (total N on dry basis) throughout the growth period, although there were evidences that the value of critical nitrogen concentration would shift considerably as the environmental and managerial conditions changed; and it is concluded that leaf color is a more reliable index of nitrogen nutrition than nitrogen concentration[14] of the leaf tissue.

The response of fruit yield to nitrogen follows the law of diminishing returns as shown in Fig. 1.[14] The most profitable rates of nitrogen found in different experiments were not always the same, owing to the variation in soil organic matter, mulching conditions and annual climates, etc. In any case, the rates which gave the pineapple leaves an exact green color were found to be the most profitable ones, which ranged from 12 to 16 grams per plant for the plant-crop, and

6 to 8 grams per sucker for the ratoon-crop.[14, 24, 25, 15] Nitrogen increases the yield of the plant-crop through the increase of mean fruit weight, while it increases the yield of the ratoon-crop mainly through the increase of fruitage.[24, 25] The cumulative yield increment per kg. of N was 81 kg. at the most profitable rate.

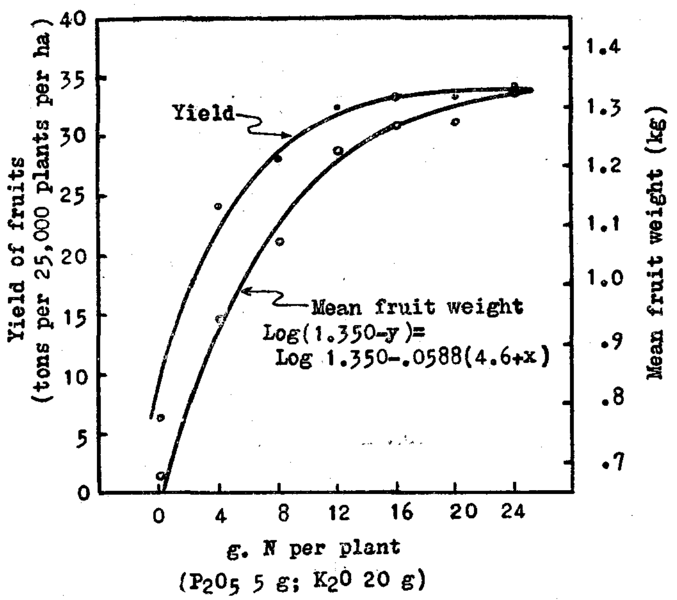

**Figure 1.**

**Mean Fruit Weight and Fruit Yield as Affected by Increments of Ammonium Sulphate —1953-55 Optimum Nitrogen Test (Plant Crop)—**

## B. Quality of Fruits

The quality of fruit is as important as the yield in the production of pineapples. Compactness of texture and intensity of yellow color of pulp are the most essential. Since compact fruit gives a distinctly dull sound like muscle flesh when tapped with finger, it is called "flesh-sound fruit" in Taiwan. Such fruits are not only compact in texture (i. e., without void spaces or spongy tissues), but are also intense in yellow color. The rate of production of "flesh-sound fruits" may reach 80% or above, and may be less than 5%, with the reason for the variation remaining unknown to the growers for a long time. Attention to this property of fruit was first paid by the author while conducting most of the field tests at Touliu. It seems that the maximum percentage of flesh-sound fruits attainable in pineapple culture is a characteristic of individual strains, and whether such maximum is approached or not depends on the climate, soil and fertility control.

Nitrogen is found to exert remarkable influence on the increase of flesh-sound fruits[14, 24] as shown in Fig. 2 and Table 2. This means nitrogen can greatly improve the compactness and color of pulp. That nitrogen can intensify the yellow color of pulp has been observed by Pan[10] and Py et al.[11] The specific gravity of fruit is also increased by nitrogen as measured with 20 fruits per treatment sampled at random on a same date (Fig. 2).

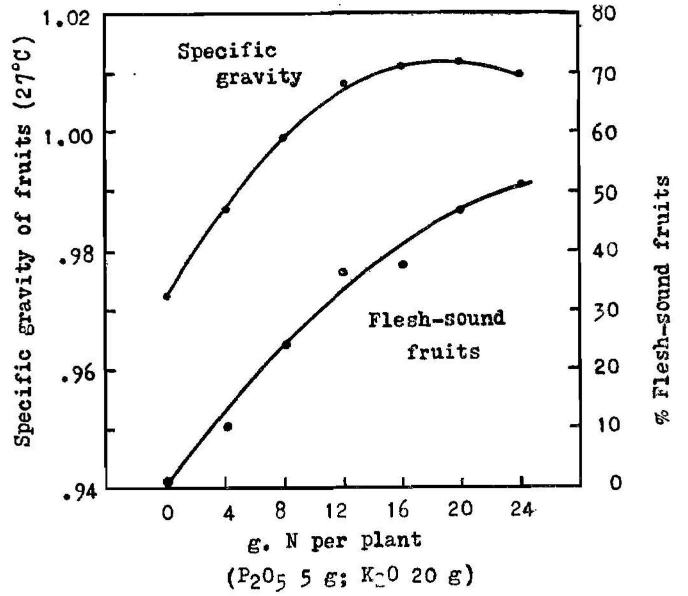

**Figure 2.**

**Effect of Nitrogen on the Rate of Production of Flesh-sound Fruits and Specific Gravity of Fruits**

**—1953-55 Experiment—**

Another remarkable effect of nitrogen is to decrease the acidity of fruit juice.[14, 24] Fig. 3 shows the sharp decline of juice acidity due to the successive increments of nitrogen observed in one of the nitrogen experiments. Similar results are reported by other authors.[10, 11, 2] Effect of nitrogen on the sugar contents of juice (total, reducing sugars and soluble solids) are insignificant and inconsistent.[14, 24]

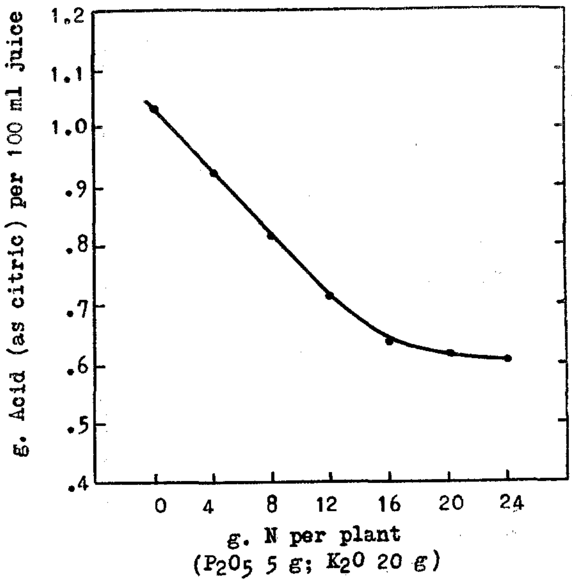

**Figure 3.**
**Acidity of Expressed Fruit Juice**
**as Affected by Nitrogen**
**—1953-55 Nitrogen Test—**

### C. Time of Fruit Maturity

In well-managed fields, usually more than 95% of the plants bear fruit in summer with only a minute portion remaining to fruit in winter. The summer fruits start to mature from late June to middle July, depending on where the pineapples are grown, and the harvest is finished by late August or early September. Highest percentage of fruits are picked per day in late July to early August (called the peak of maturity). The fruit maturity is much earlier in Southern Taiwan than in Central Taiwan. Within the same field, time of fruit maturity is shifted considerably by changes in conditions of management. Mulching and elimination of slips and crowns cause the most remarkable promotion of maturity, while dense planting delays maturity to some extent.[23, 4, 26]

Nitrogen has also some effect on the fruit maturity, though not as profound as those mentioned above. The behavior, however, is not consistent as observed in two experiments. Fig. 4 shows the maturity-delaying effect of nitrogen observed in a 1953-55 experiment.[14] The mean date of maturity was calculated by the frequency table method. The nitrogen-depleted plots bore only 32% of fruits, disregarding the apparent lateness of maturity. The maximum difference in mean date of maturity was less than 7 days. On the contrary, in a 1954-56 experiment, nitrogen enhanced the fruit maturity to a certain extent as shown in Fig. 5.[24] This

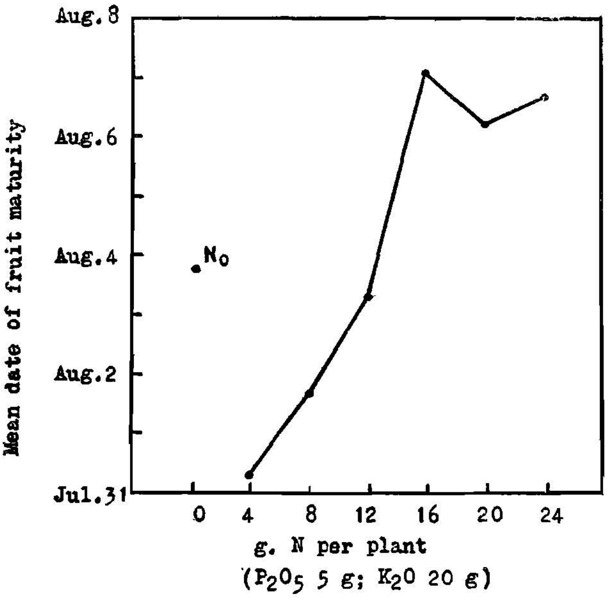

Figure 4.

Maturity Delaying Effect of Nitrogen
— 1953-55 Experiment—

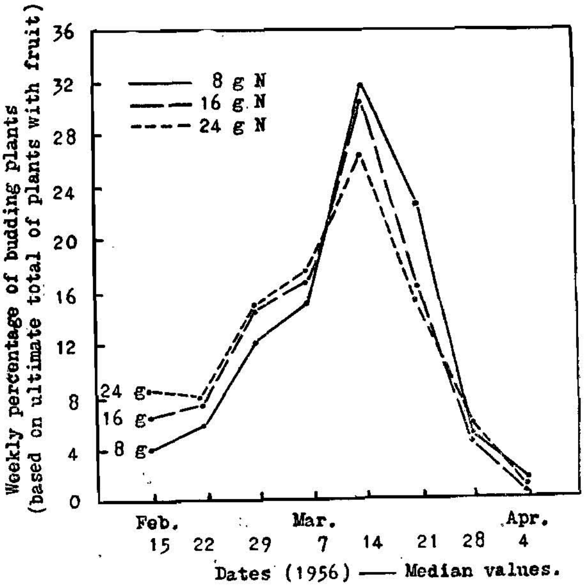

Figure 5.

Maturity Promoting Effect of Nitrogen
—1954-56 3×3×3 NPK Experiment—
(Means of All Combinations of P and K)

discrepancy is not fully explained, although a later experiment[28] has shown that the nitrogen applied after the floral differentiation may delay the maturity. In the 1953-55 experiment, more nitrogen was applied after the floral differentiation than in the 1954-56 experiment. This may be the cause of difference, and it becomes a corollary that the nitrogen applied before floral differentiation can antagonize the maturity-delaying effect of other such constant factors as potassium chloride, and cause earlier differentiation, as compared to the case where nitrogen is deficient in relation to other factors. Furthermore, the climate seems to play a role in determining the way in which the nitrogen works.

## III. Potash Effect

### A. Growth and Yield of Fruits

The growth response of pineapples to added potash is also very marked in most cases in Taiwan, according to the experiment now going on in 15 areas. The potash increases the width and length of leaves most significantly, and the number of leaves to some extent. Pineapple plants supplied adequately with nitrogen but without potash are dwarfed, and dark in leaf color because both the chlorophyll and anthocyan pigments are significantly increased.

Green plants (with adequate nitrogen) will give bigger fruits than yellowish plants (deficient in nitrogen) of the same size. Similarly, large plants (with adequate potash) will give bigger fruits than small plants (deficient in potash) of the same leaf color.

In the plant-crop, the fruitage is usually above 95%, and the increase in yield is mainly due to the increase in mean fruit weight.[16, 24] The response of yield to added potash, as potassium chloride, is represented by a Mitscherlich function as shown in Fig. 6.[16]

Potassium chloride also increased the mean fruit weight of the ratoon-crop very significantly, although too much of this fertilizer would cause a drop of ratoon fruitage, and the total ratoon yield was increased by lower rates of potash but not by the higher rates.[17, 25] The regression of total ratoon yield to added potash in the form of chloride is represented by a quadratic function (Fig. 7).

The most profitable rates of $K_2O$ found in the Touliu experiments were around 15 grams per plant for the plant-crop and around 5 grams per sucker for the ratoon-crop.[16, 17, 24, 25] At these levels, 1 kg. of $K_2O$ is calculated to produce 13.2 kg. of fruits. These values were obtained when miscanthus was mulched between the rows. Evidences have shown that over-all mulching increases the available

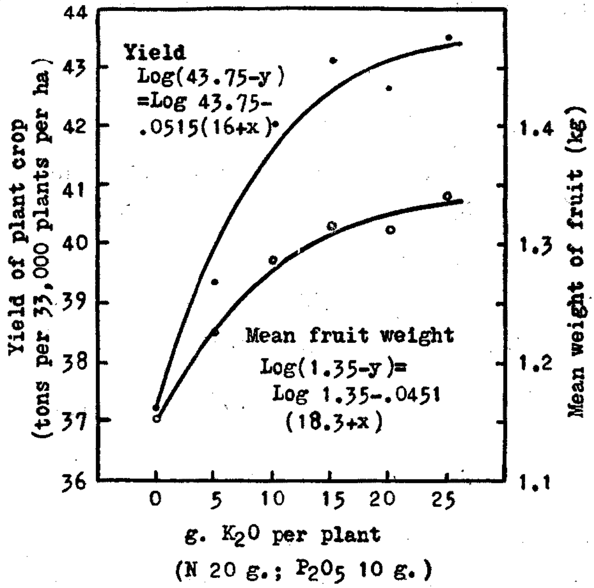

**Figure 6.**

**Effect of Increment of Potash on the Mean Fruit Weight and Yield of Fruits in Plant Crop of Pineapples —1954-56 Optimum Potash Test—**

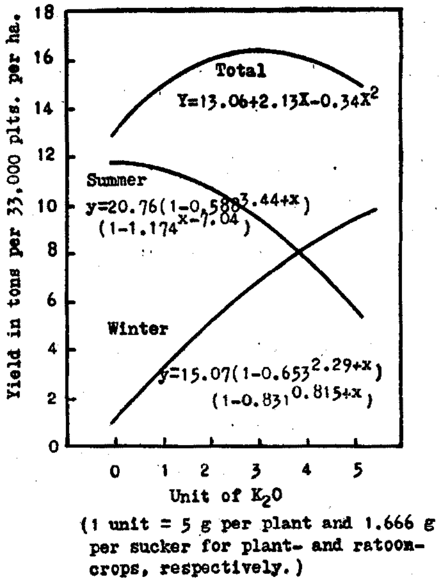

**Figure 7.**

**Yield of Ratoon Crop Fruits as Affected by KCl (Based on Calculated Values of Fruit Weight and % Fruitage) —1956-57 Optimum Potash Test—**

potassium content of the soil and total potassium content of the leaf very remarkably[22] and decreases the plant-crop requirement for fertilizer potash to 12 grams per plant.[15] In a long fallowed, heavily rice-straw-mulched plot, 15 grams of $K_2O$ as potassium chloride even caused a drop of yield as compared to the 3-gram treatment.[21] It was observed, however, that, under the same condition, the same amount of $K_2O$ as potassium sulphate brought about a significant yield increase and positive net profit.[21] This, together with other beneficial effects of potassium sulphate, is the cause for the replacement of potassium chloride by the sulphate form in Taiwan from 1960.

The critical concentration of leaf potassium has been studied, in a simple optimum K test with 6 levels of treatments, by correlation of growth and yield with the data from leaf tissue analyses.[16] It was around 2.4% during the earlier and later parts of the growth period when growth was slow, but when the growth was rapid due to high temperature and abundant rainfall, the critical concentration went up to as high as 5.5%. It is believed that the values may be applied in large plantations where crop logging is to be practised, in order to make sure that the plants are well supplied with potash at all stages of growth.

### B. Quality of Fruits

The percentage of flesh-sound fruits is greatly increased by the increase of soil available potassium as surveyed by the author in 1955.[18] In the presence of adequate nitrogen, light dressing of potassium chloride increased the percentage to some extent, although heavy amount did not bring about further increase.[17, 16, 24] When nitrogen was applied only in medium to low amounts, however, the percentage of flesh-sound fruits was decreased by raising the rate of potassium chloride.[21, 24] It is worth noting that, unlike potassium chloride, potassium sulphate not only caused no decrease of flesh-sound fruits, but even increased the percentage of this type of fruits under the same conditions. All these phenomena are shown in Fig. 8 and Tables 2a and 2b. It is suspected from various data of leaf analyses that the effect of potassium on the production rate of flesh-sound fruits is mainly through the enhanced nitrogen absorption, and that chlorine in the muriate of potash hinders the absorption of nitrate, thus causing the decrease or inefficient increase of flesh-sound fruits.

The color of pulp is also affected by potash. Py et al reported the fading of yellow color of pulp owing to the addition of potash.[11] According to the author's observation, however, the color of pulp was too light to meet the demand of consumers, and an optimum amount of potash was indispensable for developing a desired color of pulp, although an excess of potash would cause the color to fade again.[16] The relation is shown in Fig. 9.

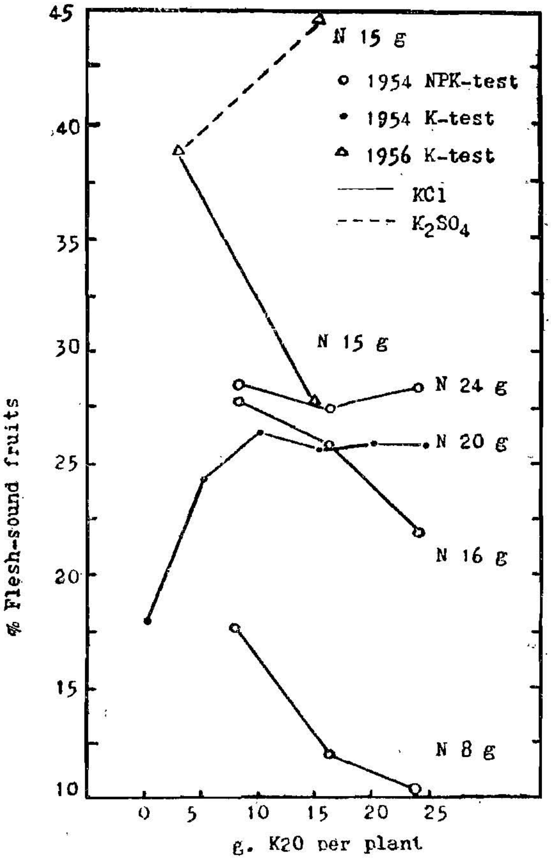

**Figure 8.**

**Rate of Production of Flesh-sound Fruits as Affected by Potash**

Of the effects of applied potash on the constituents of pressed pineapple juice, the most marked are the increases in juice acidity and ascorbic acid content (Fig. 9).[16] The effect of potash in increasing the juice acidity is just the reverse of the effect of nitrogen which is to lower the acidity. The application of potassium in proper amount may improve the flavor of the fruit through adjustment of acidity. Sugar content of juice is not always affected significantly, although in one experiment,[21] it was increased slightly by the application of potash.

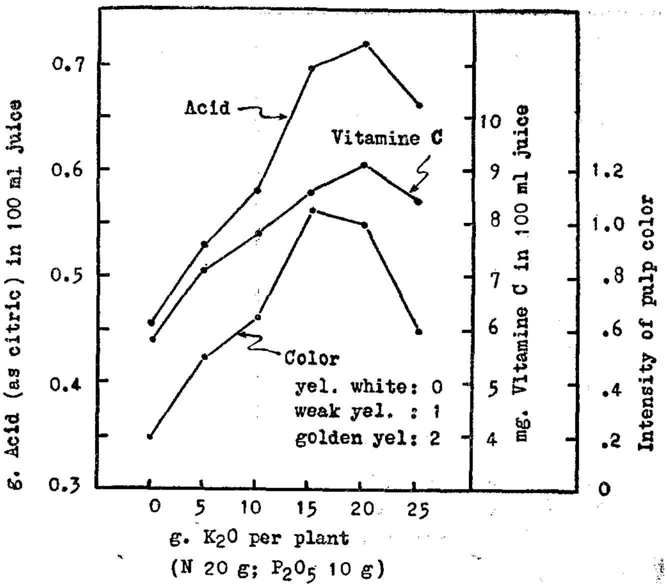

**Figure 9.**

**Effects of Potassium Chloride on the Color of Pulp, Juice Acidity and Ascorbic Acid Content of Pineapple Fruits (Results with 20 Fruits Per Treatment) —1954-56 Potash Experiment—**

## C. Time of Fruit Maturity

Potash in different forms acts differently in influencing the fruit maturity. Potassium sulphate promoted the fruit maturity a little (4 days) as observed in a 1956-58 experiment[21] and again in a 1957-59 experiment.[19] This promoting effect may not be consistent, since under other conditions potassium sulphate delayed flowering to some extent.

Potassium chloride was found to delay the flowering (emergence of flower buds) and fruit maturity of the plant-crop.[16, 24] Fig. 10 shows an example. The effect is probably due to chlorine. The effect of potassium chloride in delaying maturity becomes greater in the ratoon-crop, where increments of this fertilizer cause a sharp decrease in summer fruitage and, as a result, an increase in winter fruitage.[17, 25] In some cases, the increase in winter fruitage was less than the decrease in summer fruitage, and, as a net result, the ratoon yield dropped significantly due to the higher rates of potassium chloride.[25] A 5% decrease in plant-crop fruitage due to potassium chloride was observed in a 1956-58 experiment, while pineapple plants dressed with sulphate were found to bear fruits normally.[21]

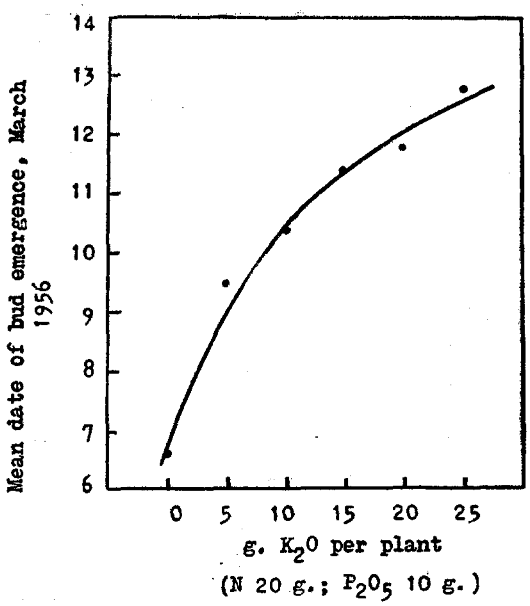

**Figure 10.**

**Effect of Potassium Chloride on the Time of Floral Bud Emergence**

It is obvious that sulphate form is superior to chloride form as potassium fertilizer for pineapple from the standpoints of fruit yield, quality and maturity.

## IV. Phosphate Effect

### A. Growth and Yield of Fruits

Superphosphate has been tested in Fengshan[10] and Touliu,[24] in combination with nitrogen and potash. In all cases, the phosphate neither improved the growth nor increased the yield of plant-crop significantly. In the 1954-57 confounded experiment at Touliu, the main effect of phosphate as a whole was not significant, although phosphate seemed to increase the plant-crop yield and mean weight of fruits to some extent when potash was applied in small amount; but, as the potash was increased, the effect of phosphate was offset. This suggests that the application of superphosphate can serve to prevent the potassium deficiency to some extent, probably through the liberation of the exchangeable potassium in the soil by the calcium ions contained abundantly in calcium superphosphate.[24]

For the ratoon-crop, the superphosphate in heavy amount resulted in decrease in yield, though not significantly. The cause was the fall in winter fruitage due to phosphate increment. In addition, the interference of heavy amount of phosphate with the potash effect on the mean fruit weight in the ratoon-crop was noted. Thus, when no phosphate was added, the fruit weight was increased very significantly by the increase of potash, but, as the rate of phosphate was increased, the effect of potash became insignificant. The data are shown in Tables 1a and 1b.[25]

### Table 1a.

### Mean Weight of Ratoon Winter Fruits (kg.) in 1954-planted 3×3×3 Confounded NPK Experiment

| | P0 | P1 | P2 | K1 | K2 | K3 | Mean | | K1 | K2 | K3 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| N1 | 1.146 | 1.164 | 1.086 | 1.064 | 1.136 | 1.196 | 1.132 | P0 | 1.012 | 1.142 | 1.258 |
| N2 | 1.148 | 1.063 | 1.052 | 1.143 | 1.121 | 1.099 | 1.088 | P1 | 1.015 | 1.143 | 1.169 |
| N3 | 1.118 | 1.099 | 1.158 | 1.012 | 1.117 | 1.246 | 1.125 | P2 | 1.092 | 1.088 | 1.115 |
| Mean | 1.137 | 1.109 | 1.099 | 1.040 | 1.125 | 1.181 | 1.115 | | | | |

Remarks: S. E. per plot: 0.0750 (6.7% of general mean)

Means: S. E.: 0.0177; L. S. D. 5%: 0.0521, 1%: 0.0708

Two-factor combinations: S. E.: 0.0306; L. S. D. 5%: 0.090, 1%: 0.122

Rates of application:
N: 8, 16 and 24 g/plt. for plant-crop, and 2.67, 5.33 and 8 g/sucker for ratoon-crop.
$P_2O_5$: 0, 4 and 8 g/plt. for plant-crop and 0, 1.33 and 2.67 g/sucker for ratoon-crop.
$K_2O$: Same as nitrogen.

### Table 1b.

### The Main Effects and Interactions for Above

| Factor | | Linear response | Curvature | Factor | Linear interaction |
|---|---|---|---|---|---|
| N | | −0.0071 | +0.0816 | N×P | +0.0501 |
| P | | −0.0383 | +0.0182 | N×K | +0.0511 |
| K | | +0.1408** | −0.0291 | P×K | −0.1113** |
| S. E. | | 0.0251 | 0.0435 | | 0.0306 |
| L. S. D. | 5% | 0.0521 | 0.0903 | | 0.0635 |
| | 1% | 0.0708 | — | | 0.0863 |

** *Significant at 1% level.*

It may be necessary to explain why the calcium superphosphate behaved differently to the potash effect in plant and ratoon-crop. It should be stated that in plant-crop, 4/5 of the fertilizer were applied in the soil, and the calcium ions from superphosphate could liberate the exchangeable potassium in soil, thus causing a positive result with regard to mean fruit weight, when potash is at deficient level. In ratoon-crop, however, all of the fertilizer was applied in leaf axils, and calcium ion from the superphosphate acted as an antagonist to the applied potassium by competing with the latter in absorption. As a result, heavy dressing of superphosphate offset the effect of increment of potash.

Although the above facts show that not only is the superphosphate useless but is even harmful to the fruit yield, existence of a triple interaction is suspected, since the ratoon-crop fruitage and yield were the highest (and extraordinarily high), when nitrogen and potash in optimum amounts were combined with a light amount of phosphate. Therefore, a little phosphate, not so much as to cause interference with the potash effect, may be recommended.

## B. Quality of Fruits

The effect of superphosphate on the production of flesh-sound fruits is positive, though small, according to a 1954-56 experiment (Tables 2a and 2b).[24] Though the differences among the two-factor combinations were not significant statistically, a close examination of Tables 2a and 2b reveals that the percentage of flesh-sound fruits of the plant-crop was increased by the increments of phosphate when potash was deficient, but, as potash was applied in sufficient amount, the phosphate effect on the percentage was effaced.

The superphosphate also lowered the juice acidity of pineapple fruits from 0.65% to 0.59% in the same experiment.

**Table 2a.**

**Percentages of "Flesh-sound Fruits" in Plant-crop of Pineapples in 1954-planted Factorial NPK-test**

| | P0 | P1 | P2 | K1 | K2 | K3 | Mean | | K1 | K2 | K3 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| N1 | 12.8 | 12.0 | 15.4 | 17.7 | 12.1 | 10.4 | 13.4 | P0 | 21.3 | 20.1 | 20.6 |
| N2 | 24.5 | 26.2 | 25.1 | 27.9 | 25.8 | 22.1 | 25.2 | P1 | 25.7 | 20.3 | 19.1 |
| N3 | 24.7 | 26.9 | 32.6 | 28.5 | 27.2 | 28.5 | 28.1 | P2 | 27.2 | 24.7 | 21.2 |
| Mean | 20.6 | 21.7 | 24.4 | 24.7 | 21.9 | 20.3 | 22.2 | | | | |

Remarks: S. E. per plot: 4.552 or 20.5% of general mean.

Means {S. E: 1.073
L. S. D. {5%: 3.1
1%: 4.3

Two-factor combinations {S. E.: 1.86
No significant interactions

Rates of fertilizers: As shown in Table 1a.

### Table 2b.

### Main Effects and Interactions of Above NPK-Test

| Factor | Linear response | Curvature | Factor | Linear interaction |
|---|---|---|---|---|
| N | + 14.7** | − 9.0** | N×P | + 2.7 |
| P | + 3.8* | + 1.7 | N×K | + 3.7 |
| K | − 4.4** | + 1.6 | P×K | − 2.6 |
| S. E. | 1.52 | 2.63 | | 1.86 |
| L. S. D. 5% | 3.1 | 5.5 | | 3.9 |
| L. S. D. 1% | 4.3 | 7.4 | | 5.2 |

* Significant at 5% level.
** Significant at 1% level.

## C. Time of Fruit Maturity

It was observed in a 1953-55 experiment that the earliness of emergence of flower bud and fruit maturity were positively correlated with the soluble phosphorus concentration in the basal tissue of semi-mature leaves.[22] In the later NPK factorial experiment, however, the influence of superphosphate was not significant.[24] This suggests that the application of superphosphate may not always be effective in raising the leaf phosphorus concentration. The latter seems to be affected much more by the levels of other nutrients than the level of added phosphate itself.

## V. Allocation of Fertilizers to Individual Growth Stages

Allocation of fertilizers to individual growth stages is very important to pineapple culture. Besides the requirement of plant itself, the influence of seasonal changes in climate should be considered.

According to an experiment conducted at Touliu, with fixed total amount, the best result was obtained when applications were most frequent, i.e. a dressing every two months. For infertile sandy soils and slope lands, frequent applications of small amounts of fertilizers are preferred to infrequent applications of relatively large amounts, as fertilizers are apt to be washed out of the root zone by the abundant rainfall.

In practice, the labor problem must be taken into consideration. During the cooler and drier months, when leaching loss is small and growth is slow, dates of fertilizer application may be spaced much wider than during the summer months when growth is rapid and leaching loss is severe. Organic manure, if obtainable, may be applied at the time of planting, although chemical fertilizers should be withheld until about a month after planting when the root system has just started to develop in order to minimize the drastic leaching loss before the plants can absorb any fertilizer. This is particularly true with the plants grown on sandy or gravelly soils.

Optimum amounts of fertilizers at individual growth stages have been studied in the Touliu experiments, cited above, by occasionally checking the growth and leaf nutrient status. Roughly speaking, the total plant-crop fertilizers may be applied at 7 applications during five seasons, namely, fall of 1st year (September); spring of 2nd year (March); summer of 2nd year (June and July); fall of 2nd year (September and November); and spring of 3rd year (March).

The 1st year fall application will give the plants a good start and rapidly establish the root system within the earliest growth stage before the cool and dry winter sets in. The plants so prepared will respond to the favorable change in climate in the next spring without delay. The warm spring with the long-awaited rain, though small in amount, induces the pre-grand growth, and, when early summer heralds its abundant rain, the pineapples enter the grand growth stage. The growth slows down in the later part of September, when sudden depletion in rain is usually recorded, though the soils are still sufficiently moist for some time thereafter. The vegetative growth ceases as the floral differentiation is started in early December in Southern Taiwan and in late December in Central Taiwan.

Nitrogen is applied in same amounts in all of the five seasons, although actually the amount per month is varied, because of the variation in the intervals between applications.[13] Phosphate, when included, is applied only during the earlier growth stages and in the fall application before the floral differentiation. According to Nightingale, pineapple requires abundant supply of phosphorus before and during the floral differentiation.[8] Potash is abundantly applied in the grand growth stage, when growth is linearly correlated with leaf potassium concentration, and the decline of the latter is rapid.[16] Since heavy dressings of potassium chloride caused delay of floral bud emergence[16] and the effect of application of potash in the fall before floral differentiation was found to be insignificant,[19] dressing of this fertilizer at this time should be lighter than in other seasons. Nitrogen is especially indispensable at this stage, and, unless the leaf color is very dark, it should be supplemented in November.

## VI. Method of Placement

Proper placement of fertilizers is as important as the total amount applied, since it greatly affects the total availability of fertilizers and the readiness to be utilized. The condition of root system, size of foliage, seasonal distribution of rhinfall and kind of fertilizer are among the most important factors deciding the choice of position.

When the pineapple plants are small, fertilizers are usually placed in a hole within the root zone. Watanabe studied the distribution of pineapple roots in the field and also by means of "root box", and concluded that over 90% of the roots were present within a depth of 20 cm. and at a lateral distance of 20 cm. He emphasized that the mode of distribution of roots should be taken into consideration in determining the methods of fertilizer placement.[31]

Since pineapple can withstand the fertilizers in the axils of mature leaves in the lower portion of the foliage, where aerial roots entwine the stem, the fertilizers may be applied in this position, after the plant has grown large.

During the earlier stages of growth, when the roots are still short and climate is dry, fertilizers must be placed very close to the plants. This is true with the commercial fertilizers and with the organic manures as well. Since pineapples need adequate supply of nutrients even at the earliest stage, the differences in growth and leaf color are marked between plants with differently spaced fertilizers at the first application. It was observed two months after the first application following the planting that the leaf color was darken in plots where the fertilizers were divided into halves and dressed to both sides of the stump than it was in plots where fertilizers were applied to one side of the stump, although the leaf nutrient concentrations were not significantly different.[27] Even in the next spring after planting, when roots are much longer than they were in the previous fall and winter, fertilizer absorption is more efficient in the 3 cm-distance placement than in the case where placement is made midway between the plants on the row, provided the depth of placement is kept at 3 cm, a reasonably convenient and safe depth. This was demonstrated in the 1957-planted plots by radioisotopic technique employing a mixed fertilizer containing $P_{32}$.[20] Since the rainfall at this stage is scarce and nutrients other than phosphorus might also remain near the point of application, the results with phosphate will be true also of potash and nitrogen.

In summer, when the root system is well established and nutrients are easily mobilized by the abundant rain, fertilizers may be placed midway between the plants on the row, if soil application is to be made. Application to leaf axil is practicable from this stage on, and is recommended for the purposes of rapid recovery of deficiency and labor-saving, taking advantage of the non-excessive rain water and abundant dews that are deposited in the lower axils. However, during the typhoon season, axil application should be avoided.

In the fall prior to the floral differentiation, the soil is drying up, thus making the soil-applied nutrients less available. Occasional small rain and dew water are insufficient to moisten the soil. At this time, the difference in effect of fertilization is very marked between the axil- and soil-applied plots. This is shown in Fig. 11.[27] Leaf nitrogen concentration was very much higher and leaf color much darken on the axil-applied plants than on the soil-applied plants. Similar trend was observed with potassium. For the phosphorus, applied as superphosphate, however, the soil application gave significantly higher leaf concentration than the axil application. (Note that the leaf nutrient concentrations were not the same at the start and that the leaf phosphorus concentration decreased due to seasonal variation.)

Harvest data revealed that difference in placement at this time alone gave 8% increase in the number of fruitlets per spiral (long) and 5% increase in mean fruit weight for the axil application over the soil application.[27]

The difficulty with which the axil-applied superphosphate is absorbed was confirmed in another test, where 1.2 grams of $P_2O_5$ as superphosphate were applied per plant at floral differentiation (January 17, 1958) in 8 replications with 100 plants per plot. Neither the soluble phosphorus content of the leaf tissue tested after 2 weeks nor the mean fruit weight were increased by this treatment as compared to the control, in spite of the favorable rains following the treatment. The mean fruit weights were 1.392 kg. and 1.380 kg. for the treated and non-treated plots, respectively, while the concentration of phosphorus in fresh leaf tissues was 185 ppm. for both.

The use of ammonium phosphate in place of superphosphate is believed to give different results, because in a short term test of absorption using a mixture of dicalcium phosphate and monoammonium phosphate tagged with $P_{32}$, the concentrations of absorbed phosphorus in fruitlet and leaf tissue were much higher for the axil application than for the soil application. The results are shown in Table 3.[20]

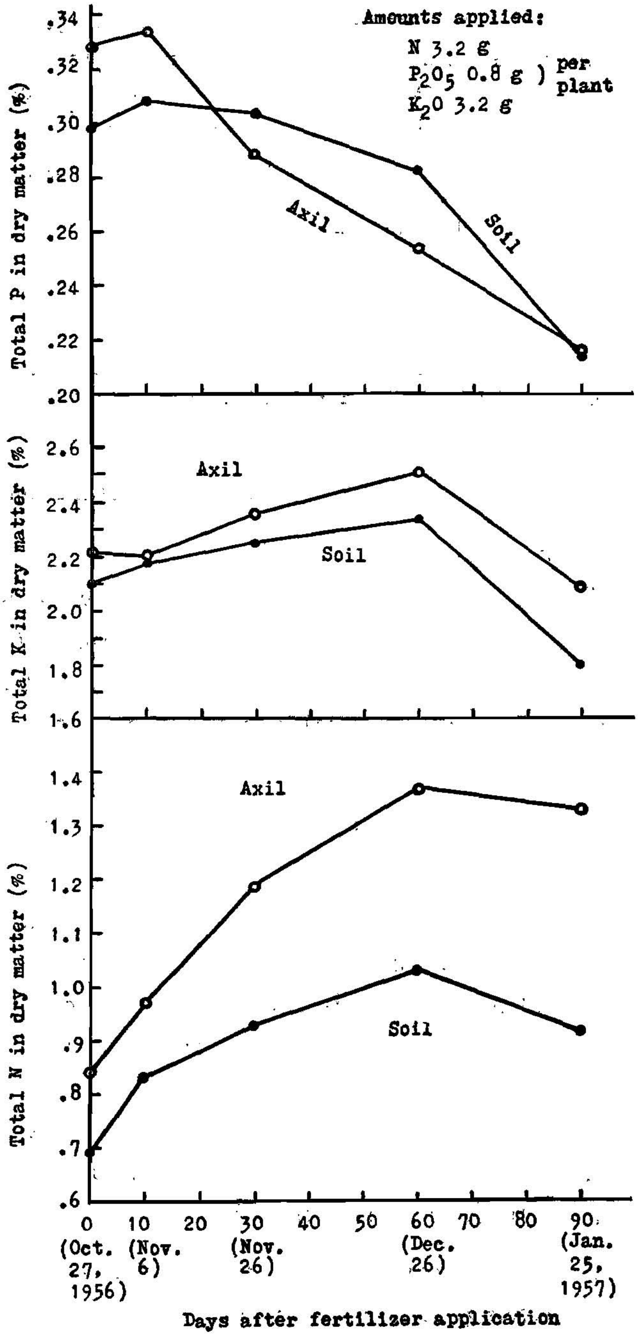

Figure 11.

**Variation of Leaf Nutrient Concentrations After the Leaf Axil- and Soil-Applications of Mixed Fertilizer at Later Stage of Growth —1955 Planted Plots—**

**(Concentrations in White Basal Tissue of Semi-mature Leaves)**

### Table 3.
### Absorption of Phosphorus at Time of Floral Bud Emergence Using Mixture of Monoammonium Phosphate and Dicalcium Phosphate Tagged With $P_{32}$
### (concentrations in ppm. P on dry basis)

| Placement | Young fruit | Basal leaf tissue | Mean |
|---|---|---|---|
| Midway between plants on row, 3 cm. deep | 6.5 | 2.1 | 4.3 |
| | ± 30.6 | | )±21.6 |
| Lower axils | 109.5 | 76.5 | 93.0 |
| Mean (±21.6) | 58.0 | 39.3 | — |

Remarks: Date of fertilizer application: February 26, 1958.
Date of sampling: March 21, 1958.

## VII. Recommendations

### A. Amounts

No fixed rates of NPK for pineapples are to be recommended for the diversified conditions in Taiwan, though the amounts given by the author in the introduction of this paper may be regarded as adequate for the average soils low in organic matter and available potassium contents, and for the average mulching condition, i.e. mulching with rice straw on the row space only.

Phosphate may be excluded from the mixture where it is known to be present abundantly in the soil.

If the soil is high in organic matter content, e.g. above 2%, and also sandy in texture, the prescribed amount of nitrogen will usually result in too dark color of leaves; and adjustment is necessary until the leaf color is just exactly green. Similar situation will be met in districts where rainfall is sufficient throughout the year—a rare case in Taiwan. Over-all mulching with rice straw gives yellowish leaf color from the grand growth stage on, in spite of the increased nitrate and total nitrogen concentration in leaves, and makes the plants respond to additional nitrogen[23], which may be around 1.5-2 g. per plant.

As for potash, the rate recommended is for the soils containing less than 50 ppm. of exchangeable K. In 1952, Chen and Wei[3] analyzed many composite soil samples taken from pineapple plantations in Southern Taiwan, and obtained an average of 31 ppm. for Bray's exchangeable K.[1] According to the author's test of soils in 1958 from 15 potash experimental fields located in representative pineapple growing districts in Eastern, Southern and Central Taiwan, the values of Bray's K were all below 110 ppm., and 2/3 of them was less than 60 ppm. These facts indicate that the pineapple soils of Taiwan are generally very deficient in potash. The leaf potassium contents in plants of Ko plots in these 15 fields were positively correlated with Bray's K value (r= +0.869, t=5.83 with a probability much lower than 1%), but not with non-exchangeable K (r= +0.304). This suggests the posibility of adjusting the rate of potash according to the exchangeable potassium content of the soil.

Magistad's experiment,[7] which showed no response of pineapple to added potash in soils containing 160-200 ppm. of replaceable potassium, and the experiments at Touliu were consulted while a tentative table was prepared for the rates of potash application adjusted according to exchangeable (and soluble) potassium content of the soil (Table 4).

**Table 4.**
**Rates of Potash ($K_2O$) Recommended Tentatively for Various Grades of Exchangeable Potassium Content of Soil**

| Exchangeable K (ppm) | Plant-crop | | Ratoon-crop | |
|---|---|---|---|---|
| | g/plant | kg/37,000-40,000 plants* | g/sucker | kg/37,000-40,000 suckers** |
| 0- 50 | 15 | 560-600 | 5.2 | 192-208 |
| 51-100 | 11.25 | 420-450 | 3.9 | 144-156 |
| 101-150 | 7.50 | 280-300 | 2.6 | 96-194 |
| 151-200 | 3.75 | 140-150 | 1.3 | 48- 52 |
| > 200 | 0 | 0 | 0 | 0 |

* Average number of plants per hectare on large plantations.

** Number of suckers assumed same as the plants.

Note: Exchangeable K regarded one grade higher in overall mulched plots.

### B. Methods of Application

In practice, the fertilizers, i.e. ammonium sulphate, potassium sulphate and calcium superphosphate (or, more preferably, ammonium phosphate) are conveniently applied in mixture, although sometimes ammonium sulphate is applied separately. When insecticide solutions are applied for the purpose of controlling the mealy bug wilt (usually 100 to 150 ml. per plant), some of the ammonium sulphate may be applied simultaneously by dissolving it in the solution (2-3%) either alone or in combination with potassium sulphate (1-2%), provided that the plant has a pressing need for the fertilizer as in case of poor start due to off-season planting or of nutrient deficiency under dry weather.

For the use under ordinary conditions, the ratios of allocations at individual applications and the methods of placement are proposed as shown in Table 5, which is based on the conclusions drawn from observations stated previously.

## Table 5.

## Fertilizer Allocation and Method of Placement Recommended for Pineapple (planted during August 10 - September 10)

| Period | Date | % of allocation | | | Position of placement |
|---|---|---|---|---|---|
| | | Amm. sulphate | Cal. superphos. | Pot. sulphate | |
| Plant-crop | Sept. 20-30 | 20 | 20 | 20 | Divided to both sides close to plant 3 cm. deep. |
| | Mar. 5 | 20 | 20 | 20 | Close to one side of plant 3 cm. deep. |
| | June 10 | 10 | 20 | 15 | Midway between plants on the row 3 cm. deep. |
| | July 30 | 10 | 0 | 15 | Lower axil, both sides. |
| | Sept. 20 | 10 | 40 | 10 | Midway between plants on the row 3 cm. deep. |
| | Nov. 10 | 10 | 0 | 0 | Lower axils, both sides. |
| | Mar. 5 | 20 | 0 | 20 | Same as above. |
| | Total | 100 | 100 | 100 | |
| Ratoon-crop | Sept. 1 | 25 | 25 or 0 | 25 | Lower axil of big cucker, base of small sucker. |
| | Nov. 1 | 25 | 25 or 0 | 25 | Same as above. |
| | Mar. 5 | 50 | 50 or 0 | 50 | Same as above. |
| | Total | 100 | 100 or 0 | 100 | |

Note: When ammonium phosphate is applied in place of calcium superphosphate, half of the 40% for Sept. 20 may be kept for Nov. 10, and both applications made to lower axils.

When fertilizers are applied in the soil, a flat-formed trowel is used to open a hole at the point on the line of the plant row, and the fertilizers are buried into the hole. A long handle is attached to the trowel after the plant has grown high. In axil-application, care must be taken not to place the fertilizer too high or too low. High placement causes burning of leaves, while too low a placement is hardly effective in dry season when only dew and small amount of rain water collected in the upper axils are used for dissolving the fertilizers. The lowest axils where dew water still reaches in reasonable amount are the best positions to adopt.

Since uniformity of dressing is so important for the economical utilization of fertilizers and for obtaining the uniformity of stand, which is a premise in successful dense planting, the fertilizers should be applied by small containers of suitable sizes. The author devised, in 1958, a set of two plastic measures, large and small, adjustable by screw to contain 9-30 grams and 4-11 grams, respectively. Each measure consists of a larger cylinder without bottom and with screw groove inside, and a smaller one with bottom and with screw groove outside. The two cylinders fit together by means of the screw. These measures are in use on plantations owned by the Taiwan Pineapple Corporation.

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# FERTILIZERS FOR TOBACCO

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## I. Introduction

Tobacco crop in Taiwan is chiefly the flue-cured type for making cigarettes. The total acreage of tobacco in recent years is around 8,000 hectares, for instance:

| | |
|---|---|
| 1958-59 | 8,391 hectares |
| 1959-60 | 7,989 hectares |
| 1960-61 | 7,606 hectares (planned) |

Tobacco grows in four regions in Taiwan. According to the statistics of 1958-59, their distribution is as follows:

A. Central region, including Changhwa, Yunlin, Nantou and Chiayi, covers 64.12% of the total.

B. Southern region, including Pingtung and Kaohsiung, covers 32.53% of the total.

C. Eastern region of Hwalien covers 3.13% of the total.

D. Northeastern region of Ilan covers only 0.22% of the total.

The yield of tobacco leaves is in the range of 1,900-1,950 kg/ha. The total yield of this island province of China is about 15,000 metric tons annually. The quality of tobacco in Taiwan is not very good. There is always a surplus of low grade leaves and a shortage of high grade leaves. Therefore, a certain amount of high grade leaves has to be imported for mixing with the local leaves. It is a main objective in tobacco research to increase the percentage of high grade leaves by means of proper method of fertilizer application.

The most popular variety of tobacco in Taiwan is Hicks. A newly-bred mosaic-resistant variety Vacks (萬國士) is also under extension by now.

In Taiwan, tobacco is a winter crop. It is seeded in August to September, transplanted in October to November, and harvested and cured from December to March of next year. With the exception of river beach in a part of the eastern and southern regions, tobacco has been either interplanted with the second crop of rice, or in rotation with it as its succeeding crop.

## II. Effect of Plant Nutrients

Nitrogen is very important for tobacco. Deficiency of nitrogen makes its growth slow, and leaves stunted and yellowish. Yield of tobacco leaves usually responds to nitrogenous fertilizers very significantly. Taking one of the experimental results for example, application of 20, 40, 60 and 80 kg/ha. of nitrogen will increase the yield by 10.8, 19.8, 25.6 and 27.8%, respectively. Therefore, the tobacco growers are inclined to use excess of nitrogenous fertilizers. Excess of nitrogen results in increase of nitrogen, protein, nicotine and ash contents, and decrease of sugar content in the leaves. As a consequence, the quality of leaves is greatly deteriorated. The poor qualities of Taiwan tobacco, such as its crude texture, poor maturity and irritating taste, are all attributed to the excess of nitrogen.

Deficiency of phosphorus retards the growth of tobacco only at the early stage. Sometimes it will induce certain unknown physiological disease of white specks at the lower leaves, but it does not affect both the yield and quality of the leaves at the harvesting time, nor does it affect the constituents of the leaves. Effect of phosphorus is usually more pronounced, if any, when the temperature is low or no organic manure is applied.

Potash deficiency greatly affects the quality of tobacco leaves, but not the yield of leaves. Sufficient potash fertilizer causes increase of potassium and sugar contents, but decrease of calcium and nicotine contents in the leaves.

During the vigorous growing stage at about 30-40 days after transplanting, beginning from the eighth to tenth leaves from the top of the plant, the tips of leaves show yellowish symptom of potash deficiency; and the symptom extends upward gradually. It is most possibly due to the disturbance of nutrient balance with excess of nitrogen. If the weather is warm, the symptom will quickly recover itself. If the temperature is low, the tips of leaves will dry off. This sort of phenomenon occurs most frequently when weather is dry and ammonium-nitrogen is applied in excess.

Magnesium and boron deficiencies have been observed in the Hwalien region, but such symptoms are only limited to some broad leaf varieties which are still at the stage of varietal test but are not ready for extension yet.

In the Pingtung region, the chlorine content of the irrigation water is as high as 65-80 ppm. As a consequence, the chlorine content of tobacco leaves of this region is 1.5-2.0% as against the 0.5-0.8% of the normal leaves of other regions. The high content of chlorine renders the dried tobacco leaves pale and lustrous, tasting abnormal, and easy to change in color.

## III. Fertilizers for Seedlings

Due to the high temperature, the seedling stage of tobacco is very short, being only 35-40 days. In the first 2/3 of the period, the growth is rather slow, and the dry weight of each plant is about 0.027-0.03 gm. In the last 1/3 of the period, the growth becomes very vigorous, and the dry weight of each plant increases to 0.55-0.65 gm. It is clear that the absorption of nutrients is mainly at the later part of the seedling stage.

Excess of nitrogen will reduce both the rate of germination and percentage of transplantable plant. For instance, in the experiments conducted in 1955 and 1956, application of 0.03 kg/m$^2$ of nitrogen reduced the germination rate to 50-61%, and percentage of transplantable plant from 60% to 33%. If the rate of nitrogen is increased to 0.06-0.12 kg/m$^2$, the tobacco appears abnormally dark green, growth becomes stunted, and the taproot becomes gross and deep with a few rootlets. Such kind of seedlings is absolutely useless. On the other hand, if nitrogen is not applied, the seedlings become yellow, tender and weak at the later stage, and the transplantable percentage decreases to 28%. Among the several common nitrogen fertilizers, seed cakes are better than urea and ammonium sulphate, if the cakes are well mixed with soil or compost for fermentation before application. Otherwise, ammonium sulphate is better than seed cakes, particularly when the rate of application is high.

The customary rates of fertilizers and manure for seedling beds of tobacco are 6-12 kg. of compost, 0.45-0.75 kg. of seed cake (N 0.02-0.03 kg.), 0.25-0.30 kg. of superphosphate ($P_2O_5$ 0.045-0.054 kg.) and 0.2-0.3 kg. of straw ash. All are applied as base dressing. Top dressing is rarely practised.

## IV. Fertilizers for Transplanted Plants

**Nitrogen.** The effect of nitrogen on tobacco is most far-reaching. According to the experimental results at fifteen localities over a period of three years from 1951-54, raising the rate of nitrogen from 40 kg/ha. to 60 kg/ha. increased the yield of tobacco leaves unanimously at all the localities. But in two-thirds of the localities, the unit price of tobacco leaves was decreased.

The effect of nitrogen on the growth of tobacco seems to be greatly influenced by the texture of soil. On moderate to heavy soil (loam to clay loam), a high rate of nitrogen may not cause increase of yield and diminution of quality. In a series of field experiments with 80 kg/ha. of nitrogen at twelve localities, the results turned out that the sandy loam soil could not stand this rate, while the heavier soils could. Therefore, to keep a better quality of the tobacco leaves, the proper rate of nitrogen would be 50 kg/ha. for most soils. If emphasis is to be placed on yield, 60 kg/ha. of nitrogen may be adopted, or even higher rate on heavy soils.

Effect of nitrogen on tobacco is also influenced by temperature. Early planting when the weather is not yet cold, tobacco yield responds significantly to nitrogen added. The increase in yield may thus partly compensate for the decrease in the unit price due to inferior quality induced by nitrogen. For late planting under low temperature, excess of nitrogen does not increase the yield, but diminishes the quality. It is entirely not worthwhile.

No much difference in fertilizing value exists among the various kinds of seed cakes. The fertilizing value of ammonium sulphate is comparable to that of seed cake at the rate of 60 kg/ha. of nitrogen. At higher rate, ammonium sulphate usually results in more yield, lower quality, potassium deficiency and white colored symptom of certain unknown physiological diseases, particularly when the weather is cold. Urea is quite similar to seed cakes, but nitrate nitrogen such as nitrophosphate and nitrochalk are definitely inferior to other nitrogenous fertilizers.

**Phosphate.** Tobacco generally does not respond to phosphatic fertilizer in Taiwan. However, on heavy soil of slate alluvium, 40 kg/ha. of $P_2O_5$ not only increases the yield, but also the unit price. If rate of $P_2O_5$ is increased to 90 kg/ha., no further effect is observed. According to observation in field, application of phosphatic fertilizer does help at the early stage of growth, and also, more or less, subdue the effect of excess of nitrogen. Therefore, 50 kg/ha. of $P_2O_5$ is recommended. According to experiment, calcium phosphate is better than bone meal and also fused phosphate.

**Potash.** Potash is most important for tobacco. Insufficient application of potassium fertilizer will cause the symptom of potassium deficiency on the tobacco leaves without exception. The effect of potassium on tobacco is, however, not to increase yield, but to improve its quality. On average, application of potassium only increases 1.48% of yield, but increases 5.12% of unit price. In Taiwan the potassium status in soils seems ample for tobacco growth. The humid weather and the frequent irrigation further slow down the serious potash starvation. Tobacco growers generally apply 150 kg/ha. of $K_2O$. If the application of nitrogen is too much or too late, potassium deficiency will further appear after the time of topping due to disturbance of nutrient balance. Further application of potassium can no more eradicate the symptom. Therefore potassium fertilizer must be applied in proper proportion to nitrogenous fertilizer at proper time so as to get its full effect. For tobacco, only potassium sulphate is used.

**Method of application.** Phosphatic fertilizer and potash fertilizer are usually applied as base dressing. Late application as top dressing will decrease their fertilizing value. Out of the total nitrogenous fertilizer, 10 kg/ha. are applied as base dressing, and the remaining portion is divided into three or four lots for top dressing. Since the growing period of tobacco is very short, it is advisable to use up all the nitrogenous fertilizer in two weeks after transplanting. Late application will cause poor maturity.

The depth of placement of fertilizers for tobacco is generally 10 cm. below the ground surface, but it has been found that placement at 25 cm. deep is better. It is generally recognized that the upper leaves of tobacco are too thick and its lower leaves too thin for making cigarettes of fine quality. Deep application of fertilizers may improve this unique feature, increase content of sugar, decrease content of nitrogenous compounds. But application at a depth more than 30 cm. is not feasible.

Recently, urea, calcium superphosphate and potassium sulphate in solution form have been used for foliar application on tobacco. It has been found that the effect of 60 kg/ha. of nitrogen in solution is equivalent to 90 kg/ha. of nitrogen in solid form. It is also found that tobacco leaves receiving foliar application of nitrogen solution contain less amount of total alkaloid and total volatile bases. The quality is therefore improved.

## V. Fertilizer Allocation for Tobacco in Taiwan

Tobacco in Taiwan is a monopolized enterprise. The cultivation of tobacco leaves is under the control of the government from the beginning to the end. The fertilizers needed are also allocated by the Taiwan Tobacco & Wine Monopoly Bureau. The technical objective of the fertilizer allocation system is to provide the growers with proper amounts and kinds of fertilizers so as to increase the tobacco yield and also to improve its quality or unit price.

By now, the recommended rate of $N$-$P_2O_5$-$K_2O$ on basis of experimental results is 50-50-150 kg/ha. However, the allocated rate is 60-60-160 kg/ha. due to the traditional concept of the growers to employ heavy application for higher yield. The gap between the recommended and allocated rates is, however, not great. The following is some important improvements in fertilization of tobacco made in recent years:

A. In earlier days, 100 kg/ha. of nitrogen was commonly used by growers for producing large yield of sun-cured tobacco. Through extension and demonstration, the rate of nitrogen has been considerably curtailed in recent years. For instance, the rate of the three elements used by growers in 1958-59 is 69.2-79.9 kg/ha. of N, 70.8-83.3 kg/ha. of $P_2O_5$ and 162.5-172.2 kg/ha. of $K_2O$, respectively.

B. Rape seed cake used to be the main nitrogen carrier for tobacco. In recent years, urea has been used in its stead; the nitrogen supplied in seed cakes accounts for only 27% of the total nitrogen.

C. Time of application has been duly adjusted in recent years. Early application of nitrogen has been advocated. As a result, cut of nitrogen rate not only improves the quality of tobacco, but also keeps the yield as much as with higher rate of nitrogen.

In conclusion, it should be mentioned that the quality of tobacco in Taiwan is by no means superior, particularly in the high content of nitrogen and other related undesirable properties. Fertilizer use should be one of the many factors to be considered for the overall improvement of the tobacco production on this island.

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# NITROGENOUS FERTILIZATION FOR THE PRODUCTION OF TEA IN TAIWAN

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## I. Introduction

There are about 46,000 hectares of tea in Taiwan, 90% of which are scattered along the hilly slopes or tableland in the northwestern part of Taiwan. The tea plants in these areas are mainly of the variety *sinensis*. Recently planting of the introduced variety *assamica* is increased in central Taiwan to an acreage of about 1,000 ha. (10).

The tea soils of both the two regions mentioned above are mainly red earth and yellow earth. The former developed mostly on quarternary diluvium, while the latter from tertiary sandstone interposed with shale or slate. There is considerable soil erosion in the tea producing regions of Taiwan (4).

In general, the tea soils in Taiwan range from light sand to heavy clay. However, most tea plants grow on clay loam with pH value ranging between 4.5 to 5.4. The average Taiwan tea soil contains abaut 0.1% of nitrogen, 40-60 ppm of available potash extracted by 25% $NaNO_3$, and about 10 ppm of available phosphorus extracted by 0.1N HCl plus 0.03N $NH_4F$ (16).

Due to the low fertility of the soils and poor soil management, the average tea yield of this Island still runs between 1,000-1,200 kg. of fresh leaves per ha. (20). Tea is one of our export goods for foreign exchange, earning about 6 million U.S. dollars per annum (1). Emphatic attention should be paid to the regeneration of old tea plantations so as to increase their unit production. This paper reports the results of the past and recent experiments on the response of tea to nitrogenous fertilizers and on the survey of nitrogen status of tea bushes over 145 Formosan tea groves with the aid of leaf analysis.

## II. Response of Tea to the Rate of Nitrogen Applied

The response of tea to 6 rates of nitrogen ranging from 0 to 150 kg. of N

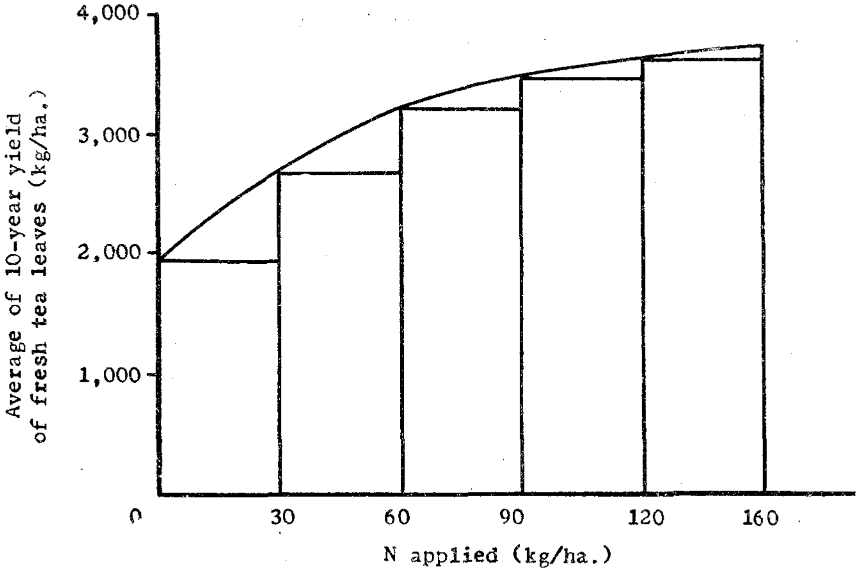


Fig. 1
Yield Response of Tea to Nitrogen Applied
(1917-1927)

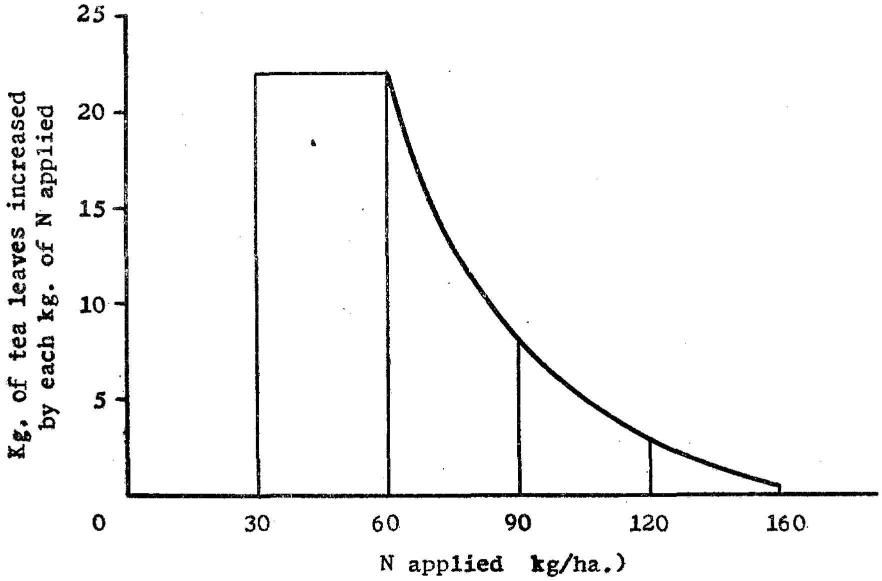


Fig. 2.
Yield Response of Tea Leaves to Successively Increased Rate of Fertilizer

per ha. was studied by the station during 1917-1927 and compiled by Hu and Yu in 1953 (5). The response curve of the average yield in relation to the amount of nitrogen applied is shown in Fig. 1, which indicates that the yield of tea leaves increased logarithmically as the rate of nitrogen application was increased, following in general the law of diminishing returns. Fig. 2 shows more evidently that more than 20 kg. of tea leaves are increased by each kg. of N applied at 30-60 kg/ha., beyond which, the increment value diminishes as the rate of fertilizer is increased. From economical point of view, the most profitable rate of application of nitrogenous fertilizer for the production of tea is within the range of 60-90 kg/ha.

## III. Response of Tea to Different Forms of Nitrogen by Soil Application as Well as by Foliar Spraying

Wu, (11) reported a 6-year test on the relative availability of chilean nitrate, ammonium sulphate, calcium cyanamide and urea to yields of tea leaves, showing that differences in tea yield due to the treatments were insignificant except chilean nitrate, which proved to be significantly worse than calcium cyanamide. In recent years, this station has carried out other experiments on the relative value of some nitrogenous fertilizers. Data (14) in Table 1 indicate that the response of tea to ammonium sulphate and calcium cyanamide was almost the same with or without PK fertilizers. It is to be noted that the yield of the plot treated with nitrogen alone was always lower than those treated with the same rate of nitrogen plus PK although their differences were statistically insignificant at the end of a 6-year period of experimentation.

**Table 1.**

**Yield of Tea Leaves as Influenced by Calcium Cyanamide and Ammonium Sulphate with or without PK Fertilizers**

| Treatment* | | Annual yield of tea leaves (kg/10,000 bushes) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 1952 | 1953 | 1954 | 1955 | 1956 | 1957 | Mean | Index |
| PK | | 1,216 | 1,054 | 603 | 1,321 | 1,035 | 693 | 987 | 100.0 |
| NcPK | | 1,238 | 1,274 | 697 | 1,769 | 1,590 | 1,736 | 1,384 | 140.2 |
| NsPK | | 1,336 | 1,142 | 667 | 1,843 | 1,631 | 1,692 | 1,385 | 140.3 |
| Nc | | 1,186 | 1,032 | 632 | 1,509 | 1,517 | 1,564 | 1,240 | 125.6 |
| Ns | | 1,312 | 1,043 | 592 | 1,563 | 1,504 | 1,452 | 1,244 | 126.0 |
| L. S. D. | 0.05 | | | | | | | 202.2 | |
| | 0.01 | | | | | | | 275.8 | |

*Superphosphate (P); muriate of potash (K); calcium cyanamide (Nc); and ammonium sulphate (Ns). N, $P_2O_5$, and $K_2O$ were applied at the rate of 8, 3, and 5 gm/bush, respectively.

Data (17) in Table 2 show the average of 3-year yield of tea as effected by different sources of nitrogen fertilizers by soil application. The relative effect was in the following decreasing order: ammonium sulphate, urea, ammonium chloride and ammonium nitrophosphate. Among them, only ammonium nitrophosphate gave yield of tea leaves distinctly lower than ammonium sulphate; insignificant differences were observed between others. This experiment is still underway, and the actual results are yet to be reported.

**Table 2.**

**Relative Availability of Ammonium Sulphate, Ammonium Nitrophosphate, Ammonium Chloride and Urea to Yield of Tea Leaves**

| Treatment* | Annual yield of tea leaves (kg/10,000 bushes) | | | | |
|---|---|---|---|---|---|
| | 1957 | 1958 | 1959 | Mean | Index |
| Ammonium sulphate | 2,252 | 1,905 | 1,434 | 1,863 | 139.1 |
| Ammonium nitrophosphate | 2,037 | 1,419 | 864 | 1,440 | 107.5 |
| Ammonium chloride | 1,911 | 1,572 | 1,305 | 1,596 | 119.2 |
| Urea | 2,303 | 1,596 | 1,400 | 1,766 | 131.9 |
| Check (without manures) | 2,077 | 1,142 | 798 | 1,339 | 100.0 |
| L. S. D. 0.05 | | | | 306.8 | |
| 0.01 | | | | 446.4 | |

*Except check plot, all of the nitrogen (N) were applied at the same rate of 8 gm/bush; $P_2O_5$ as superphoshpate and $K_2O$ as muriate of potash were applied at the rates of 6 and 5 gm/bush, respectively.

With regard to foliage application on tea bush, Chiang (2) reported that spraying of urea and ammonia gave a significant effect on yield as compared with the check or water spray treatment, but no apparent effect was obtained through foliar application of phosphatic fertilizers. He also concluded that foliar application of nitrogen, especially urea, could increase the yield of tea leaves and also improve the quality of green tea, but unfavorable result was obtained through foliar application of phosphatic fertilizer. Yield data of this study are given in Tables 3 and 4.

## Table 3.
## Responses of Tea to Different Sources of Nitrogenous Fertilizers by Foliar Application

| Treatment | Materials and concentrations | Yield of 1st spring tea (gm/10 bushes) | Index % |
|---|---|---|---|
| Urea | 0.1 mol urea plus 0.05 mol sugar and water | 683.00 | 122.9 |
| Ammonia | 0.2 mol $NH_4OH$ plus 0.05 mol sugar and water | 677.25 | 121.2 |
| Ammonium nitrate | 0.1 mol $NH_4NO_3$ plus 0.05 mol sugar and water | 643.50 | 115.2 |
| Ammonium sulphate* | 0.1 mol $(NH_4)_2SO_4$ plus 0.05 mol sugar and water | 573.20 | 102.6 |
| Ammonium sulphate* | 0.1 mol $(NH_4)_2SO_4$ and water | 402.75 | 72.1 |
| Water spraying | Water | 555.80 | 99.5 |
| Check | Without spraying | 558.80 | 100.0 |
| L. S. D. 0.05 | | 121.03 | |
| 0.01 | | 165.99 | |

*0.1 mol ammonium sulphate solution spray caused a severe marginal burn with or without 0.05 mol concentration cane sugar but this damage was reduced by decreasing the concentration of ammonium sulphate to 0.05 mol with same concentration of cane sugar.

## Table 4.
## Response of Tea to Foliar Application of Nitrogenous and phosphatic Fertilizers

| Treatment | Materials and concentrations | Yield of tea leaves (gm/10 bushes) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 1st summer tea | | 2nd summer tea | | autumn tea | |
| | | Yield | Index | Yield | Index | Yield | Index |
| Urea | 0.1M urea+0.05M sugar | 755.00 | 156.8 | 565.00 | 234.3 | 998.50 | 258.0 |
| Ammonia | 0.1M $NH_4OH$+0.05M sugar | 671.75 | 139.5 | 434.50 | 182.9 | 618.75 | 159.9 |
| Ammonia | 0.1M $NH_4OH$ | 520.75 | 108.2 | 262.00 | 110.5 | 518.74 | 134.0 |
| Phosphorus | 0.01M $NH_4H_2PO_4$+0.05M sugar | 587.00 | 121.0 | 306.50 | 129.1 | 493.00 | 127.4 |
| Urea plus phosphorus | 0.1M urea+0.01M $NH_4H_2PO_4$+0.05M sugar | 847.50 | 176.0 | 494.00 | 208.0 | 974.75 | 251.9 |
| Water spraying | Water | 472.00 | 98.0 | 316.00 | 133.1 | 453.25 | 117.0 |
| Check | Without spraying | 481.50 | 100.0 | 237.50 | 100.0 | 387.00 | 100.0 |
| L. S. D. | 0.05 | 157.08 | | 159.72 | | 157.08 | |
| | 0.01 | 215.43 | | 241.96 | | 215.43 | |

## IV. Nitrogen Removed by Plucked Leaves and Time of Applying Nitrogen Fertilizer

In Taiwan, the bush begins to send out new shoots in the spring and, if plucked properly, continues to flush throughout the year except three to four months in the cold season. As nitrogen is one of the most mobile fertilizers and is to be readily lost from soil after application, it is, therefore, important to find out the most effective time of dressing in order to match with the different phases of growth, thus minimizing the possible loss.

The relative percentage of nitrogen removed by the plucked leaves for the variety (8) Ying-tze-hong-shin during the successive growing periods throughout

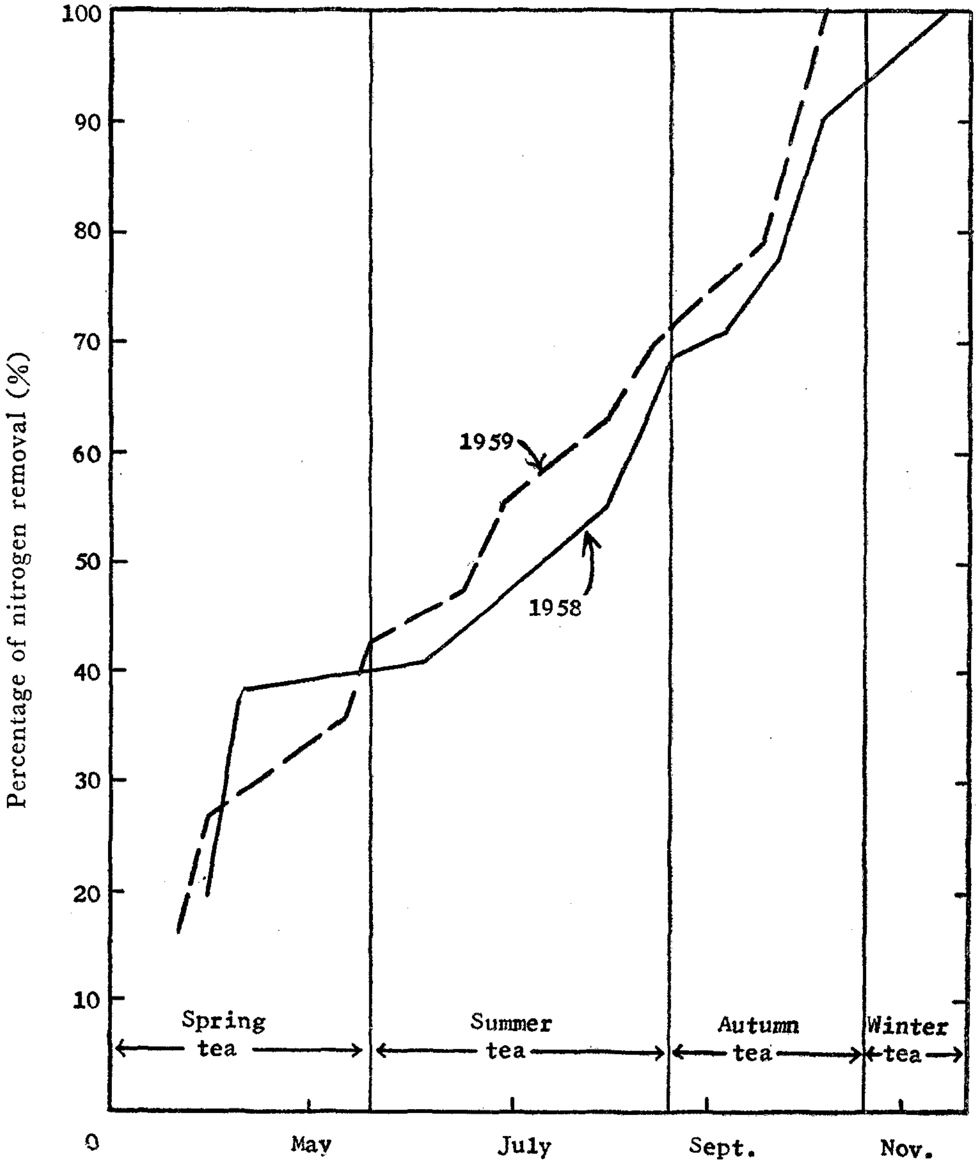


**Fig. 3.**
**Percentage of Nitrogen Removed by Plucked Leaves Through the Year**

the year was 40% for the spring tea, 30% for the summer tea and the remainder for the autumn and winter tea as shown in Fig. 3. Though nitrogen accumulated in the tissues other than the plucked leaves was not included in the data, it does indicate that about 70% of the annually required nitrogen were absorbed by tea bushes before the fall, and, therefore, fertilizer applied later than autumn would be less effective.

To illustrate the field response of tea to the time of fertilizer application, data (13) given in Table 5 show that the highest yield of tea leaves was obtained by applying the whole amount of nitrogenous fertilizer before the plucking of summer tea (No. 6). The next high yield was obtained by adding 50% of annually required nitrogen before the summer tea and dressing the rest evenly before spring and autumn tea (No. 2). The lowest yield was obtained by adding 75% of nitrogen before autumn tea and the other 25% thereafter (Nos. 1 and 3). Judging from the results, it is apparent that beneficial effect could be obtained by applying at least 50% of the annually required nitrogen before summer tea and by adding the rest not later than autumn tea.

**Table 5.**
**Yield of Tea Leaves as Influenced by Time of Applying Various Fractions of Fertilizer**

| Treatment No. | Fractional amount of N added* | | | | Annual yield of tea leaves (kg/10,000 bushes) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Before spring | Before summer | Before autumn | After autumn | 1941 | 1942 | 1943 | 1946 | 1947 | 1948 | Mean |
| 1 | 25% | 25% | 25% | 25% | 3,696 | 3,489 | 2,305 | 2,219 | 3,266 | 2,937 | 2,985 |
| 2 | 25% | 50% | 25% | | 4,296 | 4,000 | 2,743 | 2,391 | 4,253 | 3,534 | 3,536 |
| 3 | | 50% | 25% | 25% | 4,321 | 3,328 | 2,174 | 2,231 | 3,171 | 2,907 | 3,005 |
| 4 | | 50% | 50% | | 4,529 | 3,875 | 2,646 | 2,376 | 3,323 | 2,641 | 3,248 |
| 5 | | 75% | 25% | | 4,322 | 2,494 | 2,369 | 2,957 | 3,812 | 3,195 | 3,392 |
| 6 | | 100% | | | 5,114 | 4,111 | 4,345 | 2,521 | 4,042 | 2,967 | 3,850 |
| L. S. D. | | 0.05 | | | | | | | | 440.0 | |
| | | 0.01 | | | | | | | | 595.3 | |

*N, $P_2O_5$ and $K_2O$ were applied at the rates of 8, 3 and 5 gm/bush, respectively, 50% of nitrogen being from soybean cake, and the rest from calcium cyanamide. Tea variety, Chin-shin Oolong, at the age of 38 years old was used at the beginning of the experiment.

## V. Significance of Adding Compost Manure in Maintaining Productivity of Tea Soil

The continuous growth of a clean-culture crop like tea is very destructive of soil organic matter. Gokhale (3), recently gave evidence to show that, in the case of unmanured and unshaded tea, the nitrogen status of the top soil would ultimately drop by as much as 41% of its original value. The significance of compost manuring in maintaining productivity of tea soil in Taiwan may be illustrated by the data shown in Table 6 (12). It indicates that the more is the rate of compost used, the higher is the yield increased. It is of particular interest to note that the bushes annually dressed with various rates of compost manure gave more yield in the last two years than in the first two years. Single addition of NPK-fertilizers also increases the yield, but with a lesser magnitude than the combined effects of both fertilizer and manure.

**Table 6.**

**Response of Tea to Rate of Compost Manuring**

| Treatment* | Yield of tea leaves (kg/10,000 bushes) | | | | | |
|---|---|---|---|---|---|---|
| | Average of first two years | | Average of last two years | | Average 1941-1959 | |
| | Yield | Index | Yield | Index | Yield | Index |
| Without manuring | 2,622 | 100.0 | 2,182 | 100.0 | 2,459 | 100.0 |
| NPK-fertilizers only | 2,481 | 94.6 | 2,972 | 136.2 | 2,591 | 105.4 |
| NPK plus 6,000 kg/ha of compost | 2,492 | 95.0 | 3,324 | 152.4 | 2,716 | 110.5 |
| NPK plus 12,000 kg/ha of compost | 3,297 | 125.7 | 3,776 | 173.1 | 3,321 | 135.1 |
| NPK plus 18,000 kg/ha of compost | 3,064 | 116.9 | 4,087 | 187.4 | 3,368 | 137.0 |
| NPK plus 24,000 kg/ha of compost | 3,385 | 129.1 | 4,720 | 216.4 | 3,854 | 156.7 |

*In addition to the compost manure applied as mentioned in the table, N as soybean cake, $P_2O_5$ as superphosphate and $K_2O$ as potash of sulphate were dressed at the rates of 8, 3 and 5 gm/bush, respectively. 40% of the total fertilizers were added before spring bush and the remaining 60% evenly applied before the summer and autumn tea, respectively.

## VI. Effect of Combined Application of Fertilizer and Manure on Tea Yield and Soil Nutrient Level

To increase the organic matter of the soils of tea plantations in Taiwan has long been an urgent need. Lupine (7), a legume, as green manure interplanted with tea plants has been intensively studied by the station during the recent years and has been successfully extended in tea groves in northwestern Taiwan. To justify the response of tea to green manuring, the results of an experiment (15) conducted during the period of 1952-1959 are shown in Table 7. The average 8-year yield shows that ammonium sulphate is significantly better than soybean cake, lupine, and also lupine plus PK. However, calcium cyanamide plus lupine plus PK is only insigificantly lower than ammonium sulphate plus PK. For tea plantation where lupine has been successfully raised, the nitrogenous fertilizer may be supplied with 50% of nitrogen from calcium cyanamide and the other 50% from lupine as green manuring.

## Table 7.

## Yield of Tea Leaves as Influenced by Combined Application of Fertilizers and Manure

| Treatment* | Annual yield of tea leaves (kg/10,000 bushes) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1952 | 1953 | 1954 | 1955 | 1956 | 1957 | 1958 | 1959 | Mean |
| Without manuring | 990 | 511 | 1,002 | 1,364 | 1,408 | 780 | 1,038 | 923 | 1,002 |
| PK-fertilizer | 1,061 | 584 | 1,297 | 1,600 | 1,709 | 863 | 1,685 | 1,348 | 1,268 |
| Soybean cake alone | 922 | 558 | 1,149 | 1,629 | 2,122 | 1,043 | 2,205 | 1,867 | 1,437 |
| Lupine alone | 1,160 | 648 | 1,140 | 1,563 | 1,814 | 1,397 | 1,964 | 1,628 | 1,414 |
| NsPK-fertilizer | 1,117 | 622 | 1,339 | 1,879 | 2,441 | 1,855 | 3,329 | 2,712 | 1,912 |
| NcPK-fertilizer | 1,018 | 575 | 1,099 | 1,911 | 2,609 | 2,000 | 2,484 | 2,160 | 1,732 |
| NsPK plus soybean cake | 1,104 | 627 | 1,349 | 1,969 | 2,408 | 1,401 | 2,595 | 2,197 | 1,706 |
| NcPK plus soybean cake | 1,129 | 612 | 1,279 | 2,069 | 2,524 | 1,436 | 2,411 | 1,870 | 1,666 |
| NsPK plus lupine | 1,106 | 658 | 1,244 | 1,872 | 2,274 | 1,755 | 2,490 | 1,745 | 1,643 |
| NcPK plus lupine | 1,091 | 711 | 1,291 | 2,022 | 2,580 | 1,806 | 2,670 | 2,145 | 1,790 |
| PK plus lupine | 1,123 | 668 | 1,251 | 1,886 | 2,109 | 1,678 | 2,240 | 1,762 | 1,590 |
| L. S. D. 0.05 | | | | | | | | 253.6 | |
| 0.01 | | | | | | | | 340.6 | |

*Ammonium sulphate ($N_S$), calcium cyanamide ($N_C$), calcium superphosphate (P), and muriate of potash (K). All treatments except those with PK-fertilsizers or without manuring received the same amount of N, $P_2O_5$ and $K_2O$ at the rates of 8, 3 and 5 gm/bush, respectively. In the case of ammonium sulphate or calcium cyanamide added in company with lupine or soybean cake, the nitrogen derived from both sources was fifty to fifty, and, meanwhile, the rates of superphosphate and muriate of potash were proportionately curtailed according to the amount of $P_2O_5$ and $K_2O$ contained in the lupine or soybean cake, respectively.

The relative effects of the various sources of nitrogenous fertilizers on soil pH, organic carbon, total nitrogen, and available nutrients are shown in Table 8. Soil samples were taken in the spring of 1958 from the plot which had received fertilizers since 1952 (8).

From the above data, it is evident that, taking the soil pH without manuring as a check, the addition of calcium cyanamide caused significant increase in pH value in the surface soil but not in the subsoil, whereas addition of ammonium sulphate lowered the pH value in the subsoil but not in the surface soil. Neither organic carbon nor total nitrogen of the soils dressed with different nitrogen fertilizers, including green manure and soybean cake, differed markedly from one to another. Soils in the plots treated with superphosphate contained twice as much available phosphorus in the surface soil as compared with those not treated with phosphate, but no much difference was found in the subsoil. Potash also tends to accumulate in surface soil. On account of the restricted mobility of phosphatic fertilizer within the soil, special attention should be paid to the proper placement

## Table 8.
## Effect of Fertilizers on Soil pH, Organic Carbon, Total Nitrogen and Available Phosphorus, Potassium and Calcium

| Item / Depth of soil (cm.) / Treatment* | PH | | Organic carbon (%) | Total nitrogen (%) | | Available phosphorus (ppm) | | Available potassium (ppm) | | Available calcium (ppm) | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0-20 | 20-40 | 0-20 | 0-20 | 20-40 | 0-20 | 20-40 | 0-20 | 20-40 | 0-20 | 20-40 |
| Without manuring | 4.6 | 4.8 | 0.85 | 0.10 | 0.09 | 10.55 | 1.0 | 61.5 | 19.2 | 31.87 | 42.06 |
| PK-fertilizer | 4.6 | 4.9 | 0.89 | 0.11 | 0.09 | 22.00 | 0.7 | 81.6 | 38.0 | 50.98 | 49.71 |
| Soybean cake | 4.7 | 4.8 | 0.86 | 0.11 | 0.09 | 10.98 | 0.3 | 71.3 | 24.5 | 49.92 | 38.24 |
| Lupine | 4.6 | 4.8 | 0.92 | 0.11 | 0.09 | 11.00 | 0.4 | 66.6 | 32.9 | 37.81 | 39.51 |
| NsPK-fertilizer | 4.6 | 4.6 | 0.97 | 0.11 | 0.09 | 20.45 | 0.8 | 73.8 | 36.3 | 37.52 | 43.33 |
| NcPK-fertilizer | 5.3 | 4.8 | 0.90 | 0.11 | 0.10 | 18.15 | 1.1 | 90.1 | 35.1 | 352.84 | 68.40 |
| NsPK+soybean cake | 4.6 | 4.7 | 0.90 | 0.11 | 0.09 | 21.38 | 0.7 | 76.3 | 49.0 | 41.42 | 40.36 |
| NcPK+soybean cake | 4.9 | 4.8 | 0.89 | 0.11 | 0.09 | 17.28 | 1.2 | 76.3 | 40.5 | 161.44 | 64.58 |
| NsPK+lupine | 4.6 | 4.7 | 0.92 | 0.12 | 0.09 | 18.75 | 1.0 | 79.6 | 53.7 | 48.65 | 35.69 |
| NcPK+lupine | 4.9 | 4.8 | 0.92 | 0.12 | 0.08 | 16.45 | 0.4 | 80.1 | 46.3 | 167.82 | 74.78 |
| PK plus lupine | 4.7 | 4.9 | 0.93 | 0.12 | 0.09 | 18.70 | 0.6 | 87.9 | 49.5 | 46.94 | 45.46 |
| L. S. D. 0.05 | 0.13 | 0.16 | N.S. | N.S. | N.S. | 5.03 | N.S. | N.S. | 9.52 | 32.89 | 17.49 |
| 0.01 | 0.18 | 0.22 | | | | 6.77 | | | 12.82 | 44.29 | 23.56 |

* See remarks under Table 7.

of the fertilizer hereafter. Annual addittion of calcium cyanamide also caused significant increase in the Ca content of the surface soil as well as of the subsoil. It is particularly worthwhile to note that soil receiving no manures at the end of a 7-year period of experimentation contained the lowest amount of nutrients and produced the least yield of tea leaves.

## VII. Leaf Analysis Revealing Nitrogen Deficiency of Tea Bushes in Taiwan

Work done on leaf analysis of tea bushes by the station during the recent years indicated that increase in the rate of nitrogen applied would not only bring about a significant increase in the annual yield of tea leaves but also raise the nitrogen concentration of the third young leaves from the terminal of the tender shoots. Furthermore, positively significant relationship was also established between the annual yield of tea leaves and the nitrogen concentration of the third young leaves plucked throughout the plucking seasons. The results of these studies are given in Tables 9 and 10(18).

## Table 9.

## Effect of Rates of Nitrogen Applied on Annual Yield of Tea Leaves and N-concentration of Third Young Leaves at the Time of Sampling

| Treatment* | | Annual yield of tea leaves (kg/ha) | | N % on dried basis May 7, 1959 |
|---|---|---|---|---|
| | | 1958 | 1959 | |
| Nitrogen applied (kg/ha) | | | | |
| 0 | | 239.3 | 210.0 | 3.29 |
| 30 | | 1,106.5 | 1,395.3 | 3.86 |
| 60 | | 1,278.3 | 1,695.3 | 4.25 |
| 90 | | 1,324.2 | 1,907.4 | 4.50 |
| 120 | | 1,242.3 | 1,933.2 | 4.80 |
| L. S. D. | 0.05 | 112.2 | 389.3 | 0.48 |
| | 0.01 | 149.7 | 521.0 | 0.68 |

*This experiment was laid out in the design of randomized block with quadruplication. Nitrogen as ammonium sulphate was applied to different plots at the rates mentioned in the table. All treatments received the same amount of $P_2O_5$ as superphosphate and $K_2O$ as muriate of potash at the rate of 40 kg/ha. Tea variety of Ying-tze-hong-shin was used in the experiment.

## Table 10.

## Relationship of Annual Yield of Tea Leaves to N-concentration of Third Young Leaves Plucked during Successive Periods

| Year | Time of sampling | Correlation coefficient | Time of sampling | Correlation coefficient |
|---|---|---|---|---|
| 1958 | April 1 | 0.8704** | August 8 | 0.8015** |
| | April 9 | 0.7574** | August 16 | 0.7558** |
| | June 2 | 0.8224** | September 3 | 0.7157** |
| | June 25 | 0.7658** | September 20 | 0.6760** |
| | July 8 | 0.9013** | October 2 | 0.4820* |
| | July 28 | 0.8682** | October 21 | 0.5465* |
| | | | November 11 | 0.7038** |
| 1959 | March 22 | 0.5985** | July 11 | 0.8790** |
| | March 30 | 0.7899** | July 27 | 0.7780** |
| | May 7 | 0.7073** | August 10 | 0.5083** |
| | May 22 | 0.5655** | August 24 | 0.1248 |
| | June 12 | 0.8929** | September 18 | 0·6244** |
| | June 26 | 0.9053** | October 5 | 0.5590** |

* Indicating significant at 0.05 level.
** Indicating significant at 0.01 level.

To investigate the nitrogen status of tea bushes in Taiwan (19), large numbers of leaf samples were taken separately from 145 demonstration plots with and without manuring in May 1959. The percentage of samples receiving no manures collected from five prefectures are classified according to the N-concentration of leaf (Fig. 4). Taking the data given in Table 9 as the basis of diagnosis of nitrogen status, the percentage of sample leaf with less than 4.0% of N might expect an increase of yield by application of nitrogen. The percentage of such samples to the total samples is 70.3% for Taipei, 91.7% for Taoyuan, 88.3% for Hsinchu, 45.5% for Yilan and 23.3% for Miaoli. It indicates that most of the tea groves in Taipei, Taoyuan and Hsinchu may be more deficient in nitrogen than those in Yilan and Miaoli.

The critical percentage of nitrogen in tea leaves, however, varies with the variety of tea. The distribution of samples in various ranges of leaf nitrogen for different varieties as influenced by manuring is given in Table 11. It shows that the critical leaf nitrogen concentration for different varieties is 4.6% in the third young leaves for the variety Ching-shin-ta-pang, 3.6% for Huangkan, and 3.8% for miscellaneous varieties.

Data also show that 87.3% of the total samples for Ching-shin-ta-pang, 71.4% for Huangkan and 44.4% for miscellaneous varieties are deficient in nitrogen (Table 12). The former two varieties covering 18,000 hectares, occupying one-third of the total tea acreage in Taiwan.

**Table 11.**

**Percentage of Samples of Different Varieties Showing Leaf Nitrogen Raised by Manuring**

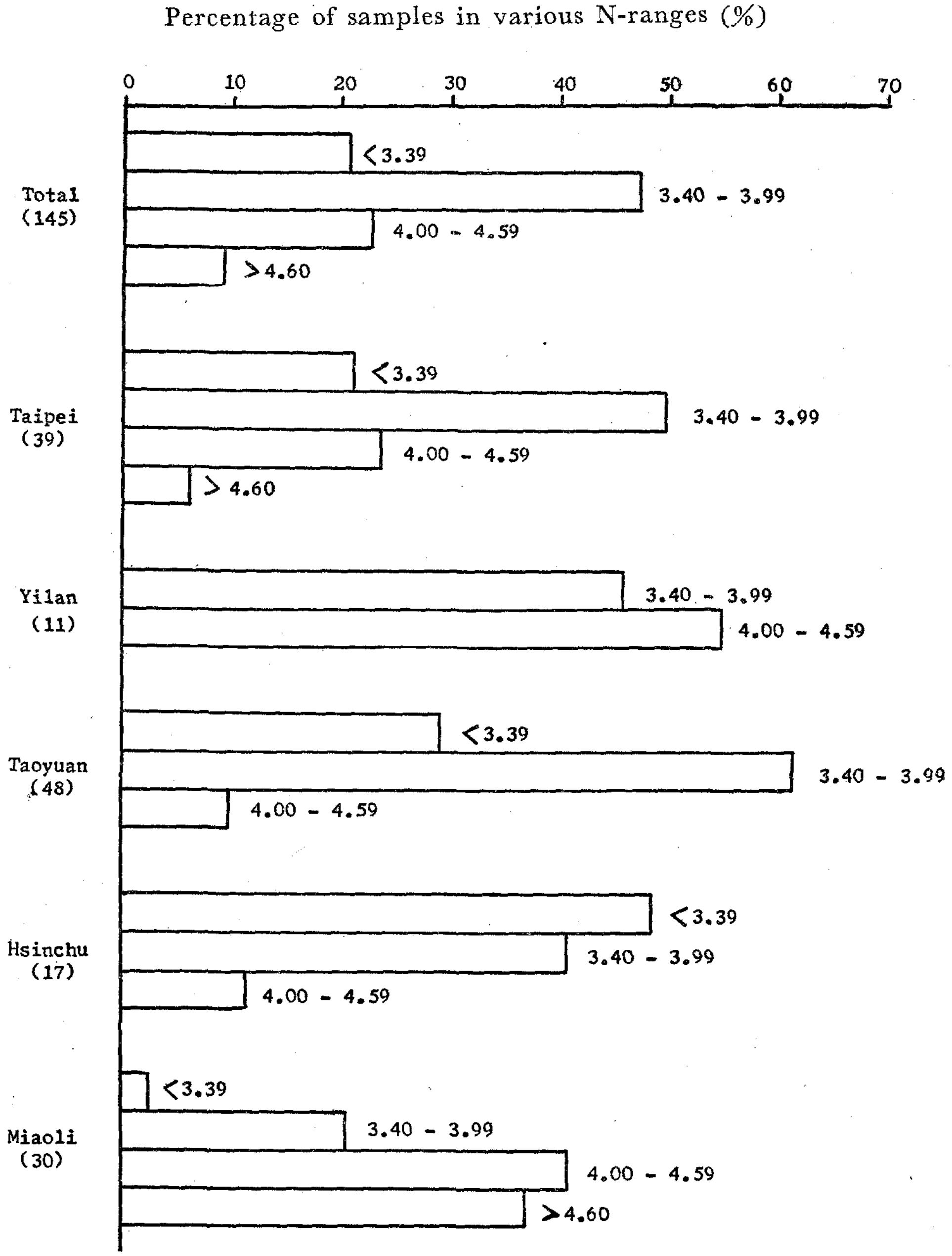
| Variety | Ching-shin-ta-pang | | | | Huangkan | | | Miscel-laneous | |
|---|---|---|---|---|---|---|---|---|---|
| Original leaf-N[1] | <3.4 | 3.4-3.9 | 4.0-4.6 | >4.6 | <3.4 | 3.4-3.6 | 3.6-4.0 | <3.8 | >3.8 |
| No. of samples analyzed | 11 | 33 | 18 | 9 | 13 | 12 | 10 | 12 | 15 |
| No. of samples showing leaf-N raised by manuring | 11 | 26 | 13 | 2 | 13 | 7 | 5 | 11 | 4 |
| Percentage of samples showing deficiency of nitrogen | 100 | 78.8 | 72.2 | 22.2 | 100 | 58.3 | 50 | 91.6 | 26.6 |
| Nitrogen status[2] | ** | * | * | ? | ** | * | ? | ** | ? |

[1] N-concentration of third young leaves from the plot without manuring.

[2] "**" indicating absolute deficiency in N; "*" deficiency in N; and "?" doubtful.

## Fig. 4.

## Percentage of Samples Taken from Five Prefectures Classified According to Leaf Nitrogen (Surveyed in May 1959)



Figures on bars refer to average total N percentage by weight of the third young leaves from the terminal after oven-dried.

Figures within brackets refer to number of samples surveyed.

### Table 12.

### Percentage of Samples Showing Deficiency in Nitrogen for Different Varieties

| Variety | Ching-shin-ta-pang | Huangkan | Miscellaneous |
|---|---|---|---|
| Number of leaf samples surveyed | 71 | 35 | 27 |
| Number of samples showing deficiency in nitrogen | 62 | 25 | 12 |
| Perentage of samples showing deficiency of nitrogen | 87.3 | 71.4 | 44.4 |

Although the concentration of leaf nitrogen has been found to be influenced by the position and age of leaves, the climate, the season, and the variety of tea bush, the results obtained from the above, at least, give the first clue as to applicability of foliar diagnosis to estimating nitrogen requirement of tea bushes and reveal the fact that the shortage of nitrogen is one of most important factors limiting tea yield in Taiwan.

## VIII. Conclusion

Tea responses readily to nitrogenous fertilizer of all forms. Evidences show that continuous growth of tea plant without manuring will not only decrease tea yield but also accelerate the deterioration of tea soil. The profitable rate of nitrogenous fertilization has been found in the range 60-90 kg/ha. Better results may be obtained by supplying 50% of N from calcium cyanamide and the other 50% from lupine as green manuring wherever lupine can be interplanted with tea during the winter. Though tea plants flush throughout the year in Taiwan, fertilizer added later than fall would be less effective. It has also been found that foliar application of nitrogen, especially urea, could increase the yield of tea leaves and simultaneously improve the quality of green tea. Leaf analysis reveals the fact that most tea bushes are deficient in nitrogen. It is one of the most important factors limiting yield of tea in Taiwan.

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# ECONOMIC APPRAISAL OF FERTILIZER APPLICATION ON RICE

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Rice is the most important crop of Taiwan. Its production depends greatly on fertilizer use. Historical data of fertilizer consumption and rice production show that the year of 1938 is the pre-war peak year for both the total quantity of fertilizer used for rice production, which was 389,334 m.t., and the yield of brown rice per hectare, which was 2,242 kg. In 1945, as a result of the World War II, the fertilizer consumption on rice dropped to 1,958 m.t. and the rice yield also decreased to 1,273 kg./ha. As the fertilizer consumption after the war has been steadily increasing each year and, since 1954, has excelled the pre-war record, the rice production per unit area has been increasing and the yield per hectare in 1956 surpassed the pre-war record.

**Table 1.**
**Consumption of Fertilizer Nutrients for Rice**

Unit: Kg./ha.

| Year | N | $P_2O_5$ | $K_2O$ | Yield of brown rice |
|---|---|---|---|---|
| 1938 (pre-war record) | 77.8 | 21.7 | 5.7 | 2,242 |
| 1945 | 0.3 | 0.6 | 0.2 | 1,273 |
| 1946 | 1.5 | — | — | 1,585 |
| 1947 | 13.8 | 9.5 | — | 1,474 |
| 1948 | 17.6 | 6.3 | — | 1,489 |
| 1949 | 23.3 | 7.8 | — | 1,624 |
| 1950 | 51.6 | 14.0 | — | 1,845 |
| 1951 | 58.6 | 11.8 | 7.3 | 1,882 |
| 1952 | 65.9 | 24.1 | 9.8 | 1,998 |
| 1953 | 67.0 | 27.6 | 11.1 | 2,109 |
| 1954 | 83.4 | 29.2 | 12.0 | 2,183 |
| 1955 | 83.7 | 33.3 | 13.8 | 2,151 |
| 1956 | 85.3 | 33.7 | 14.3 | 2,284 |

In 1956, from about 640,000 m.t. of fertilizer consumed, 490,000 m.t. or 77% of the total were used on rice. Nearly 20 million U. S. dollars were spent in that year for import of chemical fertilizer used for rice production. The increase in the amount of fertilizer used on rice is especially significant in recent years. From 279,857 m.t. in 1951 to 490,281 m.t. in 1956, it showed an increase of 75% in 6 years, and the fertilizer distributed for each hectare of paddy land has been raised from 355 kg. in 1951 to 626 kg. in 1956, representing an increase of 76 percent. During this period, the planting acreage of paddy rice has remained the same. In view of the rapid increase of fertilizer consumption on rice, questions have been raised as to whether using so much fertilizer on rice is economically justified, when considering both the farmers and the foreign exchange balance between fertilizer import and rice export.

In compilation and analysis of experimental data of field fertilizer trials on various main crops in Taiwan, fertilizer response curves on rice, sugarcane, wheat, tea, jute and sweet potato were worked out by the writer and published in Chinese in the Special Bulletin No. 12 of JCRR. The increment of crop yield with the application of each additional unit of fertilizer nutrient is shown in this study and optimum rates of fertilizer nutrients for various main crops are recommended. Basing on these physical figures, an economical appraisal of fertilizer application on rice has been made and shown in the attached tables.

From Tables 2, 3, 4 and 5, it is shown that an application rate of nitrogen on rice up to 80-100 kg./ha. (equivalent to 400-500 kg. ammonium sulphate per hectare) for the first crop and 60-80 kg./ha. for the second crop is still profitable either on the basis of farmers' income or on the basis of foreign exchange. The net returns from use of nitrogen fertilizer for the first crop of rice is greater than that for the second crop. It is estimated that the net returns of each hectare to farmer ranges from NT$1,011 to NT$1,052 (or 95-114%) from the first rice crop and NT$346 to NT$369 (or 42-52%) from the second rice crop with liberal application of nitrogen fertilizer. From the viewpoint of foreign exchange, a net return of US$61.9 to US$67.4 per hectare from the first crop and US$27.2 to US$32.1 per hectare from the second crop may be earned by the government on the same basis of the above amount of nitrogen application and the response of rice yield. For phosphorus and potash nutrients, a low rate of application, 40 kg./ha. of $P_2O_5$ or $K_2O$ (equivalent to 220 kg. calcium superphosphate and 80 kg. of potassium chloride per hectare) gives slight profit. It would not be economical to apply phosphate and potash fertilizer at a rate greater than 40 kg. of $P_2O_5$ or $K_2O$, although potash fertilizer might be used at a higher rate up to 60 kg./ha. of $K_2O$ on the second crop.

In 1955, an island-wide fertilizer demonstration on rice was carried out by the Provincial Food Bureau with the purpose of educating the farmers to use NPK balanced fertilizer. Summarizing the field data of 600 demonstrations in 300 townships, a comparison of standard rate of NPK application against no fertilizer is shown in Table 6.

Taking the rate of 80-40-40 NPK (equivalent to 400 kg, 220 kg. and 80 kg. of ammonium sulphate, calcium superphosphate and potassium chloride, respectively) with farm-produced manure as a general standard application, a net return of NT$2,320 per hectare for the first crop and NT$1,539 per hectare for the second crop can be obtained by the farmers as compared with no fertilizer. In terms of foreign exchange, a net return of US$127.6 and US$91.4 can be earned by the government from the first and second crops, respectively.

Judging either from the net return of single fertilizer nutrient or that of combined application of three major elements as shown in the tables, it is quite safe to say that the present rate of fertilizer application, 85-34-14 kg./ha., is still in the range of economical return with due consideration to the application of farm-produced manure as farmers' customary practice. However, due to the law of diminishing returns, the rate of fertilizer application hereafter cannot be rapidly increased as in the past six years. The authority working on the plan of fertilizer allocation should be aware of this point.

## Table 2.

## Anticipated Rice Yield Response from Nitrogen Fertilizer, Their Cost and Returns for the First Crop

(on per hectare basis)

| N applied (kg.) | Experiment yield of paddy rice[1] (kg.) | Expected yield of paddy rice[2] (kg.) | Increase of paddy rice yield over control (kg.) | Value of the increased paddy rice | | Cost of fertilizers | | Net return from use of fertilizers | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Farm price[3] (NT$) | Export price[4] (US$) | Farm price[5] (NT$) | Import price[6] (US$) | Farmers' income | | Foreign exchange | |
| | | | | | | | | NT$ | % | US$ | % |
| 0 | 2,848 | 2,831 | | | | | | | | | |
| 20 | | 3,103 | 272 | 602 | 27.9 | 221 | 6.5 | 381 | 172 | 21.4 | 329 |
| 40 | 3,291 | 3,336 | 505 | 1,118 | 51.8 | 443 | 13.0 | 675 | 152 | 38.8 | 298 |
| 60 | | 3,531 | 700 | 1,550 | 71.8 | 664 | 19.5 | 886 | 133 | 52.3 | 268 |
| 80 | 3,719 | 3,688 | 875 | 1,897 | 87.9 | 886 | 26.0 | 1,011 | 114 | 61.9 | 238 |
| 100 | | 3,806 | 975 | 2,159 | 99.9 | 1,107 | 32.5 | 1,052 | 95 | 67.4 | 207 |
| 120 | 3,889 | 3,886 | 1,055 | 2,336 | 108.1 | 1,328 | 39.0 | 1,008 | 76 | 69.1 | 177 |
| 140 | | 3,927 | 1,096 | 2,427 | 112.4 | 1,550 | 45.5 | 877 | 57 | 66.9 | 147 |
| 160 | 3,923 | 3,930 | 1,099 | 2,433 | 112.7 | 1,771 | 52.0 | 662 | 37 | 60.7 | 117 |
| 180 | | 3,895 | 1,054 | 2,334 | 108.0 | 1,993 | 58.5 | 341 | 17 | 49.5 | 85 |
| 200 | | 3,820 | 989 | 2,190 | 101.4 | 2,214 | 65.0 | -24 | -1 | 36.4 | 56 |

Remarks: [1] From data of fertilizer field experiments conducted at 117 localities on the Island during 1929-1942. Detailed information given in "Fertilizer Response Curves for Various Main Crops in Taiwan" in JCRR Special Bulletin No. 12 (in Chinese) and "Fertilizer Response Curves for Paddy in Taiwan", a working paper presented by the author to the Fourth Meeting of Working Party on Fertilizer, International Rice Commission, FAO/UN, in Tokyo, 1954.

[2] Calculated from the actual experiment yield by means of second degree polynomial formula.

[3] Derived from the average farm price of Ponlai paddy rice during July 1956 to June 1957 at NT$2,214 per m.t.

[4] Converted from the export price of 90% polished rice at US$147/m.t. FOB Keelung during October 1956 to July 1957 (US$120.51/m.t. of Ponlai paddy rice).

[5] Based on the barter ratios between fertilizers and paddy rice at farm price, that is:

Ammonium sulphate (20% N)=NT$2,214/m.t. or N=NT$11.07/kg.
Calcium superphosphate (18% $P_2O_5$)=NT$1,107/m.t. or $P_2O_5$=NT$6.15/kg.
Potassium chloride (50% $K_2O$)=NT$1,771/m.t. or $K_2O$=NT$3.54/kg.

[6] Based on the C&F cost of imported fertilizers:

Ammonium sulphate (20% N) =US$65/m.t. or N=US$0.325/kg.
Calcium superphosphate (18% $P_2O_5$) =US$40/m.t. or $P_2O_5$=US$0.22/kg.
Potassium chloride (50% $K_2O$) =US$50/m.t. or $K_2O$=US$0.10/kg.

## Table 3.

### Anticipated Rice Yield Response from Nitrogen Fertilizer, Their Cost and Returns for the Second Crop

(on per hectare basis)

| N applied (kg.) | Experiment yield of paddy rice$^1$ (kg.) | Expected yield of paddy rice$^2$ (kg.) | Increase of paddy rice yield over control (kg.) | Value of the increased paddy rice | | Cost of fertilizers | | Net return from use of fertilizers | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Farmers' income | | Foreign exchange | |
| | | | | Farm price$^3$ (NT$) | Export price$^4$ (US$) | Farm price$^5$ (NT$) | Import price$^6$ (US$) | NT$ | % | US$ | % |
| 0 | 2,578 | 2,572 | | | | | | | | | |
| 20 | | 2,744 | 172 | 381 | 17.6 | 221 | 6.5 | 160 | 72 | 11.1 | 171 |
| 40 | 2,887 | 2,896 | 324 | 717 | 33.2 | 443 | 13.0 | 274 | 62 | 20.2 | 155 |
| 60 | | 3,028 | 456 | 1,010 | 46.7 | 664 | 19.5 | 346 | 52 | 27.2 | 139 |
| 80 | 3,136 | 3,139 | 567 | 1,255 | 58.1 | 886 | 26.0 | 369 | 42 | 32.1 | 123 |
| 100 | | 3,230 | 658 | 1,457 | 67.5 | 1,107 | 32.5 | 350 | 32 | 35.0 | 108 |
| 120 | 3,315 | 3,300 | 728 | 1,612 | 74.6 | 1,328 | 39.0 | 284 | 21 | 35.6 | 91 |
| 140 | | 3,350 | 778 | 1,722 | 79.8 | 1,550 | 45.5 | 172 | 11 | 34.3 | 75 |
| 160 | 3,373 | 3,379 | 807 | 1,787 | 82.7 | 1,771 | 52.0 | 16 | 1 | 30.7 | 59 |
| 180 | | 3,388 | 816 | 1,807 | 83.6 | 1,993 | 58.5 | -186 | -9 | 25.1 | 43 |
| 200 | | 3,377 | 805 | 1,782 | 82.5 | 2,214 | 65.0 | -432 | -20 | 17.5 | 27 |

Remarks: See remarks under Table 2.

## Table 4.

## Anticipated Rice Yield Response from Phosphate Fertilizer, Their Cost and Returns

(on per hectare basis)

| Crop | $P_2O_5$ applied (kg.) | Experiment yield of paddy rice[1] (kg.) | Expected yield of paddy rice[2] (kg.) | Increase of paddy rice yield over control (kg.) | Value of the increased paddy rice | | Cost of fertilizers | | Net return from use of fertilizers | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | Farmers' income | | Foreign exchange | |
| | | | | | Farm price[3] (NT$) | Export price[4] (US$) | Farm price[5] (NT$) | Import price[6] (US$) | NT$ | % | US$ | % |
| 1st | 0 | 3,512 | 3,516 | | | | | | | | | |
| | 20 | | 3,595 | 79 | 175 | 8.1 | 123 | 4.4 | 52 | 42 | 3.7 | 84 |
| | 40 | 3,668 | 3,657 | 141 | 312 | 14.5 | 246 | 8.8 | 66 | 27 | 5.7 | 65 |
| | 60 | | 3,702 | 186 | 412 | 19.1 | 369 | 13.2 | 43 | 12 | 5.9 | 45 |
| | 80 | 3,719 | 3,730 | 214 | 474 | 21.9 | 492 | 17.6 | -18 | -4 | 4.3 | 24 |
| | 100 | | 3,741 | 225 | 498 | 23.1 | 615 | 22.0 | -117 | -19 | 1.1 | 5 |
| | 120 | 3,738 | 3,735 | 219 | 485 | 22.4 | 738 | 26.4 | -253 | -34 | -4.0 | -15 |
| | 140 | | 3,711 | 195 | 432 | 20.0 | 861 | 30.8 | -429 | -50 | -10.8 | -35 |
| | 160 | | 3,671 | 155 | 343 | 15.9 | 984 | 35.2 | -641 | -65 | -19.3 | -55 |
| 2nd | 0 | 2,968 | 2,970 | | | | | | | | | |
| | 20 | | 3,026 | 56 | 124 | 5.7 | 123 | 4.4 | 1 | 1 | 1.3 | 30 |
| | 40 | 3,081 | 3,073 | 103 | 228 | 10.6 | 246 | 8.8 | -18 | -7 | 1.8 | 20 |
| | 60 | | 3,112 | 142 | 314 | 14.6 | 369 | 13.2 | -55 | -15 | 1.4 | 11 |
| | 80 | 3,136 | 3,143 | 173 | 383 | 17.7 | 492 | 17.6 | -109 | -22 | 0.1 | 1 |
| | 100 | | 3,165 | 195 | 432 | 20.0 | 615 | 22.0 | -183 | -30 | -2.0 | -9 |
| | 120 | 3,181 | 3,178 | 208 | 461 | 21.3 | 738 | 26.4 | -277 | -38 | -5.1 | -19 |
| | 140 | | 3,183 | 213 | 472 | 21.8 | 861 | 30.8 | -389 | -45 | -9.0 | -29 |
| | 160 | | 3,180 | 210 | 465 | 21.5 | 984 | 35.2 | -519 | -53 | -13.7 | -39 |

Remarks: See remarks under Table 2.

## Table 5.

### Anticipated Rice Yield Response from Potash Fertilizer, Their Cost and Returns
### (on per hectare basis)

| Crop | $K_2O$ applied (kg.) | Experiment yield of paddy rice[1] (kg). | Expected yield of paddy rice[2] (kg.) | Increase of paddy rice yield over control (kg.) | Value of the increased paddy rice | | Cost of fertilizers | | Net return from use of fertilizers | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | Farmers' income | | Foreign exchange | |
| | | | | | Farm price[3] (NT$) | Export price[4] (US$) | Farm price[5] (NT$) | Import price[6] (US$) | NT$ | % | US$ | % |
| 1st | 0 | 3,632 | 3,636 | | | | | | | | | |
| | 20 | | 3,675 | 39 | 86 | 4.0 | 71 | 2.0 | 15 | 21 | 2.0 | 100 |
| | 40 | 3,716 | 3,704 | 68 | 151 | 7.0 | 142 | 4.0 | 9 | 6 | 3.0 | 75 |
| | 60 | | 3,722 | 86 | 190 | 8.8 | 212 | 6.0 | -22 | -10 | 2.8 | 47 |
| | 80 | 3,719 | 3,731 | 95 | 210 | 9.7 | 283 | 8.0 | -73 | -26 | 1.7 | 21 |
| | 100 | | 3,730 | 94 | 208 | 9.6 | 354 | 10.0 | -146 | -41 | -0.4 | -4 |
| | 120 | 3,723 | 3,719 | 83 | 184 | 8.5 | 425 | 12.0 | -241 | -57 | -3.5 | -29 |
| 2nd | 0 | 2,985 | 2,987 | | | | | | | | | |
| | 20 | | 3,044 | 57 | 126 | 5.8 | 71 | 2.0 | 55 | 77 | 3.8 | 190 |
| | 40 | 3,094 | 3,089 | 102 | 226 | 10.5 | 142 | 4.0 | 84 | 59 | 6.5 | 163 |
| | 60 | | 3,121 | 134 | 297 | 13.7 | 212 | 6.0 | 85 | 40 | 7.7 | 128 |
| | 80 | 3,136 | 3,142 | 155 | 343 | 15.9 | 283 | 8.0 | 60 | 21 | 7.9 | 99 |
| | 100 | | 3,149 | 162 | 359 | 16.6 | 354 | 10.0 | 5 | 1 | 6.6 | 66 |
| | 120 | 3,146 | 3,145 | 158 | 350 | 16.2 | 425 | 12.0 | -75 | -18 | 4.2 | 35 |

**Remarks:** See remarks under Table 2.

## Table 6.

## Economic Efficiency of Standard rate of fertilizer Application on Rice

(on per hectare basis)

| Crop | Rate of application[1] (kg.) | Yield of paddy rice[2] (kg.) | Increase of paddy rice yield over control | | Value of the increased paddy rice | | Cost of fertilizers | | Net return from use of fertilizers | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | Farmers' income | | Foreign exchange | |
| | | | kg. | % | Farm price[3] (NT$) | Export price[4] (US$) | Farm price[5] (NT$) | Import price[6] (US$) | NT$ | % | US$ | % |
| 1st | 0-0-0 | 3,968 | | | | | | | | | | |
| | 80-40-40 | 5,591 | 1,623 | 40.9 | 3,593 | 166.4 | 1,273 | 38.8 | 2,320 | +182 | 127.6 | +329 |
| 2nd | 0-0-0 | 3,350 | | | | | | | | | | |
| | 80-40-40 | 4,620 | 1,270 | 37.9 | 2,812 | 130.2 | 1,273 | 38.8 | 1,539 | +121 | 91.4 | +236 |

Remarks: [1] 80-40-40 is the NPK rate of application in form of chemical fertilizer; in addition, farm-produced manure is applied in accordance with farmers' customary practice.

[2] Average of 600 demonstrations for each crop of rice in 1955. (JCRR project TW-A-493)

[3-6] See remarks under Table 2.

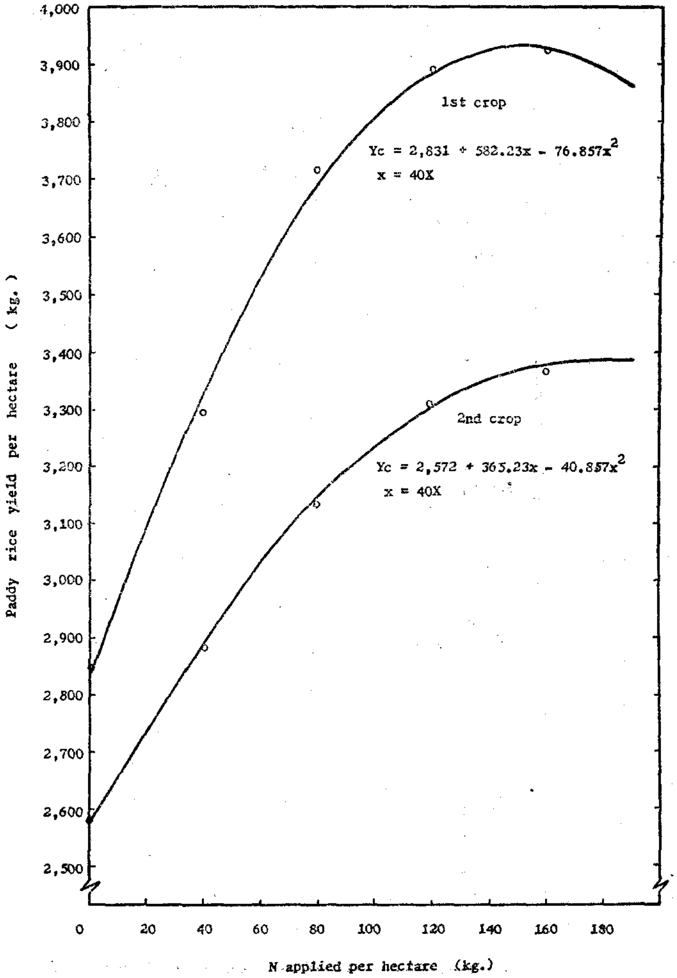

**Fig. 1. N Response Curves for Paddy**

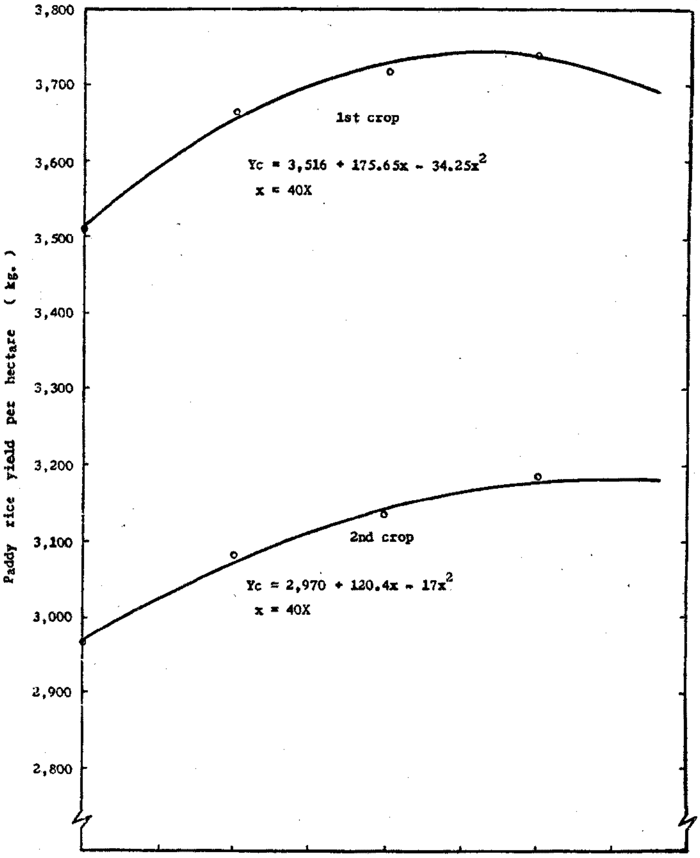

Fig. 2. $P_2O_5$ Response Curves for Paddy

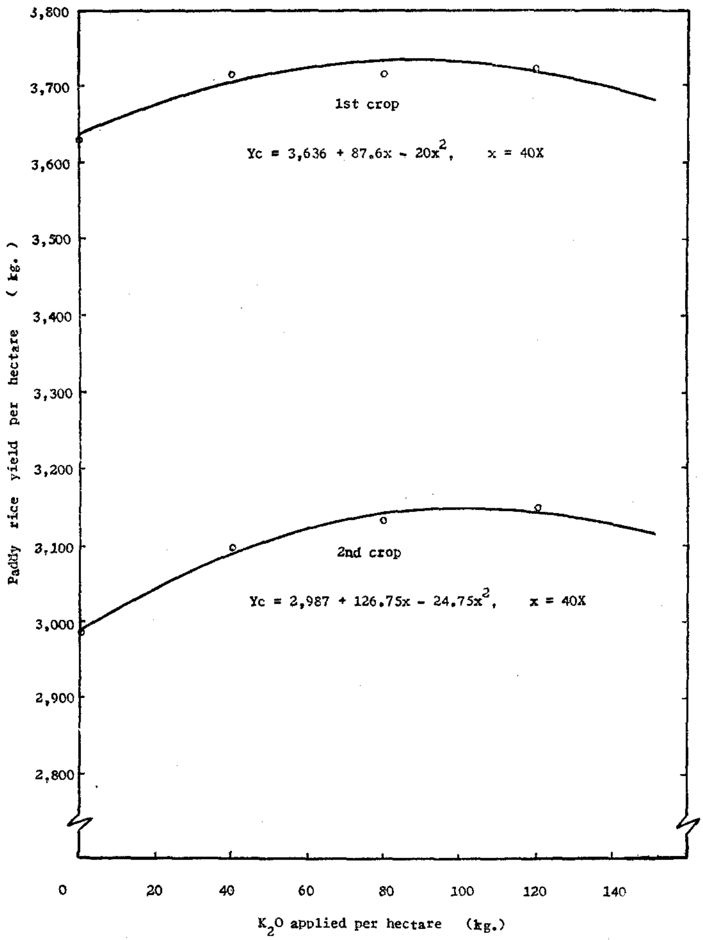

**Fig. 3. $K_2O$ Response Curves for Paddy**

# ECONOMIC APPRAISAL OF FERTILIZER APPLICATION ON SUGARCANE, SWEET POTATO, JUTE AND WHEAT

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According to the figures given in "Fertilizer Response Curves for Various Main Crops in Taiwan," JCRR Special Bulletin No. 12 (in Chinese), the optimum rates of fertilizers and the increment of crop yield obtainable from application of each additional unit of fertilizer on these crops are shown hereunder:

**Table 1.**

**Rate of Application of Fertilizers and Yield Increase of Main Crops in Taiwan**

| Crop | Optimum rate of application | | | Yield increment from each additional unit application | | |
|---|---|---|---|---|---|---|
| | Ammonium sulphate (kg/ha) | Super-phosphate (kg/ha) | Potassium chloride (kg/ha) | Ammonium sulphate (kg/kg) | Super-phosphate (kg/kg) | Potassium chloride (kg/kg) |
| Sugarcane | 750-1,125 | 410 | 150 | 4.11-5.62 | 0.53 | 5.09 |
| Jute | 200-400 | 220 | 120 | 3.62-4.52 | 1.00 | 8.09 |
| Sweet potato | 150 | 140-280 | 100 | 16.17 | 3.00-6.69 | 25.74 |
| Wheat | 200-400 | 165-330 | 40-80 | 1.13-1.61 | 0.67-1.13 | 4.20-6.60 |

Note: The yield increment for various crops mentioned above and in other places of this paper are in terms of raw sugar for sugarcane, crude fiber for jute, fresh tuber for sweet potato and grain for wheat.

Based on the above data, the net returns from use of fertilizers on various miscellaneous crops calculated according to the present prices are as follows:

## Table 2.

## Responses of Some Main Crops to Different Rates of N

| Crop | N applied (kg/ha) | Expected yield (kg/ha) | Increase over control (kg/ha) | Value of increase (NT$) | Cost of fertilizer (NT$) | Net returns to farmers | |
|---|---|---|---|---|---|---|---|
| | | | | | | NT$ | % |
| Sugarcane | 150 | 12,895 | 4,201 | 4,894* | 1,688 | 3,206 | 190 |
| | 225 | 13,327 | 4,633 | 5,397* | 2,531 | 2,866 | 113 |
| Jute | 40 | 3,035 | 808 | 1,551 | 450 | 1,101 | 245 |
| | 80 | 3,505 | 1,278 | 2,454 | 900 | 1,554 | 173 |
| Sweet potato | 30 | 23,503 | 1,586 | 822 | 338 | 484 | 143 |
| Wheat | 40 | 2,059 | 293 | 745 | 450 | 295 | 66 |
| | 60 | 2,152 | 386 | 981 | 675 | 306 | 45 |
| | 80 | 2,209 | 443 | 1,126 | 900 | 226 | 25 |

## Table 3.

## Responses of Some Main Crops to Different Rates of $P_2O_5$

| Crop | $P_2O_5$ applied (kg/ha) | Expected yield (kg/ha) | Increase over control (kg/ha) | Value of increase (NT$) | Cost of fertilizer (NT$) | Net returns to farmers | |
|---|---|---|---|---|---|---|---|
| | | | | | | NT$ | % |
| Sugarcane | 75 | 12,174 | 220 | 256* | 458 | —202 | —44 |
| Jute | 40 | 3,486 | 284 | 545 | 244 | 301 | 123 |
| Sweet potato | 25 | 23,742 | 714 | 370 | 153 | 217 | 142 |
| | 50 | 24,163 | 1,135 | 588 | 306 | 282 | 92 |
| Wheat | 30 | 2,136 | 134 | 341 | 183 | 158 | 86 |
| | 60 | 2,224 | 222 | 564 | 367 | 197 | 54 |

## Table 4.

## Responses of Some Main Crops to Different Rates of $K_2O$

| Crop | $K_2O$ applied (kg/ha) | Expected yield (kg/ha) | Increase over control (kg/ha) | Value of increase (NT$) | Cost of fertilizer (NT$) | Net returns to farmers | |
|---|---|---|---|---|---|---|---|
| | | | | | | NT$ | % |
| Sugarcane | 75 | 12,325 | 764 | 890* | 270 | 620 | 230 |
| Jute | 60 | 3,322 | 539 | 1,035 | 216 | 819 | 379 |
| Sweet potato | 50 | 23,024 | 2,325 | 1,204 | 180 | 1,024 | 569 |
| Wheat | 20 | 2,108 | 226 | 574 | 72 | 502 | 697 |
| | 40 | 2,236 | 354 | 900 | 144 | 756 | 525 |

* One half of the total value of increase for sugarcane crop is for farmers and the other half is for TSC according to the contract. The figures indicated here are one half of the total value.

From the above three tables, it can be seen that under the current prices of fertilizers and farm products, the application of ammonium sulphate, superphosphate and potassium chloride at optimum rates on these miscellaneous crops will give net returns ranging from 25-245%, 54-142% (except sugarcane) and 230-697% respectively. In some cases the maximum net returns to farmers may be obtained from heavier application of fertilizers, such as shown in Table 5.

### Table 5.

### Yield Increase and Net Returns of Some Main Crops Due to Application of Nutrient Elements

| Crop | Element applied (kg/ha) | Expected yield (kg/ha) | Increase over control (kg/ha) | Value of increase (NT$) | Cost of fertilizer (NT$) | Net returns to farmers | |
|---|---|---|---|---|---|---|---|
| | | | | | | NT$ | % |
| Sugarcane | 125 $K_2O$ | 12,577 | 1,016 | 1,184* | 450 | 734 | 163 |
| Jute | 60 $P_2O_5$ | 3,558 | 356 | 684 | 367 | 317 | 86 |
| | 180 $K_2O$ | 3,920 | 1,137 | 2,183 | 648 | 1,535 | 237 |
| Sweet potato | 60 N | 24,466 | 2,549 | 1,320 | 675 | 645 | 96 |
| | 150 $K_2O$ | 25,341 | 4,642 | 2,405 | 540 | 1,865 | 345 |
| Wheat | 50 $K_2O$ | 2,264 | 382 | 971 | 180 | 791 | 439 |

* One half of the total value of increase for sugarcane crop is for farmers and the other half is for TSC according to the contract. The figures indicated here are one half of the total value.

In other words, the current prices of fertilizers to farmers seem reasonable, except that of superphosphate, which is too high for application on sugarcane at the optimum rate, and the price of potassium chloride may be increased to some extent. However, the actual distributions for the miscellaneous crops are much less than desired except for sugarcane, wheat, jute, pineapple and tobacco. The acreage and fertilizers distributed for the various miscellaneous crops during 1956 are shown in the following table:

### Table 6.

### The Acreage and Fertilizers Distributed for Various Miscellaneous Crops, 1956

| Crop | Acreage (ha.) | Fertilizer distributed (m.t.) | Element per hectare (kg.) | | |
|---|---|---|---|---|---|
| | | | N | $P_2O_5$ | $K_2O$ |
| Sugarcane | 97,917 | 104,425 | 180.6 | 19.1 | 47.5 |
| Jute | 13,670 | 6,238 | 68.8 | 10.7 | 29.6 |
| Sweet potato | 230,236 | 6,249 | 3.0 | 1.2 | 3.2 |
| Wheat | 19,920 | 8,177 | 47.7 | 27.8 | 13.6 |
| Tea | 47,638 | 219 | 0.71 | 0.15 | 0.17 |
| Banana | 13,596 | 933 | 8.36 | 3.65 | 4.20 |
| Pineapple | 9,181 | 8,411 | 122.0 | 36.5 | 64.0 |
| Citrus | 7,938 | 1,092 | 16.6 | 7.5 | 8.5 |
| Vegetable | 81,859 | 4,213 | 6.22 | 2.74 | 2.99 |
| Tobacco | 9,709 | 7,747 | 35.9 | 55.0 | 152.3 |
| Cotton | 4,525 | 314 | 9.85 | 2.71 | 3.00 |
| Flax | 1,573 | 10 | 0.73 | 0.41 | 0.28 |
| Brown sugar | 4,500 | 563 | 20.8 | 2.3 | 5.0 |
| Green manure | 166,622 | 576 | — | 0.62 | — |
| Soybean | 37,505 | 3 | 0.004 | 0.007 | 0.009 |
| Corn | 7,716 | 4 | 0.06 | 0.03 | 0.03 |
| Peanut | 98,257 | 76 | 0.04 | 0.08 | 0.08 |
| Total: | 852,362 | 149,250 | | | |
| Average: | | | 26.61 | 4.92 | 10.04 |

The reasons for the small quantity of fertilizers used on these miscellaneous crops are: (1) farmers are not accustomed to apply chemical fertilizers, (2) the prices of crops concerned, i.e. sweet potato, peanut, tea, etc., are not favorable, and (3) financial difficulties (fertilizers are sold to farmers on cash basis). Therefore, in order to promote the use of fertilizers on the miscellaneous crops to increase the crop yield, it is necessary to set the prices of fertilizers as low as possible or to guarantee farmers a favorable return for the crop product. After farmers have been fully convinced of the effectiveness and profit of fertilizer application, the prices of fertilizers may be adjusted, if necessary.

## Table 7.

## Anticipated Yield Response from Fertilizers, Its Cost and Returns for Sugarcane Crop

(on per hectare basis)

| Element applied (kg) | | Experiment yield of RSC[1] (kg) | Expected yield of RSC[2] (kg) | Increase of RSC over control (kg) | Value of increased RSC[3, 4] (NT$) | Cost of fertilizer[5] (NT$) | Net return from use of fertilizers | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | NT$ | % |
| N | 0 | 8,699 | 8,694 | | | | | |
| | 37.5 | | 10,161 | 1,467 | 1,709 | 422 | 1,287 | 305 |
| | 75 | 11,334 | 11,350 | 2,656 | 3,094 | 844 | 2,250 | 267 |
| | 112.5 | | 12,262 | 3,568 | 4,157 | 1,266 | 2,891 | 228 |
| | 150 | 12,911 | 12,895 | 4,201 | 4,894 | 1,688 | 3,206 | 190 |
| | 187.5 | | 13,250 | 4,556 | 5,308 | 2,109 | 3,199 | 152 |
| | 225 | 13,322 | 13,327 | 4,633 | 5,397 | 2,531 | 2,866 | 113 |
| | 262.5 | | 13,127 | 4,433 | 5,164 | 2,953 | 2,211 | 75 |
| | 300 | | 12,648 | 3,954 | 4,606 | 3,375 | 1,231 | 36 |
| $P_2O_5$ | 0 | 11,954 | 11,954 | | | | | |
| | 25 | | 12,022 | 68 | 79 | 153 | – 74 | –48 |
| | 50 | | 12,096 | 142 | 165 | 306 | –141 | –46 |
| | 75 | 12,174 | 12,174 | 220 | 256 | 458 | –202 | –44 |
| | 100 | | 12,258 | 304 | 354 | 611 | –257 | –42 |
| | 125 | | 12,346 | 392 | 457 | 764 | –307 | –40 |
| | 150 | 12,440 | 12,440 | 486 | 566 | 917 | –351 | –38 |
| $K_2O$ | 0 | 11,561 | 11,561 | | | | | |
| | 25 | | 11,867 | 306 | 356 | 90 | 266 | 296 |
| | 50 | | 12,122 | 561 | 654 | 180 | 474 | 263 |
| | 75 | 12,325 | 12,325 | 764 | 890 | 270 | 620 | 230 |
| | 100 | | 12,477 | 916 | 1,067 | 360 | 707 | 196 |
| | 125 | | 12,577 | 1,016 | 1,184 | 450 | 734 | 163 |
| | 150 | 12,627 | 12,627 | 1,066 | 1,242 | 540 | 702 | 130 |
| | 175 | | 12,625 | 1,064 | 1,240 | 630 | 610 | 97 |
| | 200 | | 12,572 | 1,011 | 1,178 | 720 | 458 | 64 |
| | 225 | | 12,467 | 906 | 1,055 | 810 | 245 | 30 |

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[1] From data of 162 fertilizer field experiments conducted at 67 localities on this Island during 1943-1953 by Taiwan Sugar Experiment Station.

[2] Calculated from the actual experiment yield by means of second degree polynomial formula.

[3] Calculated at NT$2,330/MT of Raw Sugar Crystal (converted from the guaranteed price of Superior White Crystal Sugar for 1957/58 crop at NT$2,400/MT, i.e. NT$2,400÷103%=NT$2,330).

[4] One half of the total value of increase for sugarcane crop is for farmers and the other half is for TSC according to the contract. The figures indicated here are one half of the total value.

[5] Based on cash price of fertilizer distributed for miscellaneous crops:

Ammonium sulphate (20% N)=NT$2,250/MT or N=NT$11.25/kg.
Calcium superphosphate (18% $P_2O_5$)=NT$1,100/MT or $P_2O_5$=NT$6.11/kg.
Potassium chloride (50% $K_2O$)=NT$1,800/MT or $K_2O$=NT$3.60/kg.

## Table 8.

## Anticipated Yield Response From Fertilizers, Its Cost and Returns for Sweet Potato Crop

(on per hectare basis)

| Element applied (kg) | | Experiment yield[1] (kg) | | Expected yield of fresh sweet potato[2] (kg) | Increase of yield over control (kg) | Value of increased sweet potato[3] (NT$) | Cost of fertilizer[4] (NT$) | Net return from use of fertilizer | |
|---|---|---|---|---|---|---|---|---|---|
| | | Sweet potato chips | In terms of fresh sweet potato | | | | | NT$ | % |
| N | 0 | 7,196 | 21,589 | 21,917 | | | | | |
| | 15 | | | 22,788 | 871 | 451 | 169 | 282 | 167 |
| | 30 | 8,005 | 24,014 | 23,503 | 1,586 | 822 | 338 | 484 | 143 |
| | 45 | | | 24,062 | 2,145 | 1,111 | 506 | 605 | 120 |
| | 60 | 8,301 | 24,903 | 24,466 | 2,549 | 1,320 | 675 | 645 | 96 |
| | 75 | | | 24,715 | 2,798 | 1,449 | 844 | 605 | 72 |
| | 90 | 7,905 | 23,715 | 24,807 | 2,890 | 1,497 | 1,013 | 484 | 48 |
| | 105 | | | 24,744 | 2,827 | 1,464 | 1,181 | 283 | 24 |
| | 120 | 8,333 | 24,999 | 24,525 | 2,608 | 1,351 | 1,350 | 1 | 0 |
| $P_2O_5$ | 0 | 7,682 | 23,045 | 23,028 | | | | | |
| | 12.5 | | | 23,422 | 394 | 204 | 76 | 128 | 168 |
| | 25 | 7,821 | 23,462 | 23,742 | 714 | 370 | 153 | 217 | 142 |
| | 37.5 | | | 23,989 | 961 | 498 | 229 | 269 | 117 |
| | 50 | 8,301 | 24,903 | 24,163 | 1,135 | 588 | 306 | 282 | 92 |
| | 62.5 | | | 24,262 | 1,234 | 639 | 382 | 257 | 67 |
| | 75 | 7,861 | 23,583 | 24,288 | 1,260 | 653 | 458 | 195 | 43 |
| | 87.5 | | | 24,241 | 1,213 | 628 | 535 | 93 | 17 |
| | 100 | 8,117 | 24,350 | 24,120 | 1,092 | 566 | 611 | –45 | –7 |
| $K_2O$ | 0 | 6,860 | 20,579 | 20,699 | | | | | |
| | 25 | | | 21,959 | 1,260 | 653 | 90 | 563 | 626 |
| | 50 | 7,718 | 23,153 | 23,024 | 2,325 | 1,204 | 180 | 1,024 | 569 |
| | 75 | | | 23,895 | 3,196 | 1,656 | 270 | 1,386 | 513 |
| | 100 | 8,301 | 24,903 | 24,571 | 3,872 | 2,006 | 360 | 1,646 | 457 |
| | 125 | | | 25,053 | 4,354 | 2,255 | 450 | 1,805 | 401 |
| | 150 | 8,256 | 24,769 | 25,341 | 4,642 | 2,405 | 540 | 1,865 | 345 |
| | 175 | | | 25,434 | 4,735 | 2,453 | 630 | 1,823 | 289 |
| | 200 | 8,521 | 25,564 | 25,333 | 4,634 | 2,400 | 720 | 1,680 | 233 |

[1] From data of 24 fertilizer experiments conducted at 8 localities on the Island during 1952-54 by TARI.

[2] Calculated from the actual experiment yield by means of second degree polynomial formula.

[3] Based on the average farm price of fresh sweet potato during CY1957 at NT$518/MT.

[4] Based on cash price of fertilizer distributed for miscellaneous crops:
Ammonium sulphate (20% N)=NT$2,250/MT or N=NT$11.25/kg.
Calcium superphosphate (18% $P_2O_5$)=NT$1,100/MT or $P_2O_5$=NT$6.11/kg.
Potassium chloride (50% $K_2O$)=NT$1,800/MT or $K_2O$=NT$3.60/kg.

## Table 9.

## Anticipated Yield Response from Fertilizers, Its Cost and Returns for Jute Crop

(On per hectare basis)

| Element applied (kg) | | Experiment yield of crude jute[1] (kg) | Expected yield of crude jute[2] (kg) | Increase of crude jute over control (kg) | Value of increased jute[3] (NT$) | Cost of fertilizer[4] (NT$) | Net return from use of fertilizers | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | NT$ | % |
| N | 0 | 2,182 | 2,227 | | | | | |
| | 20 | | 2,673 | 446 | 856 | 225 | 631 | 280 |
| | 40 | 3,086 | 3,035 | 808 | 1,551 | 450 | 1,101 | 245 |
| | 60 | | 3,312 | 1,085 | 2,083 | 675 | 1,408 | 209 |
| | 80 | 3,629 | 3,505 | 1,278 | 2,454 | 900 | 1,554 | 173 |
| | 100 | | 3,614 | 1,387 | 2,663 | 1,125 | 1,538 | 137 |
| | 120 | 3,421 | 3,638 | 1,411 | 2,709 | 1,350 | 1,359 | 101 |
| | 140 | | 3,577 | 1,350 | 2,592 | 1,575 | 1,017 | 65 |
| | 160 | 3,520 | 3,433 | 1,206 | 2,316 | 1,800 | 516 | 29 |
| $P_2O_5$ | 0 | 3,218 | 3,202 | | | | | |
| | 20 | | 3,368 | 166 | 319 | 122 | 197 | 161 |
| | 40 | 3,439 | 3,486 | 284 | 545 | 244 | 301 | 123 |
| | 60 | | 3,558 | 356 | 684 | 367 | 317 | 86 |
| | 80 | 3,629 | 3,581 | 379 | 728 | 489 | 239 | 49 |
| | 100 | | 3,558 | 356 | 684 | 611 | 73 | 12 |
| | 120 | 3,471 | 3,487 | 285 | 547 | 733 | − 186 | − 25 |
| $K_2O$ | 0 | 2,657 | 2,783 | | | | | |
| | 30 | | 3,072 | 289 | 555 | 108 | 447 | 414 |
| | 60 | 3,629 | 3,322 | 539 | 1,035 | 216 | 819 | 379 |
| | 90 | | 3,532 | 749 | 1,438 | 324 | 1,114 | 344 |
| | 120 | 3,535 | 3,701 | 918 | 1,763 | 432 | 1,331 | 308 |
| | 150 | | 3,831 | 1,048 | 2,012 | 540 | 1,472 | 273 |
| | 180 | 3,835 | 3,920 | 1,137 | 2,183 | 648 | 1,535 | 237 |
| | 210 | | 3,969 | 1,186 | 2,277 | 756 | 1,521 | 201 |
| | 240 | 4,049 | 3,979 | 1,196 | 2,296 | 864 | 1,432 | 166 |
| | 270 | | 3,948 | 1,165 | 2,237 | 972 | 1,265 | 130 |
| | 300 | | 3,877 | 1,094 | 2,100 | 1,080 | 1,020 | 94 |

[1] From data of 15 fertilizer experiments conducted at 6 localities in Taipei, Miaoli, Taichung, Chiayi, Tainan and Lotung during 1951-1953 by TARI.

[2] Calculated from the actual experiment yield by means of second degree polynomial formula.

[3] Derived from the average purchasing price of crude jute by Taiwan Supply Bureau in 1957 at NT$1.92/kg

[4] Based on cash price of fertilizer distributed for miscellaneous crops:
Ammonium sulphate (20% N)=NT$2,250/MT or N=NT$11.25/kg.
Calcium superphosphate (18% $P_2O_5$)=NT$1,100/MT or $P_2O_5$=NT$6.11/kg.
Potassium chloride (50% $K_2O$)=NT$1,800/MT or $K_2O$=NT$3.60/kg.

## Table 10

## Anticipated Yield Response from Fertilizers, Its Cost and Returns for Wheat Crop

(on per hectare basis)

| Element applied (kg) | | Experiment yield of wheat[1] (kg) | Expected yield of wheat[2] (kg) | Increase of wheat over control (kg) | Value of increased wheat[3] (NT$) | Cost of fertilizer[4] (NT$) | Net return from use of fertilizer | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | NT$ | % |
| N | 0 | 1,756 | 1,766 | | | | | |
| | 20 | | 1,931 | 165 | 419 | 225 | 194 | 86 |
| | 40 | 2,079 | 2,059 | 293 | 745 | 450 | 295 | 66 |
| | 60 | | 2,152 | 386 | 981 | 675 | 306 | 45 |
| | 80 | 2,208 | 2,209 | 443 | 1,126 | 900 | 226 | 25 |
| | 100 | | 2,230 | 464 | 1,179 | 1,125 | 54 | 5 |
| | 120 | 2,197 | 2,216 | 450 | 1,144 | 1,350 | — 206 | —15 |
| | 140 | | 2,165 | 399 | 1,014 | 1,575 | — 561 | —36 |
| | 160 | 2,089 | 2,079 | 313 | 796 | 1,800 | — 1,004 | —56 |
| $P_2O_5$ | 0 | 1,986 | 2,002 | | | | | |
| | 15 | | 2,075 | 73 | 186 | 92 | 94 | 102 |
| | 30 | 2,174 | 2,136 | 134 | 341 | 183 | 158 | 86 |
| | 45 | | 2,186 | 184 | 468 | 275 | 193 | 70 |
| | 60 | 2,208 | 2,224 | 222 | 564 | 367 | 197 | 54 |
| | 75 | | 2,252 | 250 | 636 | 458 | 178 | 39 |
| | 90 | 2,251 | 2,267 | 265 | 674 | 550 | 124 | 23 |
| | 105 | | 2,272 | 270 | 686 | 642 | 44 | 7 |
| | 120 | 2,276 | 2,265 | 263 | 669 | 733 | — 64 | — 9 |
| $K_2O$ | 0 | 1,873 | 1,882 | | | | | |
| | 10 | | 2,007 | 125 | 318 | 36 | 282 | 783 |
| | 20 | 2,136 | 2,108 | 226 | 574 | 72 | 502 | 697 |
| | 30 | | 2,185 | 303 | 770 | 108 | 662 | 613 |
| | 40 | 2,208 | 2,236 | 354 | 900 | 144 | 756 | 525 |
| | 50 | | 2,264 | 382 | 971 | 180 | 791 | 439 |
| | 60 | 2,276 | 2,266 | 384 | 976 | 216 | 760 | 352 |
| | 70 | | 2,244 | 362 | 920 | 252 | 668 | 265 |
| | 80 | | 2,198 | 316 | 803 | 288 | 515 | 179 |
| | 90 | | 2,127 | 245 | 623 | 324 | 299 | 92 |

[1] From data of 12 fertilizer field experiments conducted at 4 localities on the Island during 1952-1954.

[2] Calculated from the actual experiment yield by means of second degree polynomial formula.

[3] Derived from the average farm price of 1956/57 crop (NT$2,542/MT).

[4] Based on each price of fertilizer distributed for miscellaneous crops:
Ammonium sulphate (20% N)=NT$2,250/MT or N=NT$11.25/kg.
Calcium superphosphate (18% $P_2O_5$)=NT$1,100/MT or $P_2O_5$=NT$6.11/kg.
Potassium chloride (50% $K_2O$)=NT$1,800/MT or $K_2O$=NT$3.60/kg.

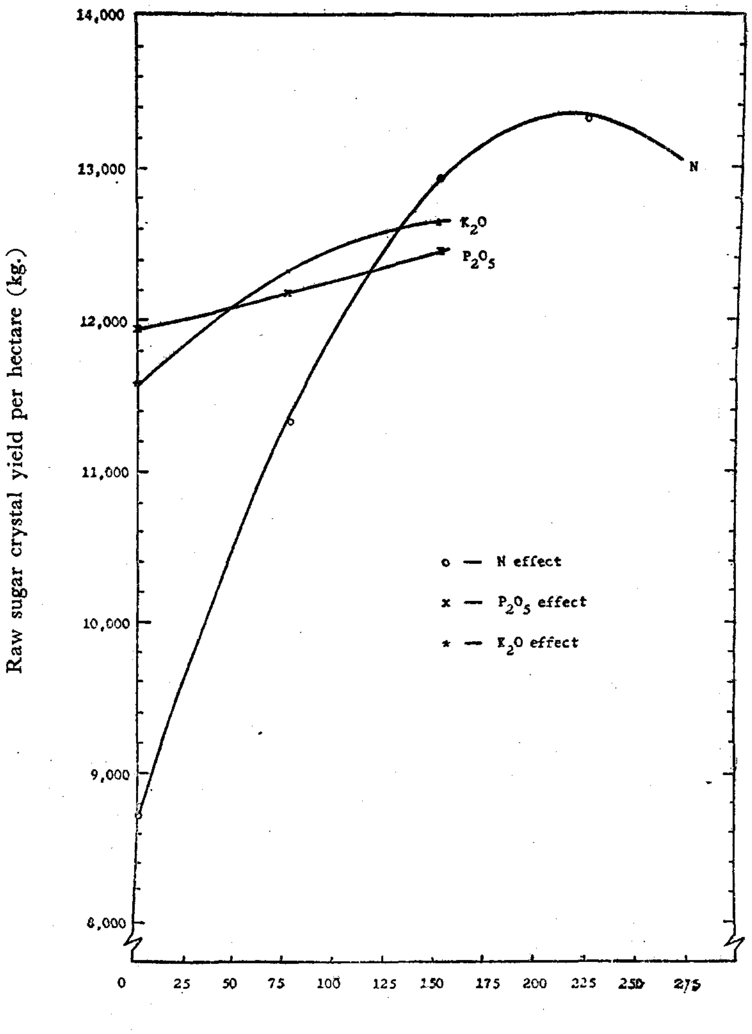

**Fig. 1. Nitrogen Response Curve for Sugarcane**

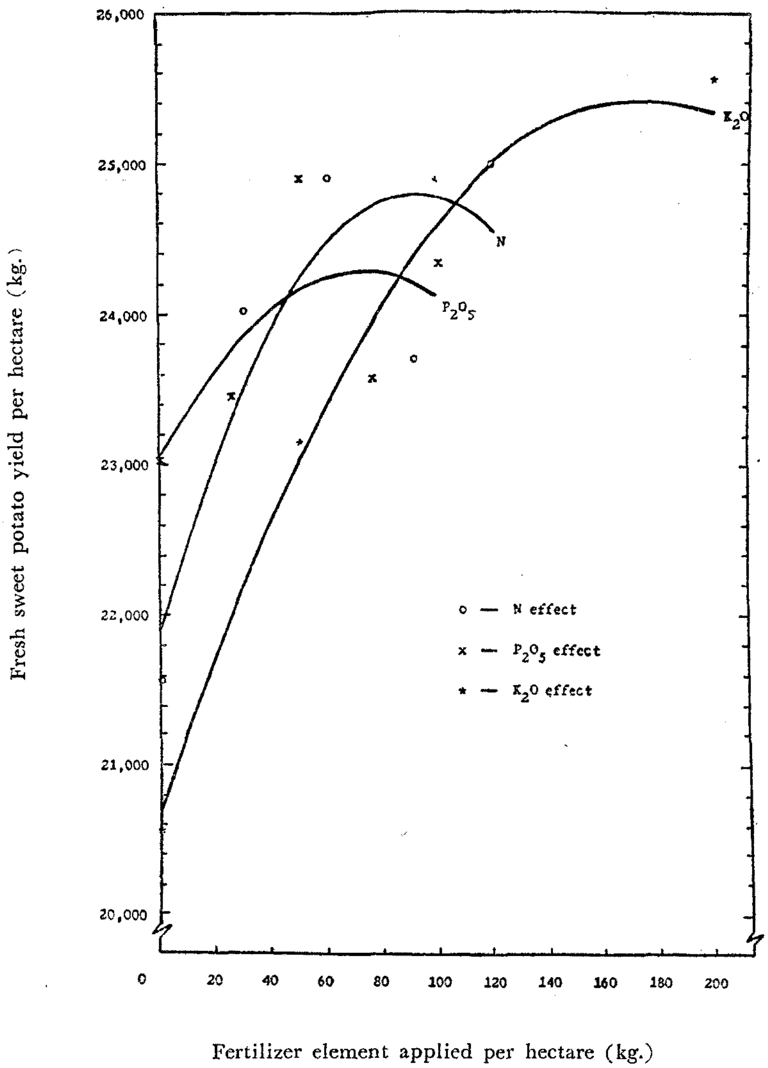

**Fig. 2. NPK Response Curve for Sweet Potato**

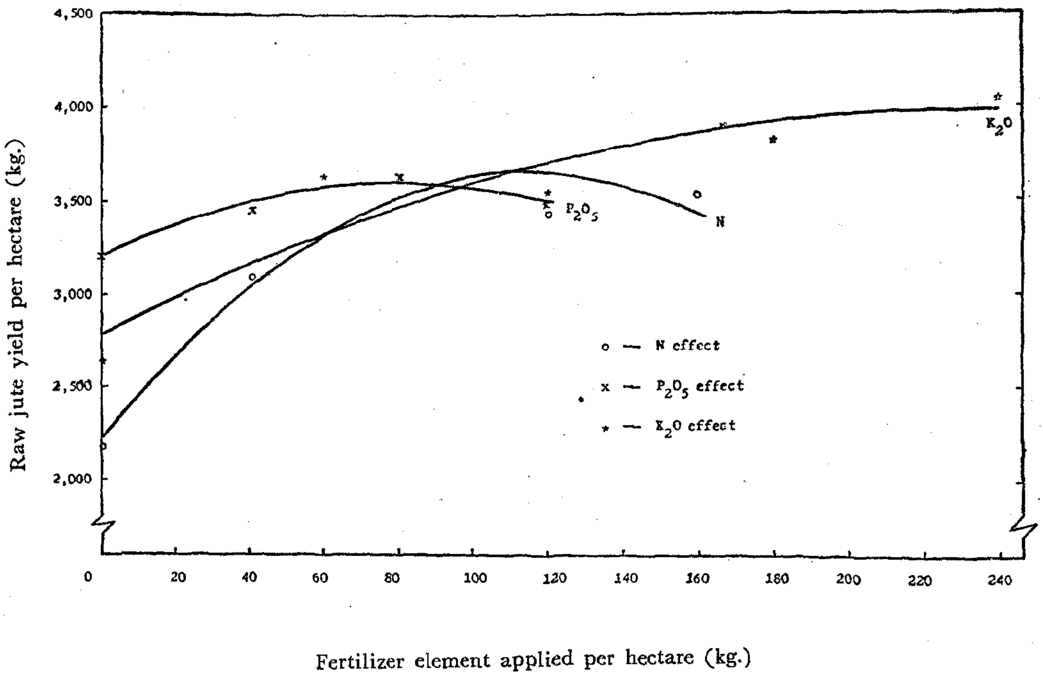

Fig. 3. NPK Response Curve for Jute

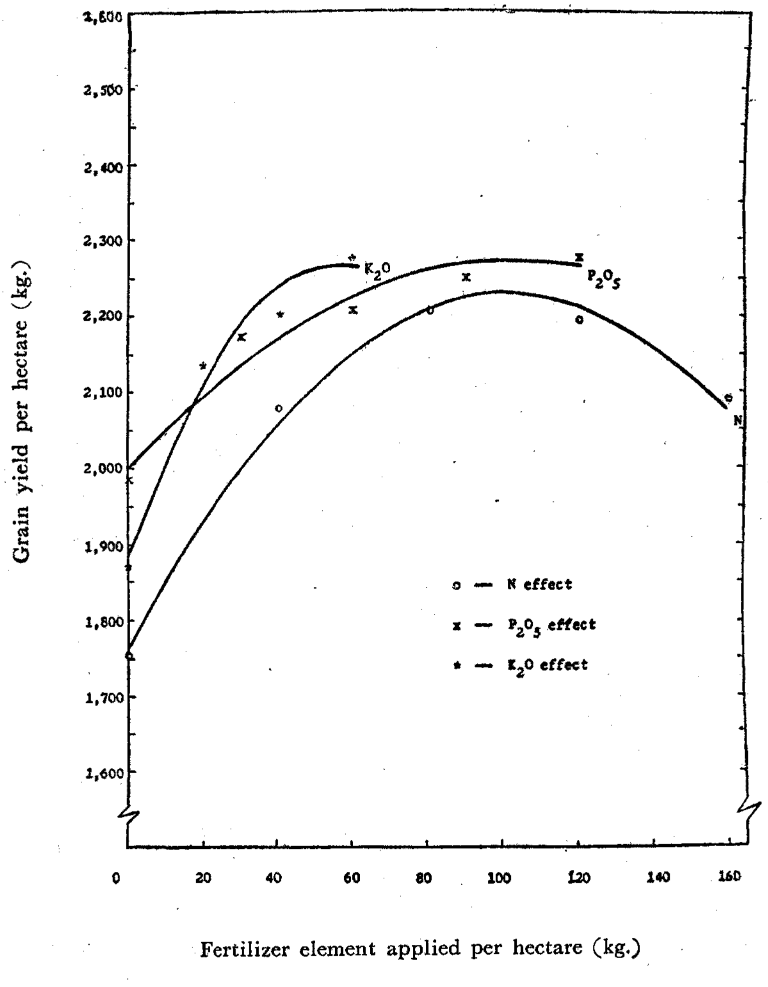

Fig. 4. NPK Response Curve for Wheat

# PRESENT DEVELOPMENT OF NODULE BACTERIA (*RHIZOBIUM*) WORK IN TAIWAN

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The importance of root nodule bacteria in Taiwan was given attention at the time of extending newly-introduced green manure crops. In the beginning, extension of yellow lupine, which was planted between rows of tea plants on acid soil of low fertility, was proved to be more economical and valuable than the application of organic manure, if the soils are indigenously abundant in nodule bacteria. In order to obtain a good result, it was recommended that soils from tea gardens already grown with lupine in previous years be mixed with seeds when planting. But this inconvenient inoculation method produced many harmful effects. Thus selecting a good strain of Rh. lupini was started in the Laboratory of Soil Microbiology, Taiwan Provincial College of Agriculture, with the financial support of the Chinese-American Joint Commission on Rural Reconstruction in 1954.

Investigations were undertaken in an attempt to determine several effective strains from five kinds of leguminous plants, namely, lupine, alfalfa, peanut, soybean and milk vetch, and to ascertain the method of making low-priced commercial inoculant. Lupine, alfalfa and milk vetch have been used as green manure, while soybean and peanut have been used as important food crops in Taiwan.

Strains under studies were introduced from abroad and isolated from native healthy plant nodules. The effectiveness of all strains is to be proved by physiological tests, pot experiments and field experiments.

## I. Nodule Bacteria of Lupine

Seven introduced strains and three native isolates of Lupine rhizobia were found to be effective in five inoculation experiments, with no significant difference observed among them. The increase of green material in the inoculated plots was from 10% to 210% over the non-inoculated ones, the variation being due

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to the location and the year of the experiments, the soils, and the climatic conditions. All these ten effective strains may be used for extension.

## II. Nodule Bacteria of Alfalfa

Of alfalfa, $AN_2$ and $AN_5$ were selected from American "Nitragin". Two field experiments were carried out in Taichung and Chunan. The yields of the inoculated plants in Taichung experiment increased by about 50.5% over the non-inoculated ones, and by about 70-170% in Chunan, the variation being due to the difference in locality and variety of alfalfa.

## III. Nodule Bacteria of Peanut

Eight strains of peanut rhizobia were collected, one from American "Nitragin", three from Crotalaria, and four from various well-grown peanut plants at different localities in Taiwan. The yield from inoculated plot was 21.43% higher than that of the non-inoculated plots.

## IV. Nodule Bacteria of Soybean

Since soybean is a crop now under energetic extension in Taiwan, selecting of effective strains is also the main work of the root nodule bacteria study. Three native strains, $GY_9$-$B_5$, $GB_{17}$-$A_4$ and $GY_{13}$-$A_1$, one strain from American "Nitragin" $GN_5$, and four from the materials supplied by the University of Wisconsin, Rh. jap. 506, 518, 523 and 525, were selected to inoculate the five varieties of soybean so as to determine the relationship of the host plant specificity in different parts of Taiwan, where optimum variety of soybean had already grown well. The increased yields of the three strains, $GY_9$-$B_5$, $GB_{17}$-$A_4$ and $GN_5$, inoculated to various varieties of soybean in different regions are shown in the following table:

**Percentage Increase of Yield of Legumes as Resulted from Inoculation**

%

| Strain | Pingtung | | | | Miaoli | Taichung | | | Kaohsiung | Chiayi |
|---|---|---|---|---|---|---|---|---|---|---|
| | Chutzu | Acadian | Palmetto | Shihshih | Sankuo | Green bean | Shihshih | Tati 13 | Palmetto | Shihshih |
| $GY_9$-$B_5$ | 10.7 | 2.24 | 15.93 | 8.4 | 98.29 | 42 | 21.67 | 7.36 | 11.54 | 15.56 |
| $GB_{17}$-$A_4$ | — | — | — | — | 97.72 | 62 | — | — | 9.54 | 5.56 |
| $GN_5$ | 29.8 | 10.2 | 4.29 | 12.07 | 3.96 | 34 | — | — | 5.92 | 13.19 |

## V. Nodule Bacteria of Milk Vetch (*Astragalus sinicus*)

Milk vetch is a good green manure for paddy soil, especially in northern Taiwan. It was inoculated in the same manner as lupine. At present, five effective strains have been obtained, $AS_5$-$E_2$ and $AS_5$-$F_2$ being the most effective ones which give more than two and half times of yields over the non-inoculated plots, with no significant difference between themselves. The other three strains, $AS_6$-$D_2$, $AS_5$-$E_3$ and $AS_6$-$D_1$, also gave double yields over the non-inoculated plants.

## VI. Commercial Inoculant

### A. The Results of Laboratory Studies

1. High content of humus is favorable to the longevity of rhizobia.

2. Dry mealy compost has been proved to be a good absorbent or substrate in making powdered inoculant.

3. 1% $CaCO_3$, used as buffer, has been proved sufficient.

4. Nutrient solution must be added when the substrate is completely sterilized.

5. 10-14 day old culture of rhizobia is the logarithmic growth phase of rhizobia both in pure culture and in powder substrate, indicating that the cells have reached their maximum rate of fission.

6. Preservation of inoculant under anaerobic and cold (below 10°C) conditions yields better results.

### B. Results of Field Experiments

1. Inoculant of root nodule bacteria of lupine after preservation for nine months increased 47.7% of the yield over the non-inoculated. Inoculant of root nodule bacteria of soybean after preservation for eight months only increased 5.57% of the yield over the non-inoculated, but pure culture of the same inoculant freshly prepared could increase the yield by 7.36%.

2. 500 ml. culture with $330 \times 10^6$ rhizobia per ml. was sufficient for treating 50 kg. of lupine seed. With this rate of inoculant, an increase of yield by 79.83% had been obtained in field experiment.

3. Commercialized inoculant with compost powder as the substrate caused an increase of 21.67% of soybean as versus 14.34% caused by pure culture.

About one hundred demonstrations will be carried out in the next year. If effective, commercial inoculant will be supplied to farmers thereafter. If the inoculant costs NT$30 per hectare, even an increase of 5 kg./ha. of soybean at NT$6/kg. will be enough to cover the cost of inoculation.

# PRODUCTION AND EXTENSION OF ORGANIC MANURES IN TAIWAN

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Under tropical and sub-tropical climatic and soil conditions of Taiwan, maintenance of organic matter in soils especially in paddy fields is considered essential. It is revealed in the Taiwan Agricultural Yearbook published by the Taiwan Provincial Department of Agriculture & Forestry that at present about 14 million metric tons of organic manures, including green manure, animal manure, night-soil, compost (hog farmyard manure), straw and ash, are consumed every year for crop production. Calculating on an island-wide basis, an average total of 8-9 m.t. of organic manures is applied to each hectare of cultivated land per annum. In terms of N, $P_2O_5$ and $K_2O$ contents in the organic manure, it is estimated that a total of approximately 60,000 m.t. of nitrogen, 32,000 m.t. of $P_2O_5$ and 46,000 m.t. of $K_2O$ has been consumed from the source of organic manure, or 35 kg. of N, 19 kg. of $P_2O_5$ and 27 kg. of $K_2O$ per hectare. (See the attached table, calculated on the basis of 1.7 million hectares of cultivated land for per hectare plant food supply.)

In view of this fact, JCRR has undertaken the promotion of organic manure production along the following lines.

## I. Repair and Construction of Compost Shelters

Compost-making in Taiwan is simply done by heaping decomposable materials until sufficiently decayed. The raw materials for compost are rice straw, sugarcane leaves, grass, rice husks and other farm refuse, to which animal manure, mainly that of hog, is added. Farmers have been taught to add calcium cyanamide to make compost in case animal manure is not available.

During the complicated chemical changes that take place in compost, care should be taken to prevent losses of valuable nutrients. As much of the nutrients contained in compost are water soluble, they are easily leached out in rainy weather. Nitrogen may be lost in gas form when the compost is exposed in the open during dry weather. Therefore, farmers in Taiwan are advised to make and store their compost manure under a shed whenever possible. However, it is not uncommon to see in the rural areas that many compost heaps are left in the open, yielding manure low in fertility value. According to the available data, the plant nutrients of compost made in the shelter contain about 0.42% of nitrogen, 0.21% of phosphoric acid and 0.15% of potash, while the contents of compost made outdoors are reduced approximately by one-half.

As shown in the attached table, compost plays the most important role among all organic manures, constituting about 54% of the total quantity consumed. In view of the importance of compost to the agricultural production programs in Taiwan, JCRR has provided funds to assist farmers in the repair/construction of compost shelters ever since 1950. Pamphlets and posters were printed and distributed to farmers. Training classes were held to stress the importance of compost and the proper methods of composting. Up to 1959, a total of 122,357 shelters has been repaired or constructed under the joint technical and financial assistance of the Chinese Government and JCRR.

Subsidies given to the beneficiary farmers are both in kind (cement) and in cash, covering about one-third to one-half of the total cost of construction, leaving the balance to be provided by the farmers themselves. Since 1950, a total of NT$31.7 million has been spent on this program.

Based on the survey conducted by the Provincial Department of Agriculture & Forestry, each compost shelter produces about 25 m.t. of compost per annum. Thus from the 122,357 compost shelters built under the program, more than 3,000,000 m.t. of compost of better quality can be produced each year, containing approximately 12,600 m.t. of nitrogen, 6,300 m.t. of phosphoric acid ($P_2O_5$) and 4,500 m.t. of potash ($K_2O$) with a total value of more than US$4.3 million estimated at current world market prices.

## II. Demonstration and Extension of Green Manure Crop

Green manure crops have been planted on this Island for many years already. They are mostly planted in paddy field for rice. At the highest record period from the year of 1948 to 1953, approximately 200,000 ha. of paddy field were planted with green manure crops which occupied about 22-25% of the total acreage of paddy land. The common green manure crops are sesbania (*Sesbania roxburghii*), soybean (*Glycine max*), radish (*Raphanus sativus*), pea (*Pisum sativum*), green bean (*Phaseolus radiatus*), cowpea (*Vigna sinensis*), etc. Among these crops the planted acreage of sesbania is the biggest, occupying about 40-50% of the total acreage of green manure crops, soybean and radish the next. Sesbania and soybean are commonly grown in southern Taiwan, green bean and cowpea in the Tainan area, pea in the central and radish in the north. Recently broad bean (*Vicia faba*) has been introduced to the Hsinchu area and astragalus (*Astragalus sinicus*) in northern Taiwan, which will be discussed in more details later.

Besides green manure crops for rice as mentioned above, the Taiwan Sugar Corporation has planted some green manure crops on their farms. They are mucuna (*Mucuna capitata*), sesbania (*Sesbania roxburghii*), crotalaria (*Crotalaria juncea*), poona pea (*Vigna sinensis*), etc.

In the past, very small acreage of green manure crops or cover crops was under cultivation on the slope land.

The program on the demonstration and extension of green manure crops is aimed at two targets: the fallow land in northern Taiwan after the harvest of the second rice crop, and the hilly or mountainous land of tea plantations and fruit orchards.

### A. Extension of Lupine for Tea Plantations

Lupine (*Lupinus leutus*) has been proved a good green manure crop for tea plantations. It is a winter legume, planted between September and October between rows of tea plants, and turned into the soil for green manuring from March to April of the following year when flowering. Before 1949, only about 800 ha. of tea gardens were planted with yellow-flower lupine, but the possible planted acreage on the tableland was approximately estimated at 13,000 ha. After a 5-year seed multiplication and extension program, tea growers have already accepted lupine as a good green manure crop for tea. At present about 5,000 ha. of tea plantations are planted with lupine.

Recently, JCRR has introduced some varieties of sweet yellow lupine from America and France which has been proved quite successful in growing. The multiplication of seeds has been undertaken in order to replace the old variety of bitter type. This sweet lupine can be used not only as green manure, but also as a source of animal feed.

### B. Extension of Astragalus as Green Manure for Rice

Although efforts were made in the earlier years to find a suitable legume to be planted in winter as green manure for the first rice crop, it had not been successful until the recent few years when *Astragalus sinicus*, so called milk vetch or ganges, was trial-tested by the Taiwan Agricultural Research Institute. The good growth and harvest of this legume indicate that it can be used as green manure for the first rice crop in the northern area. After several years of demonstration and extension, farmers in Taipei, Ilan, Taoyuan, Hsinchu and Miaoli have shown great interest in adopting this crop as green manure for paddy rice. In 1959, a total of about 8,000 ha. of paddy field has been planted to this new crop.

### C. Experiment and Demonstration of Green Manures on Hilly Land

In central and southern Taiwan, pineapple plantations are mostly located on hilly land or tableland. Soils are lateritic, acid in reaction, and lacking organic matter. Farmers are not accustomed to planting green manure crops for pineapple. Since 1952, the Taiwan Pineapple Corporation has carried out a project on the demonstration of green manuring for pineapple fields. *Mucuna capitata* was planted in the fallow land where pineapple had been cultivated for five years. The growers were taught to adopt a crop cultivation system to rotate five years of pineapple with one year of legume to maintain soil fertility. After several years of demonstration, this rotation system has finally been accepted by the pineapple growers.

Forty kinds of leguminous crops are being tested on hilly land in order to reduce soil erosion on the steep slope land where banana, citrus, Assam tea and pineapple are planted. Among these varieties it is found that centrosema (*Centrosema pubesceus*), tropical kudzu (*Puerario phaseoloides*) and desmodium (*Desmodium ovalifolium*) are rather promising.

## III. Utilization of Urban Organic Waste

Disposal of night-soil and city garbage in a sanitary manner is an important job of a modern city administration. By employing proper treatment, these two kinds of city organic wastes might be treated for sanitary disposal as well as for producing organic maure for maintaining soil fertility in areas near the cities. In view of this fact, JCRR has been giving subsidies to selected city governments to help them improve the night-soil collection and distribution system through the improvement of methods, tools, equipment and installations of night-soil collection, transportation, maturation, storage and distribution.

A pilot composting plant has been installed at Pingtung City under the sponsorship of the Institute of Environmental Sanitation of the Taiwan Provincial Government to carry out experimental work on the improvement of the collection, treatment and utilization of city garbage and night-soil. It is intended that the experimental results obtained from this pilot plant, when proved successful and economical, may be extended to other cities.

Up to now, following the similar pattern, another composting plant has been built up at Lotung, Ilan *hsien*; and a much bigger plant, being ten times of the production capacity of the Pingtung plant, has been under construction in Kaohsiung City.

To provide basic data for the development of composting or other disposal methods for city and village refuse, a survey and analysis of organic refuse was conducted by the Institute of Public Health of the National Taiwan University with JCRR financial support to collect, segregate and determine the physical composition of refuse in 12 major areas in Taiwan.

## Table Showing Consumption of Principal Organic Manures in Taiwan, 1956-1958

(on element basis)

(Unit: m.t.)

| Year | Type | Gross |  | N | $P_2O_5$ | $K_2O$ |
|---|---|---|---|---|---|---|
|  |  | Quantity | % |  |  |  |
| 1956 | Green manure | 1,544,921 | 11.1 | 7,725 | 1,545 | 7,725 |
|  | Animal manure | 2,529,885 | 18.2 | 7,590 | 3,795 | 2,530 |
|  | Night-soil | 1,652,392 | 11.9 | 8,262 | 4,131 | 8,262 |
|  | Compost | 7,327,320 | 52.8 | 30,775 | 15,387 | 10,991 |
|  | Straw | 559,774 | 4.1 | 3,191 | 1,287 | 5,878 |
|  | Ash | 257,276 | 1.9 | — | 4,297 | 8,696 |
|  | Total | 13,871,568 | 100.0 | 57,543 | 30,442 | 44,082 |
| 1957 | Green manure | 1,275,607 | 8.8 | 6,378 | 1,276 | 6,378 |
|  | Animal manure | 2,483,784 | 17.1 | 7,451 | 3,726 | 2,484 |
|  | Night-soil | 1,772,840 | 12.2 | 8,864 | 4,432 | 8,864 |
|  | Compost | 8,109,158 | 55.8 | 34,058 | 17,029 | 12,164 |
|  | Straw | 604,613 | 4.2 | 3,446 | 1,391 | 6,348 |
|  | Ash | 271,503 | 1.9 | — | 4,534 | 9,177 |
|  | Total | 14,517,505 | 100.0 | 60,197 | 32,388 | 45,415 |
| 1958 | Green manure | 1,223,802 | 8.3 | 6,119 | 1,224 | 6,119 |
|  | Animal manure | 2,919,908 | 19.7 | 8,760 | 4,380 | 2,920 |
|  | Night-soil | 1,999,864 | 13.5 | 9,999 | 5,000 | 9,999 |
|  | Compost | 7,759,409 | 52.3 | 32,590 | 16,295 | 11,639 |
|  | Straw | 593,834 | 4.0 | 3,385 | 1,366 | 6,235 |
|  | Ash | 323,864 | 2.2 | — | 5,409 | 10,947 |
|  | Total | 14,820,681 | 100.0 | 60,853 | 33,674 | 47,859 |
| Average | Green manure | 1,348,110 | 9.4 | 6,741 | 1,348 | 6,741 |
|  | Animal manure | 2,644,526 | 18.3 | 7,934 | 3,967 | 2,645 |
|  | Night-soil | 1,808,365 | 12.5 | 9,042 | 4,521 | 9,042 |
|  | Compost | 7,731,962 | 53.7 | 32,474 | 16,237 | 11,598 |
|  | Straw | 586,074 | 4.1 | 3,341 | 1,348 | 6,154 |
|  | Ash | 284,214 | 2.0 | — | 4,746 | 9,606 |
|  | Total | 14,403,251 | 100.0 | 59,532 | 32,167 | 45,786 |

Remarks: (1) Source: "Taiwan Agricultural Yearbook" published by the Taiwan Provincial Department of Agriculture & Forestry.

(2) Element content (%):

|  | N | $P_2O_5$ | $K_2O$ |
|---|---|---|---|
| Green manure | 0.50 | 0.10 | 0.50 |
| Animal manure | 0.30 | 0.15 | 0.10 |
| Night-soil | 0.50 | 0.25 | 0.50 |
| Compost | 0.42 | 0.21 | 0.15 |
| Straw | 0.57 | 0.23 | 1.05 |
| Ash | — | 1.67 | 3.38 |

# THE FERTILIZER INDUSTRY OF TAIWAN

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Taiwan Fertilizer Company

The last fourteen years have witnessed the rapid growth of the fertilizer industry of Taiwan. Tonnage-wise, the annual output of the industry is now about 453,000 metric tons, which is equivalent to 13 times the pre-war peak of 33,858 metric tons as of 1939, or 1,130 times the post-war low record of 400 metric tons as of 1945.

Many factors have contributed to that growth. Among the most influential ones is the call for heavier rates of fertilizer application to feed the crops, and indirectly to feed a growing population. In other words, the industry is blessed with a ready market, which is constantly growing in volume. The market offers a challenge for the industry to meet the increasing demand for fertilizer materials. The quick response of the industry to that challenge made possible with aid funds from the United Nations and the United States of America and the technical assistance of the J. G. White Engineering Corporation has led to the rapid growth of the industry to date.

## I. Plants and Processes

The fertilizer industry of Taiwan has kept asking itself a number of pertinent questions. The followings are typical:

A. Should the existing plants be modernized? If so, how?

B. Should new plants be built? Is so, what products should be made and which well-proven process or processes should be selected?

C. What would be the farmers' response to the new fertilizers, if new products are to be made? Have sufficient field experiments been conducted for demonstration purposes? If so, what conclusion can be drawn therefrom?

D. What would be the cost of production? And the prices of products upon delivery to the farms? Can the investment be repaid within a reasonably short period?

As can be seen from what follows, the fertilizer industry of Taiwan has been successfully guided along by the answers obtained therefrom.

There exist in Taiwan two main fertilizer manufacturers, viz. the Taiwan Fertilizer Company (hereafter referred to as TFC) and the Kaohsiung Ammonium Sulfate Corporation (KASC). TFC operates seven plants, two making calcium cyanamide, one making calcium superphosphate, one making calcium superphosphate and nitrophosphate, one making serpentine-fused phosphate, one making nitrochalk, and one making urea; KASC operates one ammonium sulfate plant, which also produces nitrate nitrogen solution. These two companies are marketing five types of simple nitrogenous fertilizers, two types of simple phosphates, and one type of N-P compound fertilizer. The distribution of the plants is shown in Figure 1.

In 1946, TFC was operating one cyanamide plant (in Keelung) and two calcium superphosphate plants (in Keelung and Kaohsiung). Capacities were low and efficiency poor. All were soon modernized, and consequently, capacities were stepped up and efficiency improved. But the three plants were far from being able to meet the increasing demand for fertilizer materials. Immediate actions were taken, and TFC's second calcium cyanamide plant (in Hsinchu) was soon on stream in April 1951, and the operation of its serpentine-fused phosphate plant (in Lotung) followed closely in August 1951.[30, 31] Three more new projects were initiated. Taking advantage of the most recent advance in fertilizer technology and applying new proven processes, TFC's nitrochalk (in Hualien), nitrophosphate (in Kaohsiung) and urea (in Nankong) plants have been put in regular operation respectively since January 1958,[27] January 1959 and January 1960.

KASC started operating its ammonium sulfate plant (in Kaohsiung) in January 1951. Expansion was soon underway, and by 1957, the plant was operating at more than three times its previous capacity. Further expansion has been undertaken, and its capacity will be enlarged very shortly to thirty times that of 1951. Ammonium sulfate and small quantities of nitrate nitrogen solution are being marketed.[25]

Several of the plants operated by these two companies employ well-known conventional processes, for instance, modified Frank-Caro process for making calcium cyanamide, modified Haber-Bosch process for ammonia synthesis, chamber, tower and contact processes for making sulfuric acid, and batch or continuous superphosphate processes complete with Svenska or Broadfield dens. Other plants apply more recent technological developments. For example, two plants make nitric acid by a modified Du Pont one-tower high-pressure process, one of them being designed for power recovery; one plant produces a N-P fertilizer by

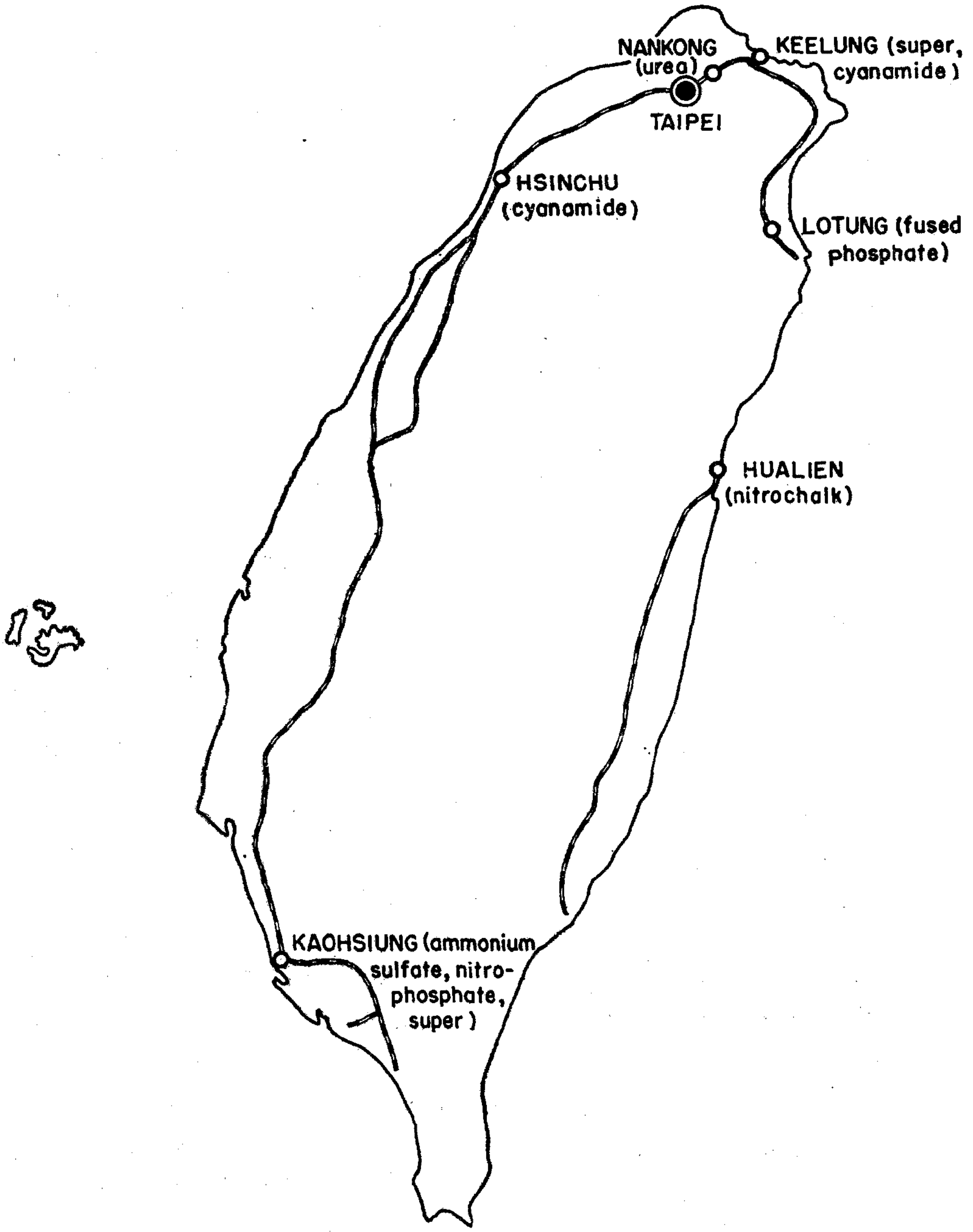

**Fig. 1. Distribution of Fertilizer Plants in Taiwan**

a carbono-nitric acidulation process owned by the Potasse et Engrais Chimique of Paris; one plant applies the Swiss Inventa process to make urea; one plant produces serpentine-fused phosphate by a process invented by TVA and plant-developed in Taiwan.[13, 14, 16, 18, 22]

The plants and the essential processes used are summarized in Table 1. The data contained therein demonstrate to some extent the thinking of those engaged in development and planning for the fertilizer industry of Taiwan and indicate how such thinking has followed the answers to the questions previously enumerated. A further discussion of such thinking follows.

Among the objectives of fertilizer industry planning as applied to the conditions of Taiwan are higher capacity, lower production cost, improved quality of products, and saving of foreign exchange. It is known to all concerned that production capacity can be stepped up by various means including installation of new equipment, modernization of existing equipment, and application of process and quality control technics, while production cost can be lowered by using cheaper raw materials, raising production efficiencies, making more concentrated products, and applying modern management technics to lower overhead charges. Fertilizer products with good handling and keeping qualities are more acceptable to the farmers and are therefore much easier to sell. Saving of foreign exchange can be effected by importing less fertilizers as a result of increased domestic production or less raw materials as would be required for making certain types of products. All these objectives are interdependent upon one another and are sometimes conflicting; so it is difficult to accomplish all the four objectives by any single project. For instance, limestone, coke and power are all locally available for the manufacture of calcium cyanamide, but cost-wise, for the production of more nitrogenous fertilizers, calcium cyanamide is no longer a suitable choice. Making serpentine-fused phosphate with serpentine mined in Taiwan is one way to save sulfur, which had to be imported in sizable quantity several years ago, but it still costs slightly more to make than calcium superphosphate. Nitrochalk, nitrophosphate and urea all do not consume sulfuric acid in the course of their manufacture, all being in granular form, and their plant food values have all been field-tested here and abroad; but many farmers still have some special preference for ammonium sulfate, partly because of the latter's excellent physical properties. Incidentally, the latest project is aimed at larger scale production of ammonium sulfate.

In short, none of the known fertilizer projects has ever accomplished the above stated four objectives all at once. To explain why this is the case, reference should

**Table 1.**

**Plants and Processes of the Fertilizer Industry of Taiwan**

(23, 25, 27, 30, 31, 33)

| Owner | Plant designation | Location | Products | Guaranteed analysis, % |  | Production as of year indicated (m. t.) | Current capacity (m. t.) | Process used |
|---|---|---|---|---|---|---|---|---|
|  |  |  |  | N | $P_2O_5$ |  |  |  |
| Taiwan Fertilizer Company | No. 1 | Keelung | Calcium cyanamide | 20 | — | 3,024 (1946) | 36,000 | Frank-Caro and Fujiyama |
|  | No. 2 | Keelung | Calcium superphosphate | — | 18 | 400 (1945) | 50,000 | Broadfield |
|  | No. 3 | Kaohsiung | Calcium superphosphate | — | 18 | 1,219 (1946) | 60,000 | Svenska |
|  |  |  | Nitrophosphate | 16 | 14 | 2,834 (1957) | 35,000 | Potasse et Engrais Chimique |
|  | No. 4 | Lotung | Serpentine-fused phosphate | — | 18 | 3,697 (1951) | 14,000 | TVA-Taiwan Fertilizer Company |
|  | No. 5 | Hsinchu | Calcium cyanamide | 20 | — | 21,012 (1951) | 39,000 | Frank-Caro |
|  | No. 6 | Nankong | Urea | 45 | — | 6,620 (1959) | 84,000 | Inventa |
|  | No. 7 | Hualien | Nitrochalk | 20 | — | 1,995 (1957) | 65,000 | Chemico-Wah Chang & Societe Belge de L'Azote |
| Kaohsiung Ammonium Sulfate Corporation |  | Kaohsiung | Ammonium sulfate | 20.5 | — | 17 (1950) | 70,000* | Chemico-Wah Chang |

*Including the equivalent of small quantities of nitrate-nitrogen solution.

be made to two important events pertinent to the world fertilizer industry which have made headlines in the last fourteen years: first, the sudden world-wide sulfur shortage in 1950-1952,[10, 11, 29, 31] and second, the dramatic post-war advances in urea technology.[2, 3, 4, 5, 6, 9, 24, 26, 28, 32] These events explain in part why thinking on fertilizer industry development has changed from time to time, and subsequently, several new names such as serpentine-fused phosphate, nitrophosphate, nitrochalk and urea have appeared in the product lists of the fertilizer industry of Taiwan. However, increased domestic supply of fertilizer materials, old and new alike, will result in substantial saving of foreign exchange as otherwise would be required for fertilizer import. Foreign exchange saving is a problem of grave concern to Taiwan.

## II. Production

Production data are compiled and shown in Table 2. The rate of phosphate capacity expansion and the appearance of new fixed nitrogen plants in the last few years are both remarkable. These facts lead to a discussion on the balanced supply of plant nutrients.

Liebig's Law of Minimum in plant nutrition may apply to the fertilizer industry, if the latter is to act as the exclusive supplier of all plant nutrients consumed. Thus, a reduced supply of or a deficiency in any plant nutrient may be harmful to the crops, if it is not made up with import. Potash has to be imported and is applied as such. This leaves nitrogen and phosphates for local production. As governed by Liebig's Law, the production of fixed nitrogen should bear a definite ratio to that of phosphates. In the case of Taiwan, the most suitable $N:P_2O_5$ weight ratio is about 3:1. Referring now to Table 3, it can be seen that the actual production ratio remained at about 1:1 in the period 1952-1957, but has been steadily increasing; and it is expected that the requirement of 3:1 may soon be complied with.

It might be interesting to take a look at the consumption-production gap. More data will be found elsewhere in this bulletin, but the figures in Table 3 are quite noteworthy. It can be seen that there has been quite a big gap between plant food consumption and production (consumption figures of potash not shown). In spite of the rapid growth of the fertilizer industry, the gap for $P_2O_5$ has remained fairly constant at an average of 11,230 metric tons per year for the period 1952-1959, while that for N appears to have been widening, reaching a maximun of 74,193 metric tons in 1957, but gradually narrowing down in subsequent years.

## Table 2.
## Fertilizer Production in Taiwan

(23, 30, 31)

Unit: m.t.

| Calendar year | Calcium super-phosphate (18% $P_2O_5$) | Serpentine-fused phosphate (18% $P_2O_5$) | Nitro-phosphate (16% N 14% $P_2O_5$) | Calcium cyanamide (20% N) | Ammonium sulfate (20.5%N) | Nitrogen solution (37% N) | Nitrochalk (20% N) | Urea (45% N) |
|---|---|---|---|---|---|---|---|---|
| 1945 | 400 | — | — | — | — | — | — | — |
| 1946 | 1,639 | — | — | 3,204 | — | — | — | — |
| 1947 | 9,205 | — | — | 8,003 | — | — | — | — |
| 1948 | 28,299 | — | — | 10,030 | — | — | — | — |
| 1949 | 31,830 | — | — | 14,010 | — | — | — | — |
| 1950 | 37,790 | — | — | 20,885 | 17 | — | — | — |
| 1951 | 54,151 | 3,697 | — | 47,582 | 4,951 | — | — | — |
| 1952 | 62,065 | 12,664* | — | 68,070 | 5,732 | — | — | — |
| 1953 | 69,145 | 15,613* | — | 73,242 | 5,839 | — | — | — |
| 1954 | 78,049 | 13,013* | — | 71,750 | 4,988 | — | — | — |
| 1955 | 80,188 | 8,830* | — | 74,010 | 4,428 | — | — | — |
| 1956 | 100,714 | 10,030 | — | 74,518 | 6,598 | 300 | — | — |
| 1957 | 103,605 | 10,055 | 2,834 | 74,790 | 15,362 | 2,574 | 1,995 | — |
| 1958 | 103,810 | 7,620 | 17,370 | 69,948 | 17,408 | 3,653 | 32,492 | — |
| 1959 | 116,550 | 10,054 | 20,050 | 65,355 | 22,104 | 4,455 | 43,358 | 6,620 |

* Including experimental quantities produced by the Taiwan Industrial & Mining Corporation.

## Table 3.
## Consumption and Production Gaps of Fixed Nitrogen and Phosphates

Unit: m.t.

| Calendar year | N | | | $P_2O_5$ | | |
|---|---|---|---|---|---|---|
| | Consumption[7,8] a | Production b, c | Difference d | Consumption[7,8] a | Production b | Difference d |
| 1950 | 48,708 | 4,180 | 44,528 | 12,790 | 6,802 | 5,988 |
| 1951 | 59,285 | 10,532 | 48,753 | 12,771 | 10,413 | 2,358 |
| 1952 | 69,488 | 14,789 | 54,699 | 22,013 | 13,451 | 8,562 |
| 1953 | 69,595 | 15,846 | 53,749 | 25,210 | 15,256 | 9,954 |
| 1954 | 82,008 | 15,373 | 66,635 | 27,330 | 16,391 | 10,939 |
| 1955 | 82,425 | 15,710 | 66,715 | 29,084 | 16,023 | 13,061 |
| 1956 | 89,439 | 16,367 | 73,072 | 30,693 | 19,934 | 10,759 |
| 1957 | 94,105 | 19,912 | 74,193 | 31,954 | 20,856 | 11,098 |
| 1958 | 98,191 | 28,188 | 70,003 | 34,072 | 22,489 | 11,583 |
| 1959 | 96,470[e] | 34,109 | 62,361 | 39,481[e] | 25,596 | 13,885 |

a Excluding the small amount sold to free market by the manufacturers.
b Computed from data in Table 2.
c Excluding ammonia for non-fertilizer uses.
d Consumption minus production.
e Preliminary.

As there are more mouths to feed in a limited land area as indicated above, more intensive farming appears to be the best solution, hence more fertilizers will be needed. This means that the gaps may eventually widen, if the fertilizer industry chooses to stand still. As the industry has the obligation to close these gaps, it has decided not to stand still.

## III. Sales

As presented above, the fertilizer industry of Taiwan is blessed with a ready market. It must be added here that the industry is also blessed with an efficient fertilizer distribution system. The system helps to minimize the industry's sales efforts and brings about prompt and timely delivery of fertilizer products to the end-using points. It helps the farmers and the industry alike.

More detailed descriptions related to the fertilizer distribution system in Taiwan will be found elsewhere in this bulletin. Suffice it to say that there is very limited retail trade in operation and that a great majority of the fertilizer products are being handled through the Taiwan Food Bureau and the Taiwan Sugar Corporation, the main channels operating under the present distribution system. These two parties are in fact the immediate customers of the industry.

## IV. Research and Development

No chemical industry can afford to operate without being followed by research and development activities. This is naturally true with the fertilizer industry of Taiwan.

The industry has taken an active part in island-wide soil and fertilizer investigations and has maintained close cooperation with all relevant agricultural research institutes referred to elsewhere in this bulletin. Of special interest to the industry are soil fertility and fertilizer efficiency studies. These studies lead to recommendations on the use of fertilizers for best results.

To conduct technological studies, no centralized facilities are available, but much works have been done at the plant level, mostly on problems of immediate and practical concern. Some of such works have successfully gone through the commercial development stage, while others are being studied on the pilot-plant or bench scale. Published information includes a process for the granulation of calcium cyanamide with molasses and carbon dioxide[1], a process for the fusion of rock phosphate with serpentine and studies of the physical, chemical and agronomic properties of such fusion products,[12, 13, 14, 16, 18, 21, 22, 30, 31, 32] and a process for the conversion of calcium superphosphate into dicalcium phosphate, monocalcium phosphate, phosphoric acid, triple superphosphate, ammonium phosphate, sodium phosphate, a calcium sulfate-fused phosphate, and high analysis complete fertilizers.[15, 17, 19, 20] The purposes of such works are to improve the handling and keeping properties of the products, to make use of cheaper raw materials, or to open up new sources of fertilizers or chemicals, all aim at increased economic gains for the industry.

## V. Summary

The fertilizer industry of Taiwan has made rapid progress in the last fourteen years, and is now capable of turning out annually 75,000 metric tons of calcium cyanamide, 70,000 metric tons of ammonium sulfate, 65,000 metric tons of nitrochalk, 84,000 metric tons of urea, 110,000 metric tons of calcium superphosphate, 14,000 metric tons of serpentine-fused phosphate, and 35,000 metric tons of nitrophosphate. This has been made possible through regular expansion, operation of an efficient fertilizer distribution system, and research and development activities; however, the total production capacity is still lagging behind the actual demand for nitrogen and phosphates. Further expansion is anticipated.

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# FERTILIZER CONSUMPTION AND ITS TREND IN TAIWAN

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## I. Trend of Consumption, Local Production and Import of Chemical Fertilizers

Appendix Table 1 gives data pertinent to this topic, covering a period from 1952 through 1964. 1952 is the year preceding the First 4-Year Plan for Economic Development of Taiwan and the ensuing period covers that of three consecutive 4-Year Plans. The figures used are on plant nutrient basis, i.e., N, $P_2O_5$ and $K_2O$. This is necessary because of the different nutrient contents of the different fertilizers involved. To use the gross tonnage of fertilizers will not present an accurate picture. From appendix Table 1, the following observations could be made:

A. The consumption of the N, P, K fertilizers has continuously been increasing in the past and will continue to increase in the future. The increase in absolute amount is largest in N. However, when expressed in indices, the increase is fastest in potash fertilizer, followed by phosphorous and nitrogenous, indicating a healthy trend of more balanced application of N, P, K by the Taiwan farmers.

| Year | Consumption index | | |
|---|---|---|---|
| | N | $P_2O_5$ | $K_2O$ |
| 1952 | 100 | 100 | 100 |
| 1959 | 148 | 154 | 234 |
| 1964 (Plan) | 170 | 208 | 451 |

B. The local production of nitrogenous and phosphorous fertilizers increased little during the First 4-Year Plan period, but more rapidly during the Second 4-Year Plan period due to the construction of new plants. Percentage-wide, it increased at a more rapid rate than the consumption increase.

| Year | Local production index | |
|---|---|---|
| | N | $P_2O_5$ |
| 1952 | 100 | 100 |
| 1959 | 231 | 190 |
| 1964 (Plan) | 649 | 247 |

C. Although the local production index increased at a faster rate than the consumption index, the actual deficit of nitrogenous fertilizer did not show clear sign of decrease until 1960 due to the larger absolute increase in consumption than production. The reduction in deficit of the nitrogenous fertilizer during the Third 4-Year Plan period will be significant. The deficit of phosphorous fertilizer will continue at about 10,000 m.t. even at the end of the Third 4-Year Plan, 1964.

Taking N, P, K as a whole, it may be generalized that, in 1952, locally produced fertilizers made up 27.2 percent of the total consumption. In 1959, they made up 36.0 percent. By 1964, it is expected to make up 58.8 percent of the total consumption. By that year, about 80 percent of the nitrogen fertilizer and 72 percent of the phosphorous fertilizer will be supplied domestically. However, the deficit of potash fertilizer will continue to increase as fast as the increase of consumption, as Taiwan does not produce, nor plans to produce, potash fertilizer.

D. The actual import of the fertilizers does not coincide exactly with the "deficit" due obviously to variations in carry-over stock and discrepancies in time of consumption requirement, production and import arrival.

## II. Trend of Use of Fertilizers on Rice, Sugarcane and Other Miscellaneous Crops

Appendix Table 2 deals with the trend of use of fertilizers by rice, sugarcane and "miscellaneous crops" meaning all crops other than rice and sugarcane. It consists of 4 parts: (1) Total of N, $P_2O_5$ and $K_2O$, (2) N, (3) $P_2O_5$ and (4) $K_2O$. From these tables, the following observations are made:

A. During the period from 1952 to 1959, amounts of fertilizers consumed by rice, sugarcane and other miscellaneous crops have all increased. In absolute quantities, the rice fertilizers increased by the largest amount, miscellaneous crops second and sugarcane the least.

B. However, when expressed in index, the fertilizers for miscellaneous crops increased at a more rapid rate. Since 1957, the fertilizer for miscellaneous crops began to make up 10 percent more of the total fertilizer consumption. It continued to increase in 1958 and 1959. In 1959, for the first time since the end of the War, rice fertilizer fell below 70 percent of the total fertilizer consumption. By 1964, it is estimated that miscellaneous crops will take up about 20 percent of the total fertilizer consumption, rice 66 percent and sugarcane 14 percent.

C. Trend of rice fertilizer consumption. Appendix Table 3 shows that the recommended rate of fertilizer application on rice, based on island-wide N, P, K testing done before 1955, as against the actual distribution record of 1958 is as follows:

| | N | $P_2O_5$ | $K_2O$ |
|---|---|---|---|
| Recommended optimum rate, rice (kg/ha.) | 80 | 40 | 40 |
| Actual distribution record, 1958 (kg/ha.) | 90.0 | 34.9 | 18.6 |

It is apparent from the above that, allowing 10 percent plus and minus, the present actual rates of N and $P_2O_5$ application on rice have reached optimum, while that of $K_2O$ is still below optimum. This explains why $K_2O$ consumption for rice is planned to be increased at a faster rate than N and $P_2O_5$ during the Third 4-Year Plan period as may be seen in (2), (3) and (4) of appendix Table 2.

D. Trend of sugarcane fertilizer consumption. Appendix Table 2 shows that the rate of sugarcane fertilizer consumption projected for the Third 4-Year Plan period remains almost constant. This is due the fact that no change in sugarcane acreage and the rate of fertilizer application are being planned. Maintaining acreage at constant is explained by the limitation of export quota by the International Sugar Conference. Keeping the rate of application unchanged, however, is problematic.

Appendix Table 3 shows the optimum rate of fertilizer application for sugarcane and the actual distribution record of 1958 as follows:

| | N | $P_2O_5$ | $K_2O$ |
|---|---|---|---|
| Recommended optimum rate, sugarcane (kg/ha.) | 150-225 | 75 | 75 |
| Actual distribution record, 1958 (kg/ha.) | 187.9 | 29.7 | 51.7 |

Obviously, N is already within the optimum range, while both $P_2O_5$ and $K_2O$ are still short of optimum. The cause of such conservativeness in using more $P_2O_5$ and $K_2O$ on sugarcane is a mixture of technical viewpoint aggravated by operational consideration of the Taiwan Sugar Corporation (TSC). TSC has succeeded in allocating more P and K fertilizers in the Second than in the First 4-

Year Plan period. As the land competition becomes increasingly disadvantageous to sugarcane and temptation for farmers to shift to other short growing crops becomes increasingly stronger, the TSC field men urge that they should refrain as much as possible from things that the cane growers do not as yet appreciate.

E. Trend of fertilizer consumption by miscellaneous crops· Appendix Table 2 shows that the trend of fertilizer consumption by crops increased steadily for all 3 elements in the past years and will continue to increase in the Third 4-Year Plan period.

In order to make a more detailed analysis, the consumption of fertilizers by the various crops included under miscellaneous crops in the past years is tabulated in appendix Table 4. (It should be pointed out that in appendix Table 4 data of actual tonnage of fertilizers consumed are used, instead of nutrient elements as is the case with appendix Tables 1 and 2, in order to save time of computation.) From this table, the following points may be pointed out:

1. The increase of fertilizer consumption by this category of crops in the past years is mainly due to the increase made by wheat, banana, pineapple, citrus, jute, vegetables and tobacco. These are crops with high economic return and steady market.

2. Fertilizer consumption by crops with large acreage but fluctuating price did not register increase, i. e. sweet potato, peanut and tea.

3. From technical viewpoint, the potential for further increase of further consumption by the miscellaneous crops is good. Appendix Table 3 clearly indicates that with the exception of pineapple, citrus, jute and tobacco, the actual rates of fertilizer consumption by the rest of the miscellaneous crops are yet way below the recommended rates. Hybrid corn, cotton, rape seed and other new crops with prospect of expanding in acreage will demand more fertilizers in the future.

# APPENDIX

## Table 1.
## Trend of Consumption, Local Production and Import of Chemical Fertilizers in Taiwan

Unit: m.t.

| Year | Consumption[1] | | | Local production | | Deficit | | | Actual import | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | N | $P_2O_5$ | $K_2O$ | N | $P_2O_5$ | N | $P_2O_5$ | $K_2O$ | N | $P_2O_5$ | $K_2O$ |
| 1952 | 69,488 | 22,013 | 12,368 | 14,789 | 13,451 | 54,699 | 8,562 | 12,368 | 65,605 | 14,797 | 14,883 |
| 1953 | 69,595 | 25,210 | 14,671 | 15,846 | 15,256 | 53,749 | 9,954 | 14,671 | 49,925 | 11,655 | 25,108 |
| 1954 | 82,009 | 27,330 | 16,704 | 15,373 | 16,391 | 66,636 | 10,939 | 16,704 | 64,768 | 6,491 | 6,498 |
| 1955 | 83,341 | 29,084 | 17,369 | 15,710 | 16,023 | 67,631 | 13,061 | 17,369 | 67,309 | 13,741 | 10,364 |
| 1956 | 90,769 | 30,693 | 19,487 | 16,367 | 19,934 | 74,402 | 10,759 | 19,487 | 74,316 | 10,262 | 19,080 |
| 1957 | 97,027 | 31,954 | 23,635 | 19,910 | 20,821 | 77,117 | 11,133 | 23,635 | 76,869 | 11,993 | 24,407 |
| 1958 | 102,095 | 34,072 | 26,722 | 28,188 | 22,489 | 73,907 | 11,583 | 26,722 | 74,434 | 12,897 | 29,622 |
| 1959 | 103,025[2] | 33,940[2] | 28,901[2] | 34,109 | 25,596 | 68,916 | 8,301 | 28,801 | 77,976 | 12,319 | 29,614 |
| 1960[3] | 102,440 | 39,698 | 37,541 | 53,030 | 23,140 | 49,410 | 16,558 | 37,541 | 55,800 | 14,060 | 35,540 |
| 1961[3] | 108,100 | 42,966 | 42,390 | 67,200 | 23,300 | 40,900 | 19,666 | 42,390 | | | |
| 1962[3] | 111,166 | 43,488 | 47,543 | 88,870 | 24,280 | 22,296 | 19,208 | 47,543 | | | |
| 1963[3] | 114,735 | 45,226 | 52,879 | 95,920 | 33,280 | 18,815 | 11,946 | 52,879 | | | |
| 1964[3] | 118,002 | 45,888 | 55,773 | 95,920 | 33,280 | 22,082 | 12,608 | 55,773 | | | |

Remarks: [1] Including both fertilizers distributed through the regular government channel and a small amount of the locally produced fertilizers sold to free market by the manufacturers.

[2] Preliminary.

[3] Estimation.

Source of data: (1) The consumption figures for years 1961 to 1964 are based on estimations of the 3rd Agricultural 4-Year Plan. They are subject to revision.

(2) The local production figures for years 1961 to 1964 are based on estimations of the 3rd Industrial 4-Year Plan. They are also subject to revision.

(3) The actual import figures are based on official statistics.

## Table 2.

## Fertilizer for Rice, Sugarcane and Miscellaneous Crops[2]

### (1) Total of N, $P_2O_5$ and $K_2O$

| Year | Total |  |  | Rice |  |  | Sugarcane |  |  | Miscellaneous |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  | Amount (m.t.) | % | Index | Amount (m.t.) | % | Index | Amount (m.t.) | % | Index | Amount (m.t.) | % | Index |
| 1952 | 103,869 | 100.0 | 100.0 | 78,510 | 75.59 | 100.0 | 19,760 | 19.02 | 100.0 | 5,599 | 5.39 | 100.0 |
| 1953 | 109,476 | 100.0 | 105.4 | 82,323 | 75.20 | 104.9 | 16,965 | 15.50 | 85.9 | 10,188 | 9.30 | 182.0 |
| 1954 | 126,043 | 100.0 | 121.3 | 96,767 | 76.77 | 123.3 | 20,352 | 16.15 | 103.0 | 8,924 | 7.08 | 159.4 |
| 1955 | 128,878 | 100.0 | 124.1 | 98,217 | 76.21 | 125.1 | 20,787 | 16.13 | 105.2 | 9,874 | 7.66 | 176.4 |
| 1956 | 139,619 | 100.0 | 134.4 | 104,445 | 74.81 | 133.0 | 23,483 | 16.82 | 118.8 | 11,691 | 8.37 | 208.8 |
| 1957 | 149,694 | 100.0 | 144.1 | 107,399 | 71.74 | 136.8 | 25,577 | 17.09 | 129.4 | 16,718 | 11.17 | 298.6 |
| 1958 | 158,985 | 100.0 | 153.1 | 111,683 | 70.25 | 142.3 | 25,791 | 16.22 | 130.5 | 21,511 | 13.53 | 384.2 |
| 1959 | 161,137 | 100.0 | 155.1 | 112,750 | 69.97 | 143.6 | 26,897 | 16.69 | 136.1 | 21,490 | 13.34 | 383.8 |
| 1960[1] | 179,679 | 100.0 | 173.0 | 118,651 | 66.03 | 151.1 | 27,575 | 15.35 | 139.5 | 33,453 | 18.62 | 697.5 |
| 1961[1] | 193,456 | 100.0 | 186.2 | 125,632 | 64.94 | 160.0 | 30,100 | 15.56 | 152.3 | 37,724 | 19.50 | 673.8 |
| 1962[1] | 202,197 | 100.0 | 194.7 | 132,246 | 65.40 | 168.4 | 30,100 | 14.89 | 152.3 | 39,851 | 19.71 | 711.8 |
| 1963[1] | 212,840 | 100.0 | 204.9 | 139,772 | 65.67 | 178.0 | 30,100 | 14.14 | 152.3 | 42,968 | 20.19 | 767.4 |
| 1964[1] | 219,663 | 100.0 | 211.5 | 143,990 | 65.55 | 183.4 | 30,100 | 13.70 | 152.3 | 45,573 | 20.75 | 814.0 |

Remarks: [1] Estimation.

[2] Figures for 1952 through 1959 given in Table 2 (1), (2), (3) and (4) are the amounts distributed through the regular government channel. However, since 1955, there has been a small but increasing amount of fertilizers sold directly by the local fertilizer factories to farmers. These amounts, as given in the following table, cannot be broken down according to usage by different crops. They also explain the discrepancies between the total N, $P_2O_5$ and $K_2O$ consumed by all crops given in Table 1 and Table 2 (2), (3) and (4).

### Quantity of Locally Produced Fertilizers Sold to Free Market

(Unit: m.t.)

| Year | Ammonium sulphate | Calcium ammonium nitrate | Total N |
|---|---|---|---|
| 1955 | 4,468 | — | 916 |
| 1956 | 6,488 | — | 1,330 |
| 1957 | 14,227 | 27 | 2,922 |
| 1958 | 18,503 | 556 | 3,904 |
| 1959 | 22,254 | 834 | 4,729 |

## Table 2.

### (2) Nitrogen

| Year | Total | | | Rice | | | Sugarcane | | | Miscellaneous | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Amount (m.t.) | % | Index | Amount (m.t.) | % | Index | Amount (m.t.) | % | Index | Amount (m.t.) | % | Index |
| 1952 | 69,488 | 100.0 | 100.0 | 51,833 | 74.59 | 100.0 | 14,791 | 21.29 | 100.0 | 2,864 | 4.12 | 100.0 |
| 1953 | 69,595 | 100.0 | 100.2 | 52,163 | 74.95 | 100.6 | 12,673 | 18.21 | 85.7 | 4,759 | 6.84 | 166.2 |
| 1954 | 82,009 | 100.0 | 118.0 | 64,762 | 78.97 | 124.9 | 13,195 | 16.09 | 89.2 | 4,052 | 4.94 | 141.5 |
| 1955 | 82,425 | 100.0 | 118.6 | 62,857 | 76.26 | 121.3 | 14,957 | 18.15 | 101.1 | 4,611 | 5.59 | 161.0 |
| 1956 | 89,439 | 100.0 | 128.7 | 66,878 | 74.78 | 129.0 | 17,244 | 19.28 | 116.6 | 5,317 | 5.94 | 185.6 |
| 1957 | 94,105 | 100.0 | 135.4 | 68,299 | 72.58 | 131.8 | 18,014 | 19.14 | 121.8 | 7,792 | 8.28 | 272.1 |
| 1958 | 98,191 | 100.0 | 141.3 | 70,032 | 71.32 | 135.1 | 17,993 | 18.33 | 121.6 | 10,166 | 10.35 | 355.0 |
| 1959 | 98,296 | 100.0 | 141.5 | 69,105 | 70.30 | 133.3 | 18,637 | 18.96 | 126.0 | 10,554 | 10.74 | 368.5 |
| 1960[1] | 102,440 | 100.0 | 147.4 | 67,320 | 65.72 | 129.9 | 19,655 | 19.19 | 132.9 | 15,465 | 15.09 | 540.0 |
| 1961[1] | 108,100 | 100.0 | 155.6 | 69,888 | 64.65 | 134.8 | 21,000 | 19.43 | 142.0 | 17,212 | 15.92 | 601.0 |
| 1962[1] | 111,166 | 100.0 | 160.0 | 71,982 | 64.75 | 138.9 | 21,000 | 18.89 | 142.0 | 18,184 | 16.36 | 634.9 |
| 1963[1] | 114,735 | 100.0 | 165.1 | 74,096 | 64.58 | 143.0 | 21,000 | 18.30 | 142.0 | 19,639 | 17.12 | 685.7 |
| 1964[1] | 118,002 | 100.0 | 169.8 | 76,230 | 64.60 | 147.1 | 21,000 | 17.80 | 142.0 | 20,772 | 17.60 | 725.3 |

Remark: [1] Estimation.

## Table 2.

### (3) Phosphoric Acid

| Year | Total | | | Rice | | | Sugarcane | | | Miscellaneous | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Amount (m.t.) | % | Index | Amount (m.t.) | % | Index | Amount (m.t.) | % | Index | Amount (m.t.) | % | Index |
| 1952 | 22,013 | 100.0 | 100.0 | 18,948 | 86.08 | 100.0 | 1,793 | 8.14 | 100.0 | 1,272 | 5.78 | 100.0 |
| 1953 | 25,210 | 100.0 | 114.5 | 21,511 | 85.33 | 113.5 | 1,510 | 5.99 | 84.2 | 2,189 | 8.68 | 172.1 |
| 1954 | 27,330 | 100.0 | 124.2 | 22,708 | 83.09 | 119.8 | 2,399 | 8.78 | 133.8 | 2,223 | 8.13 | 174.8 |
| 1955 | 29,084 | 100.0 | 132.1 | 25,020 | 86.03 | 132.0 | 1,736 | 5.97 | 96.8 | 2,328 | 8.00 | 183.0 |
| 1956 | 30,693 | 100.0 | 139.4 | 26,375 | 85.93 | 139.2 | 1,954 | 6.37 | 109.0 | 2,364 | 7.70 | 185.8 |
| 1957 | 31,954 | 100.0 | 145.2 | 26,280 | 82.24 | 138.7 | 2,295 | 7.18 | 128.0 | 3,379 | 10.58 | 265.6 |
| 1958 | 34,072 | 100.0 | 154.8 | 27,152 | 79.69 | 143.3 | 2,845 | 8.35 | 158.7 | 4,075 | 11.96 | 320.4 |
| 1959 | 33,940 | 100.0 | 154.2 | 26,662 | 78.56 | 140.7 | 3,105 | 9.15 | 173.2 | 4,173 | 12.29 | 328.1 |
| 1960[1] | 39,698 | 100.0 | 180.3 | 30,294 | 76.31 | 159.9 | 2,520 | 6.35 | 140.5 | 6,884 | 17.34 | 541.2 |
| 1961[1] | 42,966 | 100.0 | 195.2 | 30,784 | 71.65 | 162.5 | 3,100 | 7.21 | 172.9 | 9,082 | 21.14 | 714.0 |
| 1962[1] | 43,488 | 100.0 | 197.6 | 30,969 | 71.21 | 163.4 | 3,100 | 7.13 | 172.9 | 9,419 | 21.66 | 740.5 |
| 1963[1] | 45,226 | 100.0 | 205.5 | 31,996 | 70.75 | 168.9 | 3,100 | 6.85 | 172.9 | 10,130 | 22.40 | 796.4 |
| 1964[1] | 45,888 | 100.0 | 208.5 | 32,186 | 70.14 | 169.9 | 3,100 | 6.76 | 172.9 | 10,602 | 23.10 | 833.5 |

Remark: [1] Estimation.

## Table 2.

### (4) Potash

| Year | Total | | | Rice | | | Sugarcane | | | Miscellaneous | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Amount (m.t.) | % | Index | Amount (m.t.) | % | Index | Amount (m.t.) | % | Index | Amount (m.t.) | % | Index |
| 1952 | 12,368 | 100.0 | 100.0 | 7,729 | 62.49 | 100.0 | 3,176 | 25.68 | 100.0 | 1,463 | 11.83 | 100.0 |
| 1953 | 14,671 | 100.0 | 118.6 | 8,649 | 58.95 | 111.9 | 2,782 | 18.96 | 87.6 | 3,240 | 22.09 | 221.5 |
| 1954 | 16,704 | 100.0 | 135.1 | 9,297 | 55.66 | 120.3 | 4,758 | 28.48 | 149.8 | 2,649 | 15.86 | 181.1 |
| 1955 | 17,369 | 100.0 | 140.4 | 10,340 | 59.53 | 133.8 | 4,094 | 23.57 | 128.9 | 2,935 | 16.90 | 200.6 |
| 1956 | 19,487 | 100.0 | 157.6 | 11,192 | 57.43 | 144.8 | 4,285 | 21.99 | 134.9 | 4,010 | 20.58 | 274.1 |
| 1957 | 23,635 | 100.0 | 191.1 | 12,820 | 54.24 | 165.9 | 5,268 | 22.29 | 165.9 | 5,547 | 23.47 | 379.2 |
| 1958 | 26,722 | 100.0 | 216.1 | 14,499 | 54.26 | 187.6 | 4,953 | 18.53 | 156.0 | 7,270 | 27.21 | 496.9 |
| 1959 | 28,901 | 100.0 | 233.7 | 16,983 | 58.76 | 219.7 | 5,155 | 17.84 | 162.3 | 6,763 | 23.40 | 462.3 |
| 1960[1] | 37,541 | 100.0 | 303.5 | 21,038 | 56.04 | 272.2 | 5,400 | 14.38 | 170.0 | 11,103 | 29.58 | 758.9 |
| 1961[1] | 42,390 | 100.0 | 342.7 | 24,960 | 58.88 | 322.9 | 6,000 | 14.16 | 188.9 | 11,430 | 26.96 | 781.3 |
| 1962[1] | 47,543 | 100.0 | 384.4 | 29,295 | 61.62 | 379.0 | 6,000 | 12.62 | 188.9 | 12,248 | 25.76 | 837.2 |
| 1963[1] | 52,879 | 100.0 | 427.5 | 33,680 | 63.69 | 435.8 | 6,000 | 11.35 | 188.9 | 13,199 | 24.96 | 902.2 |
| 1964[1] | 55,773 | 100.0 | 450.9 | 35,574 | 63.78 | 460.3 | 6,000 | 10.76 | 188.9 | 14,199 | 25.46 | 970.5 |

Remark: [1] Estimation.

## Table 3.

## Quantity of NPK Fertilizers Distributed in 1958 and Optimum Rate of Fertilizer Application for Various Crops

| Crop | Optimum rate of application (kg/ha.) | | | Actual distribution record in 1958 | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Total quantity (m.t.) | | | For each ha. (kg)[1] | | |
| | N | $P_2O_5$ | $K_2O$ | N | $P_2O_5$ | $K_2O$ | N | $P_2O_5$ | $K_2O$ |
| Rice | 80 | 40 | 40 | 70,032 | 27,152 | 14,499 | 90.7 | 34.9 | 18.6 |
| Sugarcane | 150-225 | 75 | 75 | 17,993 | 2,845 | 4,953 | 187.9 | 29.7 | 51.7 |
| Sweet potato | 30 | 25 | 50 | 907 | 333 | 1,278 | 4.0 | 1.5 | 5.6 |
| Wheat | 80 | 60 | 40 | 586 | 346 | 161 | 25.8 | 15.2 | 7.1 |
| Corn | | | | 356 | 156 | 155 | 38.4 | 16.8 | 16.7 |
| Sorghum | | | | 31 | 13 | 13 | 8.6 | 3.8 | 3.8 |
| Peanut | 10 | 30 | 40 | 4 | 8 | 12 | 0.04 | 0.07 | 0.11 |
| Soybean | 10 | 30 | 40 | 1 | 5 | 3 | 0.03 | 0.11 | 0.07 |
| Tea | 37.5-75 | 19 | ? | 884 | 243 | 200 | 18.3 | 5.0 | 4.2 |
| Banana | 150 | 150 | 225 | 1,042 | 460 | 535 | 75.3 | 33.2 | 38.6 |
| Pineapple (general) | 200 | 50 | 200 | 2,118 | 637 | 1,487 | 194.1 | 58.4 | 136.3 |
| Pineapple (TSC) | 200 | 50 | 200 | 276 | 78 | 195 | 241.3 | 67.9 | 170.8 |
| Citrus | 200 | 200 | 200 | 666 | 292 | 340 | 69.8 | 30.6 | 35.6 |
| Jute | 80 | 40 | 60 | 1,199 | 250 | 835 | 94.8 | 19.8 | 66.0 |
| Cotton | 80 | 60 | 60 | 482 | 140 | 179 | 106.3 | 31.0 | 39.5 |
| Flax | | | | 100 | 35 | 47 | 63.8 | 22.5 | 30.0 |
| Tobacco | 80 | 80 | 210 | 324[2] | 589[2] | 1,318[2] | 38.7[2] | 70.2[2] | 157.1[2] |
| Vegetables | | | | 789 | 345 | 344 | 9.0 | 4.0 | 3.9 |
| Sugarcane for brown sugar | | | | 196 | 33 | 56 | 45.3 | 7.7 | 12.9 |
| Green manure | | | | — | 66 | — | — | 0.5 | — |
| Others (for schools and other organizations) | | | | 205 | 46 | 112 | | | |
| Others (indigenous fertilizers sold to free market) | | | | 3,904 | | | | | |
| Total: | | | | 102,095 | 34,072 | 26,722 | | | |

Remarks: [1] Calculated by dividing the actual total distribution by the planted acreage.
[2] Not including about 300 kg. of oil cakes per hectare.

## Table 4.

## Fertilizer Distribution for Miscellaneous Crops, 1952-1959

Quantity: m.t.

| Crop | 1952 | | 1953 | | 1954 | | 1955 | | 1956 | | 1957 | | 1958 | | 1959[1] | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Q'ty | % | Q'ty | % | Q'ty | % | Q'ty | % | Q'ty | % | Q'ty | % | Q'ty | % | Q'ty | % |
| Sweet potato | 2,485 | 10.74 | 10,481 | 27.97 | 8,254 | 24.26 | 1,368 | 3.53 | 6,257 | 13.95 | 7,029 | 10.76 | 8,405 | 10.22 | 2,657 | 3.27 |
| Wheat | 3,320 | 14.35 | 3,750 | 10.01 | 5,317 | 15.63 | 6,452 | 16.67 | 8,149 | 18.17 | 10,978 | 16.81 | 3,932 | 4.78 | 10,123 | 12.45 |
| Soybean | — | — | — | — | — | — | 86 | 0.22 | 3 | 0.01 | 30 | 0.05 | 42 | 0.05 | 36 | 0.04 |
| Peanut | — | — | 3 | 0.01 | 709 | 2.08 | 130 | 0.34 | 76 | 0.17 | 20 | 0.03 | 81 | 0.10 | 326 | 0.40 |
| Corn | — | — | — | — | — | — | — | — | 4 | 0.01 | 545 | 0.83 | 2,865 | 3.48 | 950 | 1.17 |
| Sorghum | — | — | — | — | — | — | — | — | — | — | 110 | 0.17 | 247 | 0.30 | 111 | 0.14 |
| Banana | 1,200 | 5.19 | 1,548 | 4.13 | 2,351 | 6.91 | 1,709 | 4.42 | 936 | 2.09 | 6,069 | 9.29 | 8,554 | 10.40 | 9,361 | 11.52 |
| Pineapple | 2,168 | 9.37 | 4,397 | 11.74 | 1,769 | 5.20 | 5,546 | 14.33 | 8,411 | 18.76 | 12,177 | 18.65 | 18,202 | 22.13 | 14,634 | 18.00 |
| Citrus | 730 | 3.16 | 1,510 | 4.03 | 1,114 | 3.28 | 1,023 | 2.64 | 1,092 | 2.44 | 4,104 | 6.28 | 5,455 | 6.63 | 6,906 | 8.50 |
| Jute | 4,803 | 20.76 | 3,410 | 9.10 | 4,066 | 11.95 | 7,699 | 19.89 | 6,239 | 13.92 | 4,457 | 6.83 | 8,659 | 10.53 | 11,521 | 14.17 |
| Flax | 54 | 0.23 | — | — | 113 | 0.33 | 282 | 0.73 | 10 | 0.02 | 426 | 0.65 | 764 | 0.93 | 749 | 0.92 |
| Cotton | — | — | 611 | 1.63 | — | — | 765 | 1.98 | 314 | 0.70 | 2,431 | 3.72 | 3,452 | 4.20 | 4,114 | 5.06 |
| Tea | 2,259 | 9.76 | 5,209 | 13.90 | 1,768 | 5.20 | 3,109 | 8.03 | 219 | 0.49 | 2,384 | 3.65 | 6,030 | 7.33 | 4,172 | 5.13 |
| Vegetables | 51 | 0.22 | — | — | 2 | 0.01 | 20 | 0.05 | 4,213 | 9.40 | 5,180 | 7.94 | 6,363 | 7.73 | 6,881 | 8.47 |
| Green manure | 2,002 | 8.65 | 1,836 | 4.90 | 3,223 | 9.47 | 3,175 | 8.20 | 576 | 1.28 | 424 | 0.65 | 367 | 0.45 | 311 | 0.38 |
| Tobacco | 3,755 | 16.23 | 3,889 | 10.38 | 4,218 | 12.40 | 5,620 | 14.52 | 7,749 | 17.28 | 7,757 | 11.88 | 7,600 | 9.24 | 7,035 | 8.66 |
| Brown sugar | 310 | 1.34 | 826 | 2.20 | 1,117 | 3.28 | 1,722 | 4.45 | 587 | 1.31 | 1,184 | 1.81 | 1,238 | 1.50 | 1,395 | 1.72 |
| Total | 23,137 | 100.00 | 37,470 | 100.00 | 34,021 | 100.00 | 38,706 | 100.00 | 44,835 | 100.00 | 65,305 | 100.00 | 82,256 | 100.00 | 81,282 | 100.00 |

Remark: [1] Preliminary.

Note: This table differs from Tables 1 and 2 in that the data are in terms of actual tonnage of fertilizer, not nutrient elements.

# MARKETING AND DISTRIBUTION OF CHEMICAL FERTILIZERS

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Concurrently Convener, Fertilizer Sub-Committee
Agricultural Planning & Coordination Committee
Ministry of Economic Affairs

Fertilizers used in Taiwan come from two sources, the local production and importation. They are marketed through a rather unique system.

## I. The Fertilizer Committee

The planning of the fertilizer program is performed by the Fertilizer Sub-Committee under the Agricultural Planning & Coordination Committee (APCC) of the Ministry of Economic Affairs. The Sub-Committee is composed of members from the following organizations:

APCC (presiding)

Taiwan Provincial Department of Agriculture & Forestry
    (Agricultural administration, research, extension)

Taiwan Provincial Food Bureau
    (Food administration, distribution of fertilizers for all crops except sugarcane)

Taiwan Sugar Corporation
    (Sugar production, distribution of fertilizers for sugarcane)

Taiwan Fertilizer Company
    (Fertilizer production)

Taiwan Provincial Communications Bureau
    (Transportation of fertilizers)

Industrial Planning & Coordination Group
    (Planning, coordination and supervision of fertilizer production)

Central Trust of China
(Foreign procurement of fertilizers)

Joint Commission on Rural Reconstruction
(Technical advisory service)

Council for United States Aid
(U. S. aid for fertilizers)

The Committee has the following important functions:

A. It estimates the total fertilizer requirement of each year, based on requirements individually estimated for various crops by a panel of specialists.

B. After having taken into consideration the projected local production of the year, it plans on the quantities of nitrogenous, phosphorus and potash fertilizers to be imported.

C. Based on the above, prepares each year a budget requirement for procurement of fertilizers both from local factories and abroad.

D. Screens the fertilizer allocation plan for various crops.

E. Recommends selling prices of various kinds of fertilizers to farmers. The prices of the imported and the locally produced fertilizers are pooled, and the costs of inland transportation are averaged so that farmers all over the Island can get the same kind of fertilizer at a uniform price. In the case of rice fertilizers which farmers would barter with paddy, the Committee recommends the barter ratio between paddy and each kind of fertilizer.

F. After final approval by the Ministry of Economic Affairs, the Taiwan Provincial Government and the Foreign Exchange & Trade Control Commission, the fertilizer program as mapped out by the Committee is implemented accordingly by its member organizations each within its respective scope of activities. From there on, the progress of each phase of the program is reported and problems encountered thrashed out at the monthly meetings of the Committee.

## II. Fertilizer Distribution Agencies

Sugarcane fertilizers are distributed to cane farmers by the government-owned Taiwan Sugar Corporation on interest-free loan basis. The cost of the fertilizers is deducted from farmers' share of sugar price after harvest and milling of cane.

Distribution of fertilizers for rice and "miscellaneous crops" (all crops other than rice and sugarcane) are handled by the Taiwan Provincial Food Bureau. Fertilizers for rice growers are distributed in a rather complicated manner. The farmer brings paddy along and barters on spot for 40 percent of his lot of fertilizers, and gets the remaining 60 percent on loan basis. After harvest, he repays the loan in terms of paddy plus a 3 percent interest. The barter ratios for different fertilizers, as mentioned above, are recommended by the Fertilizer Sub-Committee and approved by the Government.

Fertilizers for crops other than rice and sugarcane are sold to farmers on cash basis only.

With the concurrence of the Government, a small amount of the locally manufactured ammonium sulfate and calcium ammonium nitrate are being sold to the market by the fertilizer factories directly.

## III. Distribution of Fertilizers to End-users

Sugarcane fertilizers are distributed through the sugar mills of the Taiwan Sugar Corporation to their contract cane growers. Fertilizers for rice and all other crops are distributed by the Provincial Food Bureau through the various farmers' associations. All township farmers' associations have warehouses built especially for the storage of fertilizers. Following a shipping schedule worked out by the Food Bureau, fertilizers are shipped directly from ports or local factories to various farmers' associations' warehouses by the Taiwan Provincial Communications Bureau. In taking delivery, farmers only have to travel a few kilometers by their ox-carts to their respective association godowns to get the fertilizers.

The per hectare fertilizer application rates as recommended by the Fertilizer Sub-Committee are announced by the Food Bureau. Past distribution records, farmers' habits of fertilizer application and requirements of crops and soils are all considered while determining the per hectare allocation for each crop. The allocation plans for rice and sugarcane have different standards for different areas; but for other crops there is a uniform standard of allocation for the whole province. All kinds of fertilizers are allocated on a tie-in basis and are distributed at the announced fixed ratios. Individual farmers register the acreages of the crops they will plant with their respective township offices where cadastral index cards and maps for all farm lands in the township are available for checking. A list of the amount of chemical fertilizers each farmer is entitled to buy is compiled by each township office according to the registration and sent to the farmers' association of the same township. The latter would then distribute the fertilizers accordingly. Farmers may barter (rice growers) or buy (other crop growers) 20 percent more or less than the allocated amount. In case of bartering, the paddy brought in by the farmers are examined and received by the township farmers' association and stored in the paddy warehouses on behalf of the Provincial Food Bureau. These paddy form the bulk of rice collected by the Government dispensing rations for servicemen and government employees, for market stabilization and for export. The farmers' associations receive commission for handling both fertilizers and paddy on tonnage basis.

## IV. Evaluation of the Existing System

The existing system of fertilizer marketing and distribution serves the following useful purposes:

A. It places some 700,000 metric tons of chemical fertilizers made available annually at the easy reach of some 750,000 farm households. The prices are fixed and pre-announced. There is no danger of getting adulterated fertilizers from the farmers' associations. Thus, after he sees a fertilizer demonstration or reads an extension education material, a farmer can easily figure out the cost of fertilizers and the gain from the increased crop yield, and decide whether he should use fertilizers or not. When he does, he can always get them from his own farmers' association a few kilometers away.

B. For the two major crops of Taiwan, rice and sugarcane, the farmers get fertilizers on loan basis (100 percent for sugarcane and 60 percent for rice). This removes to a great extent farmers' reluctance in buying fertilizers due to financial stringency at planting time.

C. The per hectare fertilizer allocation rates for different crops are recommended by specialists based on regional field trials and demonstrations. It has succeeded in guiding the farmers towards a more balanced application of N, P and K.

D. It provides an effective channel through which fertilizers needed by farmers are exchanged for rice needed by the Government for the above mentioned important purposes. Its contribution to protecting the armed forces and government employees and their dependents from the menace of rice price fluctuation cannot be over-emphasized.

The existing system has the following drawbacks:

A. Since the per hectare fertilizer allocation rates for different crops are based on regional field trials, they do not necessarily fit the truly optimum rates for a great multitude of individual farms. It could only be regarded as a system expedient to the present circumstance. After better soil survey is completed, a soil testing system established, and when farmers' appreciation of the proper usage of fertilizers further improved through the extension educational system, efforts will be made towards the distribution of fertilizers according to the need of the individual farms.

B. Since the rice fertilizers are distributed on a fertilizer/paddy barter basis and those for all other crops (including sugarcane) on cash sale (cash loan for sugarcane) basis, there always exists a price discrepancy between the rice fertilizers and those for other crops. The situation is not serious when the rice price is stable, as the cash sale prices may be adjusted to keep the discrepancy to a minimum. But it becomes difficult at times when rice price shows significant fluctuations, such as after a natural calamity. A high rice price on the market would mean also a high price of fertilizers for rice growers unless the barter ratio is readjusted. It is, however, not practical to shift barter ratio frequently while the rice price changes from day to day or week to week. Situations like these inevitably bring complaints from farmers and arguments among parties concerned over the pros and cons of this unique fertilizer/paddy bartering system.

With all factors weighed, it is held by all agricultural agencies that the existing fertilizer marketing and distribution system, though by no means an ideal one, is ingeniously tailored to fit the special circumstances Taiwan found itself during the past decade and will remain feasible and effective in the immediate future.

# THE EXTENSION WORKERS' PART IN FERTILIZER PROGRAMS

Agricultural Extension Division
Chinese-American Joint Commission on Rural Reconstruction

Carrying information directly to farmers on the use of fertilizer is an important part of the job of township farm and 4-H club advisors. These advisors, who are a vital part of the cooperative extension program in agriculture and home economics, are employed in 216 of the 317 agricultural townships in Taiwan.

These farm advisors, who cooperate very closely with workers of other agencies, make use of the following methods of carrying information to farm families in such a way as to get them to make the best use of it.

A. Result demostrations—a result demostration is carried on by a farmer who grows a certain crop or carries out a certain farm practice under instructions from the township advisor, as a demonstration to other farmers in the community. These demonstrations are usually rather simple in nature and not as complicated as field tests designed to obtain research data. The extension workers also cooperate very closely in carrying out the fertilizer tests and demonstrations financed by the Provincial Food Bureau.

B. Another mothod of carrying information to farmers is by organizing farm tours that visit demonstration plots and agricultural improvement stations. A total of 1,750 such tours were conducted last year. On most of these, observations were made on the use of fertilizers on rice and other crops.

In carrying information to farmers, extension workers make use of farm discussion groups. A total of 1,839 such groups were organized by township farm advisors in 1960. These groups had a membership of 32,103. They meet monthly to discuss problems in connection with their farm operations. The use of fertilizers is an important subject for discussion at certain seasons of the year. The farm advisor attends most of these meetings and often invites a specialist to discuss specific subjects such as fertilizer. These specialists come from the district agricultural improvement stations, vocational agricultural schools and provincial or prefectural offices. The interesting thing about these farm discussion groups is that the farmers do not go to them to listen to a lecture on fertilizer or some other subject, but to carry on their own discussions. The farm advisor or specialist is there to answer questions or give suggestions, not to make speech.

A large percentage of the result demonstrations are carried on by farmers selected by their farm discussion groups. Because they have had a part in starting these demonstrations, the farmers naturally are more interested in them.

Other methods of carrying information to farmers are through method demonstrations on how to carry on certain practices. Slides, and to some extent, movies have been used at night meetings to carry information regarding fertilizers and other subjects of interest to farmers.

Information on improved farm practices is carried to farm families also through the 4-H clubs. Last year out of a total of 3,389 village 4-H clubs in Taiwan with 40,133 members, information on the use of fertilizer was given to 20,378 members who carried on rice, sweet potato, vegetable, and other crop projects.

The cooperative extension program in agriculture and home economics is carried on, under the sponsorship of the Provincial Department of Agriculture & Forestry, by the provincial, prefectural and township farmers' associations. Farmers' associations and local government offices cooperate at all levels. Advisory committees at all levels are made up of representatives of various agencies interested in increasing agricultural production and in rural development.