

SOME CITRUS PROBLEMS*

ROOT FORMATION AND FERTILIZING

THE results of a study of the root formation of citrus trees in Puerto Rico shows the feeding root area, in clay soils, to be much more limited than has been generally believed. This is of much importance considering that most of the existing groves are planted on clay soils. This paper was read at a citrus growers' field meeting held on March 31, 1931, and it is being published after consultation with the fruit-growers who have co-operated in the work upon which it is based. Some of these growers have already profited by the findings here reported and it is hoped that many more will do so after becoming acquainted with existing conditions.

Differences in root development that may be ascribed to the part of the tree above the bud-union were not studied, neither were differences due to individuality of the stock upon which any tree was budded. The conclusions drawn from the study are based entirely upon the root development of the average, apparently normal, tree growing in light sandy soil, heavy clay soil and some of the intermediate soil types.

Rough Lemon Stock.—The rough lemon is, at present, the predominating stock in most of the older groves in Puerto Rico, and therefore the data in connection with that are very complete. In well-aerated sandy soil the horizontal spread of the roots was found to be much greater than the horizontal spread of the branches of the same tree. The depth was found to be variable, usually the largest number of the feeding roots were found in the upper eight inches of the soil, but frequently many were found at a depth of two feet and occasionally as far down as five to six feet or more. But in no case a well-developed tap-root encountered.

In heavy clay soil the horizontal spread of the roots was found to be practically equal to that of the branches. In few cases only were feeding roots found a few inches beyond the horizontal spread of the branches. The depth of the feeding roots was found to be surprisingly small. Some roots were encountered at a depth of about twelve inches but practically all the feeding roots were located in the upper eight inches of soil, and usually more were present in the upper two than in the lower two inches of the eight-inch stratum. A well-developed tap-root was not found on any of the trees examined.

In loose, well-aerated clay soils or in sandy clay, that was not too compact, the extent of the root development was found to differ according to the compactness, the amount of vegetation and the frequency of plowing or cultivation. Soils that had not been plowed or cultivated for many years, and which were covered by a heavy sod, were usually found to be fairly permeable. In such soils some feeding roots were usually found at some distance beyond the horizontal spread of the branches, but never as in the soil under the branches.

Sour Orange Stock.—For the purpose of the present discussion it is sufficient to state that in clay soils the horizontal spread of the roots of the sour orange is as great as that of the rough lemon but the number of roots per square foot is usually much less. The depth of the anchor roots

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of sour orange is usually much greater than that of the rough lemon, but most of the feeding roots are located close to the surface, similar to those of the rough lemon. A well-developed tap-root was found on most of the trees examined. It may be mentioned that in the heavy clay soils many of the deeper roots seemed to be unusually much decayed. That is perhaps due to a lack of aeration at some prolonged period in the trees' existence.

Grapefruit Stock.—The root development of grapefruit stock on clay soils seems to differ mainly from that of rough lemon stock in having some deep anchor roots. The feeding roots were found mainly in the upper eight inches of soil, spreading horizontally to a distance similar to those of the rough lemon stock in similar soils. A well-developed tap-root was usually found.

Root Formation on Hillsides.—The purpose of tree roots is partly that of anchorage and special provisions are usually made for resisting strains caused by wind or gravity. This is always noticeable on hillsides where the root system of citrus trees is much more extensive on the upper than on the lower side of the slope. That is of importance in fertilizing and will be discussed later.

Conclusions.—The following conclusions may be drawn from the data at hand: (1) In more or less impermeable soil, in which sufficient aeration is lacking, the feeding roots do not extend much below the upper eight inches. The horizontal spread is seldom beyond that of the tips of the branches except where the soil is not plowed or cultivated, where the surface is kept permeable by a heavy growth of annuals; (2) in well-aerated soils the feeding roots may spread out an indefinite distance beyond the branches, even though the soil is cultivated periodically, for under those conditions the roots may thrive in the deeper strata; (3) it is evident that soil aeration is the underlying reason for high planting, as practised in Puerto Rico, and that any contemplated change in method of planting must be based upon soil aeration. (4) The present method of planting must involve mulching in order that it may be most successful. The soil in the mound upon which the tree is planted is much subject to drying especially during the first few years before the branches afford much shade. Inevitably that restricts root development, and it can be prevented, to some extent, by maintaining a heavy grass mulch.

An Experiment in Planting.—With the premises that depth of root formation is governed by soil aeration, and that soil aeration is governed mainly by physical condition and moisture content, the conclusion follows that by meeting those requirements a deep root system can be induced. That this conclusion is correct needs to be proved and the following experiment was started for that purpose: Holes 5 feet in diameter and 4 feet deep were dug in clay soil. At one side of each hole a small excavation was made and filled with rock. A tube—4½ to 5 feet long was placed vertically upon that rock after which the hole was filled. Some holes were filled with clay mixed with varying amounts of decayed material from the San Juan dump heap. In other holes bamboo stakes were placed vertically a few inches apart and soil of varying composition was filled in. After the soil had settled, trees, budded on rough lemon, sour orange and grapefruit stocks were planted in the soil mounded up to a height of about 12 inches over each hole, and a heavy grass mulch was applied.

These trees will be liberally fertilized, and watered when the moisture content of the soil goes below what may be considered the minimum for normal tree growth. Once a week, or oftener when necessary, a rod will be let down into the tube, mentioned previously, when the water content of the hole is large enough to be pumped out the water will be removed by means of a hand pump inserted through the tube. After a few years'

growth the trees will be removed, a few at a time, for the purpose of studying root development. If the method is successful it can be used, advantageously, especially on hilly land where drainage can be provided by tubing connecting one hole with another and with the outlet at the bottom of the slope.

Method of Fertilizing and Probable Loss of Fertilizers.—The fertilizer problem includes many phases, two of which have been studied by the writer during the past few months. One, where shall the fertilizer be applied and how shall it be covered? And the other, what is the probable loss after it is applied? The first question will be answered upon the basis of the study of the root system mentioned previously, and the second upon the basis of present knowledge of soil physics and chemistry applied to local conditions.

Where shall the Fertilizer be Applied?—Three distinct methods of fertilizing have been practised in Puerto Rico in groves with trees ten years old, or older. (1) Spreading the fertilizers broadcast over the whole soil area except close to the trunk of the tree; (2) applying the fertilizer in a trench around the tree at the same distance from the trunk as the tips of the horizontal branches; (3) spreading the fertilizer on the soil area covering the outer part of a circle in which the tree trunk is the centre and the tips of the horizontal branches the circumference.

With present knowledge of root development it is obvious that no one will use the first-mentioned method on clay soils. The trench method has apparently given good result in many cases and it seems reasonable to suppose that it may do so. Yet, it must be remembered that after cutting most of fine roots in the region, in which the trench is made, much loss of fertilizer salts may take place before new roots are formed.

The third method has the advantage over the two former that the fertilizers cannot fail to come in contact with an abundance of feeding roots; and if there is sufficient moisture in the soil the roots will be able to avail themselves of the fertilizers immediately.

The trench method offers no problem in regard to covering the fertilizer, but the last-mentioned method does. The tree roots are so close to the surface that even very shallow hoeing destroys many of them. In one grove water is pumped from irrigation furrows and applied under each tree by means of a hose. That is an excellent method and not as costly as it may appear to be. One of the disadvantages of it is that it puddles the soil, more or less, and leaves it in a condition that is not very favourable to the tree roots.

The best method suggesting itself is that of mulching. A cover crop can be grown in most of the groves, for the trees seldom cover the ground entirely. If that were cut, from time to time, and spread over the roots, no hoeing would be needed. The old-time argument that mulch is undesirable because it draws the roots to the surface is valueless in this case for roots are as close to the surface as they can get. A combination of mulching and a suitable system of sprinkle irrigation will be almost ideal. The mulch will prevent puddling of the soil when the water is applied and it prevents evaporation after it is applied.

Probable Loss of Fertilizers.—In the loss of fertilizers after being applied the following factors are involved: (1) The amount of water supplied by precipitation or irrigation within a given period of time; (2) the chemical composition of the fertilizer and soil; (3) the amount of fertilizer applied at one time; (4) the physical condition of the soil and the inclination of the terrain.

The Water Supplied.—The importance of the amount of water reaching the surface of the soil in relation to the loss of fertilizers by leaching or percolation may be illustrated by the following concrete example: In a clay soil containing 65% colloidal matter, the trees have a spread of 20 feet and the fertilizer is applied under the branches. The weight of this soil is 40 Kg. per cubic foot and the water-holding capacity 30% of the weight. The question to be answered is how much rain may fall or how much irrigation water may be applied before fertilizer salts will be carried down below the feeding root. This question may be answered by means of the following calculations:

With the roots covering an area which is a circle 20 feet diameter, the total root area will be 314.16 sq. ft.

The feeding roots being in the upper 8 inches of soil the root inhabited soil mass will be 209.44 cubic feet.

At 40 Kg. per cubic foot the air-dry soil in the root area will weigh 8377.6 Kg.

With a water-holding capacity of 30% that volume of soil will be saturated with 2513 liters, or 664 gallons.

In percolation the rule is that the fluid applied replaces an equal amount of that present. Therefore, it should be possible to apply 2500 liters of water to this 314 square feet of soil after fertilizing without any of the soluble salts being percolated below the upper 8-inch limit. But practical experience with soils shows that some percolation takes place with an application of three-fourths or less of the water-holding capacity. In this case none of the salts applied were carried below the 8-inch limit when 1400 to 1500 liters water was added, or 4.72 liter per square foot, equal to 2 inches of rain.

In dealing with soils different from the one here considered the above calculations apply, provided the weight and water-holding capacity of the air-dry soil is known.

The Chemical Composition of the Fertilizer and Soil.—The tendency in fertilizing nowadays is to use concentrated salts which are mostly water-soluble; hence the importance of controlling the water supply after fertilizing. Fortunately most soils are not merely filters through which the fertilizer salts, in solution, may pass without change in quantity or quality. In fact most soils are so complex that with present knowledge it is not always possible to predict the changes that may take place in a fertilizer after it has been applied. It is known that organic matter is more or less retentive; that bases in the soil, such as calcium, are replaced by bases in the fertilizer, such as ammonium and potassium; that bases in the soil such as calcium, magnesium, manganese, iron, and aluminum, combine with phosphoric acid forming salts which are not water-soluble.

On the basis of this general knowledge a number of citrus soils were examined for the purpose of determining their retentivity towards the various fertilizer salts. Measured soil areas in the field were enclosed by covered frames. Fertilizers were applied within the frames and measured volumes of water were added from time to time. Soil samples from these areas were analyzed from time to time and soil samples of the same types as that within the frames were air-dried, pulverized and used for percolation experiments in the laboratory. The results from this work indicate what may be expected to take place under field conditions.

In the experiments, field as well as laboratory, the fertilizer formula 6-8-10 was used as the basis, applied at the rate of 30 lb. per tree, because that approaches what many planters are applying to large trees. Thirty

pounds of a 6-8-10 mixture supplies 819 gr. nitrogen, 1090 gr. phosphoric acid, P_2O_5 , and 1361 grams potash, K_2O . If that is applied on the outer 5 feet of a 20-foot circle it will cover 236 square feet, the soil of which, to a depth of 8 inches, will weigh 6294 Kg., at 40 Kg. per cubic foot. Consequently the fertilizing is at the rate of 130 mg. nitrogen per Kg. soil, 173 mg. P_2O_5 and 216 mg. K_2O , which may also be expressed part per million, abbreviated ppm. The water was always applied in portions corresponding to the total water-holding capacity of the soil.

Nitrate Nitrogen.—When nitrogen is present in fertilizers as nitrates it occurs, usually, in the forms of sodium, potassium or calcium nitrate, which salts are readily soluble in water. No great quantity of nitrate nitrogen is retained by any soil. In the clay soil, formerly mentioned, the probable percolation through the upper 8 inches will be 50% or more of the quantity applied if water amounting to three-fourths of the soil's water-holding capacity is applied shortly after fertilizing, and about another 25% if a similar application is made within a few days. In other words the probable loss from the upper 8 inches of that soil, under a 20-ft. tree as described above, will be about 1 lb. nitrogen by an application of 6 liters water per square foot, or a rainfall of 2.55 inches. And another rain following shortly after will be liable to remove about one-half pound nitrogen, leaving but two to three ounces of the, nearly, 29 ounces applied.

How much the tree roots may remove within a given time is not yet clear but the indications are that the quantity is considerable. Several soil samples from among roots of large trees were examined and only few ppm.-nitrogen were found three to six weeks after fertilizing. That phase of the problem will be reported on later.

Ammonia Nitrogen.—Nitrogen in the form of ammonia occurs in fertilizers, usually as sulphate or phosphate which salts are water-soluble. It is absorbed and held with considerable tenacity by the colloidal matter of the soil so that even very heavy rains remove but a small per cent of the amount applied in the fertilizer. The replaceable lime in the soil is of much importance in this respect, and most of the clay soils examined contain enough lime in replaceable form to make the ammonium loss negligible in the drainage water from a rainfall equal to the soil's water-holding capacity. If, however, rains fall equal to twice the water-holding capacity of the soil the ammonia loss may amount to upwards of 20% the amount applied unless the replaceable lime content is much larger than what it usually is, but calculated on a clay soil such precipitation is unusual.

After a few days the ammonia begins to nitrify in the soil, that is, it changes into nitric acid which is subject to loss by leaching, similar to that of the nitrates formerly mentioned. But although nitrification starts soon after fertilizing, all of the ammonia applied is not necessarily converted in a short time. In these experiments where ammonium sulphate was applied in covered frames, appreciable amounts of nitrates was found after a few days, yet some ammonia was present after six weeks. Which shows that loss of nitrogen, by leaching, is very much less with ammonia than with nitrates.

The question is often asked, what is the probable loss of fertilizer salts by evaporation when the fertilizers are not covered by soil? The answer is: None of the salts are volatile. Ammonia may escape into the air if there is much lime on the surface of the soil, but it is not volatile until it is liberated from its acid bond.

Phosphorus.—The phosphorus is present in fertilizers as phosphoric acid which is usually combined with calcium, potassium or ammonium. The two latter combinations are water-soluble as is also one form of calcium phosphate. The loss from leaching is therefore a possibility and undoubtedly some loss takes place in the sandy soils that are deficient in colloidal matter. But from the clay soils, as well as the sandy soils containing some clay, the loss is negligible according to the results from the percolation and covered-frame experiments.

The main loss of phosphorus is usually due to chemical combinations with bases in the soil from which plants cannot recover it. To what extent that takes place in the soils under consideration is not within the scope of this article. But the iron and manganese content was found to be sufficiently high in all of them to provide for possible combinations of phosphates that may supposedly be slowly or entirely unavailable to plants.

Potassium.—The potassium is usually present in fertilizers in combination with one of the following acids: sulfuric, hydrochloric, nitric, phosphoric and occasionally carbonic. These salts are all water-soluble but like ammonia the potash is held by the colloidal matter of the soil and it replaces lime. The results of these experiments show that the loss of potash by leaching is negligible provided the soil contains considerable colloidal matter and replaceable lime.

Calcium.—While calcium is present in commercial fertilizers only as a by-product it may properly be considered in this paper for it is as necessary to a citrus tree as are any of the, so-called, fertilizer elements. But aside from that it is, as mentioned previously, very important in connection with leaching of ammonia and potash. Most of the soils examined were found to contain some leachable lime, for instance the clay soil, mentioned previously, yielded in the first percolate 22 ppm CaO, but the second percolate none. After applying an ammonia or potash salt, and continuing the percolations, the first percolate contained 25 ppm, the second 45 ppm, the third 22 ppm, the fourth 10 ppm, and the fifth 4 ppm. Which shows that a small amount of the lime present would be lost in the first rain, but the rest of it the soil was capable of holding, at least until it should become more soluble. Yet the soil was not capable of retaining it after the ammonia or potash salts were applied. Seventy ppm were leached out in the first two percolates corresponding to 8 inches of rain and corresponding amounts of the other salts were retained by the soil.

The importance of lime in relation to phosphoric acid is also worth considering. It converts the water-soluble monobasic phosphate into the insoluble tribasic form which is undesirable. Yet tribasic calcium phosphate is more readily available to plants than are the iron and aluminum combinations and probably the latter feature outweighs the former.

The Amount of Fertilizer Applied at any one Time.—Soils containing an abundance of colloidal matter and replaceable bases are capable of retaining considerable quantities of ammonia, potash and phosphate, and in many cases the loss of these ingredients by leaching may not be much greater when 30 to 60 lb. are applied per tree than if only 15 pounds were applied. But in most cases the loss is liable to be comparatively great if very heavy rains fall shortly after the fertilizer has been applied. In the case of nitrate nitrogen there is no question but what the loss will be great under those conditions. How best to proceed is largely a local problem. If heavy rains are not to be feared large applications may be made. If, on the other hand, heavy rains may be expected the question becomes one of the probable value of the fertilizers lost by leaching, against the cost of making one or more extra applications.

THE PHYSICAL CONDITION OF THE SOIL AND THE INCLINATION OF THE TERRAIN

It is superfluous to state that water runs down hill and that aside from gullying the soil it carries with it all the water-soluble matter. In some soils erosion is less a problem than in others due to the rapid absorption of the rain-water as it falls. Some of the tobacco soils on the steep hills in the Comerio district, which have been under cultivation for many years, may be pointed to as an example. In some of the heavy clay soils erosion is not as serious a problem, while the soil is covered with vegetation, as it is after the vegetation is removed, which is not due entirely to the fact that vegetation arrests the soil but partly so to the more or less porous condition of a soil permeated by plant roots.

This naturally suggests a system of cultivation in which the sod between the trees is left undisturbed. All of the fertilizer will naturally be applied on the hillside above the tree, especially in view of the fact that the main portion of the roots are there, as explained in the first part of this article. If a ditch is dug, running crosswise of the slope between the trees, for the purpose of catching the run-off, it should preferably be close enough to one of the rows to allow the roots of the trees in that row to get the benefit from it. Naturally, a heavy mulch around the trees will greatly minimize the run-off.