bacteria. The tank is constructed on a trailer frame and is six feet long and three feet wide with a working depth of 18 inches. It is equipped with an oil-fired furnace to heat the water and with an automatic temperature control that maintains water temperature with an accuracy of ∓ 1 F. The water is re-circulated by a centrifugal pump to maintain an even temperature throughout. Six to ten quarts of seed to be treated are placed in galvanized containers 12 x 12 x 18 inches having ⅛ inch hardware cloth on two sides to permit free water circulation through the seeds. After a ten minute period of treatment at 125 F, the seeds are allowed to drain momentarily, and then are dipped thoroughly in a fungicide slurry made of Arasan 75 (five pounds per four gallons of water). This surface coating of fungicide protects against recontamination during handling and storage. When the excess slurry has drained off, the basket is positioned over a forced-air duct, where the seeds are tumbled dry in a period of four to five minutes. To speed drying, heating coils are provided in the air-intake duct warming the air to not more than 100 F. Formaldehyde solution is used to clean equipment and work areas as a sanitary precaution against recontamination of treated seeds.

When the seeds are dry enough to pour freely, they are packaged in polyethylene bags and labeled. They are ready for immediate planting or for refrigerated storage at 40 to 45 F.

Discussion

In the greenhouse trials, 90-97% of the seeds germinated, excluding the *P. trifoliata* and sweet lime from storage, and the sweet seedling. The lower germination rate for these three lots was attributed to poor condition of the seeds, as the untreated checks also had a comparably low germination rate. Results of treatments described compare favorably to those obtained in California, and it is apparent that no appreciable reduction in germination is sustained when seeds in good condition are hot water treated. Nurserymen in California report storage periods up to a year with no ill effects.

Benefits gained through the treatment of seeds are lost unless sanitary practices are followed in the seedbed and nursery growing area to prevent recontamination. A complete program of nursery sanitation should include preplant soil fumigation of the seedbed and growing area, and close supervision of nursery practices to prevent introduction of pathogens on tools and equipment. Soil fumigation, in addition to the obvious advantage of disease and weed control, is recommended as an added protection against introduction of the burrowing nematode into the nursery site. Hot water treatment of seeds completes the sanitation program at little extra cost, and contributes to production of premium quality citrus trees.

Current recommendations suggest fumigation of vacant tree spaces prior to resetting. Where these recommendations are followed, nursery stock produced under a complete sanitary program is preferable.

Growers and nurserymen may have seeds treated from October 1 through November 30, and January 1 through February 28, by contacting the Budwood Registration office, Division of Plant Industry, Winter Haven, telephone AC 813, 294-4267, for appointment.

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YIELD EXPECTANCY AND THE BASIS OF CITRUS FERTILIZATION

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Although man has practiced the art of growing plants for several thousand years, it was only about 125 years ago that serious thought was given to the quantitative relation between yield and enironmental factors affecting growth. The German chemist, Justus von Liebig, suggested in 1843 that soil fertility could be maintained by adding fertilizers. Liebig believed that, if several factors were not adequate for maximum growth, only the one present in least amount actually limited growth. This became known as the "law of the minimum." For over half a century it was believed that a simple proportionality existed between yield and the supply of the limiting factor. In other words, all steps of increase in the limiting factor produced equal increase in yield until maximum yield was reached.

As this concept was tested over a period of time, controversy developed and in 1909 Mitscherlich (4) proposed a new theory called the "law of diminishing return." According to this concept, the increments of yield increase become progressively smaller as the maximum response is approached. In other words, a logarithmic relation was involved instead of a direct proportionality. Also in contradition to Liebig's law of the minimum was Mitscherlich's statement that if several factors are suboptimal, an increase in any one will cause some increase in yield (4).

In the last half century, the results of numerous experiments with plants show that the law of diminishing returns is more nearly in accord than is the law of the minimum. According to Bray (2) there is truth in both theories under certain conditions, but the concept of diminishing returns is most applicable under the conditions of crop production.

The response to different levels of plant nutrients is easy to measure with annual crops but is much more difficult with slow growing tree crops. The principle, however, appears to be the same. Intelligent fertilization requires some knowledge of the basic response pattern of plants to different levels of fertility. The present report discusses, in a general way, the nature of a yield response curve and how it relates to citrus fertilization in Florida.

Nature Of Yield Response Curves

Yield response curves are sigmoidic in character and may be expressed mathematically. There is still some dispute over a formula that encompasses all possible factors (2, 8). For a general idea of the nature of yield response curves, however, only simple calculations are necessary. The main points of consideration are as follows:

1. *Yield increase.*—Each time the supply of a limiting factor is doubled, the yield is increased by an amount equal to one-half the difference from the maximum yield (Fig. 1).
2. *Maximum yield.*—The highest possible yield under a given set of conditions, *when the factor under consideration is not limiting.* This does not mean the greatest potential yield under all conditions. Since absolute yields vary with different conditions, yield is indicated as percent of a maximum in Fig. 1. One orchard, for instance, may have a much larger potential yield than another but both approach their respective maximum in the same way when controllable limiting factors are relieved.
3. *Limiting factors.*—Any component of the plant's environment can be limiting to growth. The individual essential chemical elements are frequently thought of as limiting factors because they are relatively easy to control. Other factors such as water, light, and temperature can also be limiting factors (8).
4. *A second limiting factor.*—A second limiting factor reduces the maximum yield response to the first limiting factor but does not change the fundamental nature of the response curve (Fig. 1). It is important to understand that a second limiting factor does not reduce the quantity of the first factor needed to attain maximum response (1). The second limiting factor simply changes the magnitude of the maximum response.

Fertilization Of Citrus

Fertilization has long been the main cost factor in citrus production in Florida because of the lack of native fertility in our soils. This may not always be so in the future as irrigation becomes more widely practiced or as other costs continue to rise. Pest control is already a close rival to fertilization in cultural costs. One advantage in growing fruit on highly infertile soils is that it is possible to control the nutrient status of the trees by judicious fertilization. Fruit quality, for instance, can be appreciably altered by the level of K provided.

Theoretically, any of the 10 or 11 essential fertilizer elements that we supply could be a limiting factor if the supply were inadequate.

Fortunately, many elements call attention to their incipient shortage long before they become serious limiting factors. This means that, for most elements, visible deficiency symptoms would be present. A few shoots with Zn or Mg deficiency are easy to see and corrective measures are taken long before the deficiency becomes intense enough to affect production measurably. A few malfunctioning leaves amongst 100,000 or more green leaves on a tree is a rather small factor. No doubt there have been instances of multiple limiting nutritional elements in our past history. Dieback (Cu deficiency), bronzing (Mg deficiency), frenching (Zn deficiency), and Fe chlorosis on marl soils undoubtedly were at times limiting factors. In other words, while these deficiencies were limiting growth, they were also lowering the ceiling of the yield response to nitrogen. The quantities of the trace elements used by citrus trees are relatively small and the recommended practice almost eliminates the likelihood of chronic deficiencies.

Considering the major mineral elements, much Ca and Mg are supplied in the dolomitic lime used for pH control. The need for additional Mg is indicated by bronzing in the fall months. P deficiency is not common and most groves have accumulated soil reserves of this element. Because K stress reduces fruit size before it lowers yield, this element is used at rates that are adequate for high production. This leaves N as the main nutritional element controlling production of fruit. It has been known for a long time that N is the key element in affecting the quantity of fruit produced by a citrus tree. Because of this relation there has been some tendency to use excessively high rates of N in an attempt to stimulate the largest possible crop of fruit. Some growers have used rates as high as 500 lb. N per acre despite recommendation of a maximum rate of 250 lb. (5).

The N rate studies that have been conducted in Florida are generally so limited in range that they only show a small segment of a yield response curve. In order to obtain measurements in the steep part of the curve, rather low rates are required and the trees become quite pale and unthrifty. On the other hand, rates may be chosen so high that all rates are in the leveling-off zone and the response is too small to measure by ordinary experimental methods. Yield differences generally are difficult to measure reliably from the standpoint of statistical *analysis* unless they are of a magnitude of 15 or 20 percent. Two recent reports show ranges sufficiently wide to illustrate the diminishing yield type of curve but the magnitude of yield suggested some other limiting factor (11, 12).

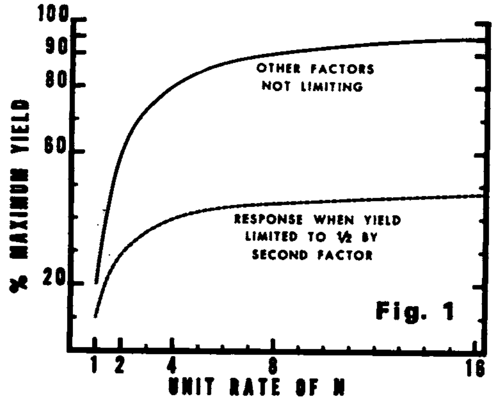
In recent years we have been maintaining Marsh grapefruit trees on low rates of N to determine the effect on fruit quality. Quality factors have been but slightly affected by rate of N so far, but yield data are of interest from the standpoint of a yield curve. Per acre yields have been relatively high considering that the trees are now only 15 years old and are spaced only 50 to the acre.

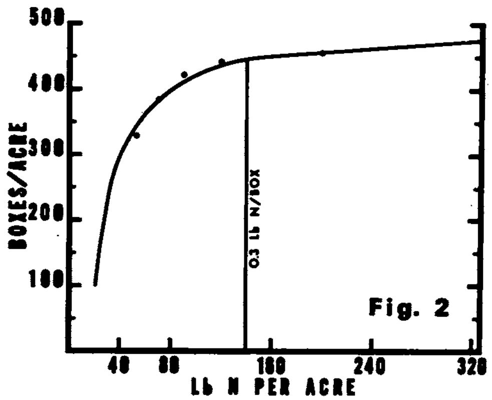
The average annual yields for the last 5 years on 5 rates of ammonium nitrate are indicated as dots on Fig. 2. Abstract figures for rate and yield have been used as coordinates instead of the relative values in Fig. 1. The line is the expected yield curve if one assumes a maximum production of about 500 boxes per acre at a rate of 400 lb. of N. It can be seen that the experimental yield values follow the curve reasonably well. The trees receiving 50 lb. N are yielding about 75 percent as much as those receiving 200. For practical purposes 120 lb. is producing nearly as much as 200. Using the recommended value of 0.3 lb. N per box these trees should receive between 130 and 140 lb. per acre per year. The expected yield at 140 lb. is indicated by the vertical dotted line.

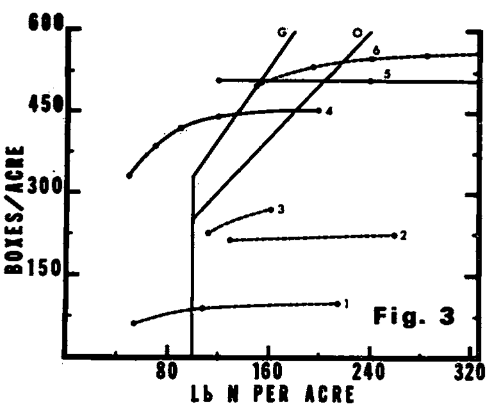
While the trees receiving only 50 lb. N are yielding about 75 percent of a maximum crop, they are thinly foliated, yellow green, and the wood tends to be black and "hard" from exposure and reduced growth. The trees obviously decline markedly in vegetative condition before sacrificing fruit production.

Other examples of the responses that we have found in experiments involving different rates of N during the past 2 decades are shown in Fig. 3. Some of these show curvature in the upper part of a yield response curve, others were obviously above the critical level and no yield response was evident. Some of the experiments were on relatively young trees, others on old or mature trees. Ammonium nitrate was the source of N in all experiments and the trees were on deep, sandy soil. Some pertinent information on each is briefly indicated as follows:

1. Valencia orange trees on Rough lemon, 9-12 years, 72 trees per acre (6). A fairly







good yield response curve is indicated but soil was probably too acidic for full response to N (topsoil pH 5.0-5.3). Subsequent tests in the same area showed increased yield when the pH was maintained about 6.0 (10).

2. Valencia orange trees on Rough lemon, 9-19 years, 72 trees per acre (7). No response as both rates above critical level.

3. Pineapple orange trees on sweet orange, 9-15 years, 50 trees per acre. Replanted grove on high Cu soil, pH 6.8-7.2. Wide planting distance handicaps per acre yield on young trees. Yields hampered by 1962 freeze damage.

4. Marsh grapefruit on sweet orange, 11-15 years, 50 trees per acre (9). Replanted grove on high Cu soil, pH 6.8-7.2. Excellent performance. Same curve as in Fig. 2.

5. Marsh grapefruit on Rough lemon, 11-18 years, 60 trees per acre (10). No suspected cultural limiting factors and all 3 N rates above critical level of curve. Lowest level was about .25 lb. N per box.

6. Valencia orange on Rough lemon, 36-44 years, 96 trees per acre (9). Soil high in Cu, pH 6.5-7.0. Yield excellent. The 5 N rates show the upper part of the response curve and indicate that a rate between 240 and 285 lb. N per acre are appropriate for this grove. Yield values are somewhat depressed by virtue of the effect of the 1962 freeze on 2 or 3 crops. The average N per box for 8 years at the 240 lb. rate was 0.44.

The experiments on orange trees are indicated by broken lines; those on grapefruit by solid lines. Most of the orange trees were relatively young and of low production capacity. The lines for these fall on the lower part of the chart, while those for the grapefruit and one high yielding Valencia block occur near the top. Four of the six experiments show some response to N rate. The others were conducted

Fig. 1.—Mitscherlich yield response curves when governed by a single factor and when a second factor is only sufficient for one-half of the maximum yield (After Bonner and Galston). Fig. 2.—Average yields of Marsh grapefruit from 5 rates of N superimposed on hypothetical yield curve. The similarity is apparent. Vertical line indicates probable yield if 0.3 lb. N per box used as a guide. Fig. 3.—Yield values from several N rate experiments on citrus (see text) in relation to recommended rates for commercial use (5). Dotted lines represent oranges; solid lines grapefruit. Line G is calculated rate for grapefruit based on 0.3 lb. N per box of fruit. Line O is calculated for oranges using 0.4 lb. N per box. Common line results from the minimum rate of 100 lb. N per acre regardless of yield. The trees in experiments 1, 2, and 3 were relatively young and had not reached full bearing capacity. Four of the tests show some response curvature; the other 2 indicate that the rates used were above the critical range for yield.

with N rates that were on the plateau, or leveling-off zone, of a yield curve.

Lines G and 0, with the common vertical base, represent the N rates presently recommended for grapefruit and oranges, respectively (5). These were calculated by using the factors of 0.3 and 0.4 (lb. N per box) on the range of yields shown on the vertical cordinate. The lines join because a minimum rate of 100 lb. N per acre is recommended for trees of producing size, regardless of yield.

The recommended rate lines may be seen to cross the yield lines on, or near, the plateau zone in 5 of the 6 cases. This indicates that the present guide for grower use is rather appropriate. The lone exception, line 3, indicates that the recommended rate would not be quite adequate. This probably is explained logically by the wide spacing (50 to the acre) of the trees and the fact that they were young (9-15 years during the experiment). Apparently the root systems were not extensive enough to use N, broadcast over the entire area, quite as efficiently as closer spaced young trees. Also, it should be noted, these trees suffered from the 1962 freeze and the yields shown in Fig. 3 are somewhat lower than might otherwise be expected.

It is hoped that this discussion on the nature of a response to fertilization will help growers to understand some of the factors involved in making recommendations and in making decisions as to how to fertilize each specific grove. It should be apparent why large excesses of N, or a mixed fertilizer, cannot be expected to improve yield and, contrariwise, why substantial reduction from the recommended rates can be made during low economic return periods without drastically lowering production. The cost of N, in relation to the value of the fruit however, is relatively small and potential ecenomy is not large.

In view of the yield response curve *and the* effect of limiting factors, it becomes apparent why unthrifty groves require about the same quantity of fertilizer as a vigorous grove in order to attain maximum production on each. A grove with a low production ceiling because of disease, shallow soil, poor moisture conditions, etc. will require as much N to achieve maximum production as one relatively free of handicaps and with a high yielding potential (see Fig. 1). The report by Koo and McCormack (3) illustrates the increased yield potential provided by irrigation without increasing the N requirement.

For the reasons outlined above, using N rate as a guide for applying all needed fertilizer elements is a logical procedure. This is the basis of the official recommendations to growers (5).

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