Gainesville
April 7, 1967

Dear Wilson:

I am sorry that I did not see you again before you got away. My sister-in-law came on Friday after two or three months in Mérida (Yuc.), and stayed until Monday, and in the excitement I forgot your departure.

For the past fortnight I have been trying to write something on Climates & Soils, and while I am not wholly pleased with my endeavors, I am submitting the manuscript for your amelioration. I had hoped to get started also on "Cultural Practices", but this will have to wait until our return in mid-May. A letter from Campinas says that I will be expected to present a seminar on fruit production, and preparation for this will take my available time in the week remaining before we leave.

I hope the flow of visitors allows you some time for work. By the way, a letter from George Samuels, the chief research man on pineapples at Rio Piedras, says that a large acreage was put under mulch by one organization on the Hawaiian-based canner's advice, but that the practice is likely to be abandoned for lack of economic justification. It has not been adopted by other growers.

Mary joins in sending warm regards.

Sincerely
Herb

Chapter

The Climates and Soils of Tropical America

Climates

Climate refers to the average weather conditions during the year. The principal factors determining climate are temperature and rainfall, although sunshine, humidity, and wind also play a part. These factors are, of course, interdependent, since rain or clouds will restrict sunshine, which in turn affects temperature.

Horticulturists are accustomed to classify fruit crops as temperate, subtropical, or tropical as to climatic requirements, and to setting approximate limits of latitude for these conditions. Within the geographical tropics, however, i.e., between the Tropics of Cancer and Capricorn, elevation creates conditions such that subtropical and temperate zone crops may be grown at suitable altitudes. In effect, the zoning is vertical instead of horizontal. As a general rule, average temperature at any given latitude decreases 0.6°C for each 100 m of increase in elevation. Yet, at any given altitude, from sea level to 4000 m, the average mean daily temperature tends to decrease as one goes further from the equator. In the tropical lowlands this decrease is never great enough to permit frost, but frost may occur at increasingly lower elevation in the highlands as one goes polewards within the tropics.

Mean Temperatures not only average highest at sea level, but they tend to vary during the year very little there. The mean daily temperature usually varies only about 2°C throughout the year at sea level on the equator, from 25 to 27°C; while at an elevation of 1000 m the mean may be about 20°C with a range from 18 to 22°C, and at 2000 m an annual mean of 14°C represents a range during the year in mean daily temperatures from 10 to 16°C. Yet this is not inevitably the case, due to the operation of other factors. Quito and Guayaquil, in Ecuador, are both on the equator, the former at 3000 m elevation and the latter at sea level; but they both have very little variation in daily temperatures during the year, although the mean daily temperature of Quito is about 13°C lower than that of Guayaquil. More typical is the case of Port of Spain, Trinidad, and Caracas, Venezuela, both at 10°N and close to each other. Port of Spain, at sea level, has a range of monthly averages of mean daily temperatures from 24 to 26°C, and a daily temperature range of 10 to 12°C. Caracas, at 1100 m, has a monthly mean range from 19 to 22°C and a daily range of 16 to 21°C.

The influence of latitude is shown more by its effect on the annual range of daily means than by variation in annual means. Thus, whereas at sea level on the equator, as just noted, the daily mean varies only from 25 to 27°C usually, at 20° of latitude the range may be from 28° in summer to 22°C in winter as daily means; yet the mean annual temperature of the two locations at sea level may be only 2°C. For example, Belem, Brazil, at 0° lat., has the usual annual range of daily means from 25 to 27°C only; Colon, Panama, at 10°N, has a range from 25 to 29°C; and Vera Cruz, Mexico, at 20°N, has a range of 22 to 28°C. All are at sea level and the difference in annual mean temperature among them is only 1 or 2°C. All have a daily range in temperature of 8 to 11°C; but while the average daily maximum for the hottest month and minimum for the coldest month are 32 and 21°C, respectively, for Belem, they are 33 and 16°C for Vera Cruz.

In Central America, three climatic zones have long been recognized, and Popenoe in 1919 described the fruit crops characteristic of each. The tropical zone, or <u>tierra caliente</u>, is considered to extend from sea level to about 800 m, and has an annual range of daily means from 26 to 22°C. Tropical fruits which do not tolerate cool weather thrive here, and the West Indian race of avocado is limited to this zone, while the mango can be grown at higher elevations but is chiefly found here. The subtropical zone, or <u>tierra templada</u>, is found at elevations of from 800 to 2000 m, and has a range of mean daily temperatures from 22 to 15°C. Oranges, avocados of the Guatemalan race, cherimoyas and jocotes are fruits typical of this zone. Near its upper limits frosts are common but not severe, while at its lower limits they never occur, as is true also of subtropical regions outside the tropics. In this zone the living conditions are more pleasant than ~~in~~ at elevations above or below it, the climate being neither uncomfortably hot nor unpleasantly cool.

The temperate zone, or *tierra fria*, lies above 2000 m, and may be considered to have its upper limit at around 3500 m, since hardly any agriculture is carried on above this level. The mean daily temperatures range from 15 to 4°C for the year in this zone, and killing frosts are common, increasing in intensity with altitude. Deciduous fruits from northern areas such as apples, pears, peaches, and plums are grown in this zone, but only the Mexican race of avocado succeeds here. While this classification of climate is probably widely applicable to tropical America, it should be kept in mind that nearer the equator the upper limits of the zones will be at increasingly higher elevations, while polewards the reverse will be true.

It should be clear from the above discussion that the mean annual temperature is not very helpful to know for the fruit grower. He needs to know whether temperatures are ever low enough to be injurious, and how long a growing season he can expect. Injuriously low temperatures are not necessarily those associated with frost. For such fruits as the breadfruit, temperatures around 4 to 5°C are very harmful, while for apples the thermometer may fall to -30°C without injury when the trees are dormant. The grower needs to know the temperature at which a particular crop is endangered, and whether that minimum is likely to occur where he plans to grow this fruit.

Quite a different matter is the length of the growing season. There is a temperature below which no growth takes place, although the plants suffer no injury. If there are too many days with temperatures too low for growth, the crop cannot mature properly. The threshhold temperature for growth is not the same for all fruit crops, being higher for those of the tropical zone than for those needing a temperate climate. For apples the lowest temperature at which growth takes place is 5°C, for oranges 13°C, and for cacao 15°C. The number of days with mean daily temperatures above these minima is the length of the growing season. Of course, the higher the daily means above this base point, the more rapidly growth proceeds, up to the point where the increasing transpiration as temperatures increase finally exceeds water intake, and wilting occurs.

Rainfall is the second great factor of climate, and influences plant growth both directly, as the source of water needed, and indirectly, through its effect on temperature. At elevations of 1000 m or more, when there is an alternation of wet and dry seasons, the rainy season is often called "winter", even though it coincides with the longest days of the year, because it ~~is so~~ may be uncomfortably chilly then. The night temperatures are usually lower in the season of shortest days (called "winter" outside the tropics), but during the day the sun warms the air and the people. In the rainy season it is chilly all day. In the lowlands of the tropics rain has little influence on temperature, but the resulting high humidity makes the rainy season more uncomfortable than the dry season.

A climate in the tropics which has less than 720 mm of rain in the year is considered an arid one, such as that of the Peruvian coastal deserts. Such rainfall is not sufficient to compensate for evaporation losses and only the most drought-enduring plants can grow naturally in such a climate. When the rainfall exceeds 1200 mm, with no month having less than 100 mm, the climate is wet or humid, as on the Caribbean coast of Central America. Very commonly a rainfall of 2000 mm or more is so distributed that some months have none or have less than 100 mm. Thus the Isle of Pines, Cuba, receives an average of 1800 mm annually in 7 months, with little or none the other 5 months. And Mayaguez, Puerto Rico, has an average of over 2000 mm of rain annually, distributed so there are 8 wet months, 1 dry one, and 3 intermediately moist. In many parts of the tropics the total rainfall is between 750 and 1000 mm, and if there are wet and dry seasons, the climate is considered semi-arid. Many crops may succeed in such areas if they are able to make all or most of their growth in the rainy season, and tree crops mat survive the dry months if they can develop deep root systems or can shed their leaves.

It should be remembered that rainfall may vary greatly from year to year, some exceeding the average and some falling far below it. Thus an annual average of 1000 mm may represent as little as 600 mm in some years and as much as 1500 mm in others. If 1000 mm is just sufficient to maintain a moderate soil moisture supply, then in a year of only 600 mm rainfall there will be drought. Furthermore, much of the rain in the tropics comes in heavy downpours, and an area with 2000 or 3000 mm of rainfall may have a great part of it lost by runoff, leaving an effective amount which is marginal.

The various possible combinations of tropical, subtropical, and temperate zones of temperature with humid, semi-arid, and arid rainfall zones provide a great variety of local climatic patterns; and these are further complicated by the varying lengths of wet and dry seasons. Even a small area may have a dozen different climatic types.

Soils

Soils are mixtures in varying proportions of inorganic and organic particles, together with a highly variable population of living organisms. A soil may be almost wholly inorganic, as beach sand dunes are, or almost wholly organic, as in peat beds; but the great majority of agricultural soils are mostly inorganic with a small percentage of organic matter. Wholly organic soils are valued for some vegetable crops but are rarely used for fruits.

The inorganic portion of soils may vary widely in texture, i.e., in the size of the individual particles of the soil. These may ~~vary~~ range from fine gravel particles 2 mm in diameter to clay particles less than 0.002 mm in diameter. Soils chiefly of gravel are rare, but often a soil may consist mostly of coarse or fine sand with particles large enough to feel easily, and many soils contain little but clay, the particles of which are too small to see with the unaided eye, let alone to feel. The common agricultural soils, in descending order of particle size, are sandy, loamy sand, loam, silt loam, silty clay loam, clay loam, silty clay, and clay.

The ability of a soil to retain water against the pull of gravity is inversely proportional to particle size, and in the list of soil textures just given, water-holding increases from sandy to clay. However, plant roots require oxygen from the air, and the porosity of soils is just the opposite of their water-holding capacity. Sands are very porous, draining quickly after showers and admitting oxygen readily to plant roots, while clays have microscopic pores which often let water drain ~~only~~ away very slowly, and oxygen penetrates such soils ~~very~~ with difficulty. The loams are mixtures of sand, clay, and silt which are intermediate to sands and clays in both water-holding and aeration, and usually they are the most desirable soils for agricultural use. However, some clays are well-drained and porous because of having desirable structure.

Briefly, structure refers to the way in which soil particles are grouped into larger units. In a sand, the particles are all quite separate and the soil has no structure at all. In a clay, clods of various size may form, or the soil may adhere into one solid mass. A very desirable type of structure for a clay is a granular or crumb structure, so that on drying out the soil particles adhere into small units the size of bread crumbs, making for ease of cultivation, and of penetration of water, air, and roots. Growing grasses on clay soils usually helps to maintain an initial granular structure, thanks to the penetration by a dense mass of roots and the organic matter left all through the upper foot of soil by the death of these roots.

Many clay soils in the tropics, as the result of severe weathering in a hot, moist climate, have naturally a granular structure which can be easily maintained by good practices of tillage and crop rotation. Cultivation is usually the greatest destroyer of good structure, changing it from fine granules to large clods, especially when the soil is plowed too wet.

In the humid tropics, soils have been very thoroughly leached for millenia, and they tend to be reddish in color because oxides of iron are very insoluble and remain while most other metals have been leached away. However, these lateritic soils are often very friable--easily worked--and then are valuable for agriculture.

The depth of a soil, i.e., how deeply roots are able to penetrate, is an important characteristic, especially for fruit trees. Vegetable crops may thrive on very shallow soils, but trees must be able to send roots deep into the soil, both for ~~the~~ anchorage and to have a large volume of moisture on which to draw in periods of drought. In humid climates in the tropics, a high water-table is most often the factor limiting depth. This may or may not be capable of correction by drainage ditches. Laterite soils may be as much as 20 m deep in the wet tropics, but where there is a high water table, a hardpan may develop just above it. Such a hardpan layer is more often found in semiarid climates, where water entering the soil in a rainy period rises by capillarity in the following dry period. These hardpans are usually found at a depth of less than 1 m from the surface, so that tree roots have only a shallow soil in which to develop. Soils developed from volcanic lava and ash are often found in Central America and are usually very deep and fertile.

Every fruit grower should have a soil auger, which will easily enable him to determine the texture of the soil to the depth of a meter, and whether there is a hardpan or impermeable layer of clay a short distance below the surface. A fairly satisfactory auger can be made by welding a 1-in. wood-auger bit to one end of a 1 m length of ½-in. galvanized steel pipe, with a short length of pipe welded across the other end as a handle.

Another important soil characteristic is the <u>reaction</u>, i.e., whether the soil is acid, alkaline, or neutral. Scientists use a scale of pH values to indicate the reaction. On this scale, 7 represents the neutral point, neither acid or alkaline. Values less than 7 indicate increasing acidity, and those greater than 7 increasing alkalinity.

A soil of pH 6.0 -6.5 is called slightly acid, at 5.5-6.0 moderately acid, at 5.0-5.5 strongly acid, and at 4.5-5.0 very strongly acid. This last degree of acidity is too great for almost any horticultural crop. On the other side of neutrality, 7.5-8.0 is mildly alkaline, 8.0-8.5 moderately alkaline, ~~and~~/8.5-9.0 strongly alkaline, and above 9.0 very strongly alkaline. The satisfactory range of pH values for fruit crops is usually between 4.5 and 8.0 for clay soils, but sandy soils have a narrower range for good growth and are usually satisfactory only with pH values from 5.5 to 6.5. Fortunately it is fairly easy to make acid soils less acid by application of lime, but reducing alkalinity is much more difficult.

Soils of the humid tropics are always more or less acid, because the basic elements (calcium, magnesium, potassium, sodium) have been leached out. In semiarid climates soils are likely to be neutral or mildly alkaline. Only in arid climates are highly alkaline and salty soils likely to be found, and not all desert soils are like this.

The natural fertility of a soil is the product of many factors: texture, structure, depth, reaction, salinity, and content of mineral nutrients. This last factor is really the least important one for the fruit grower, because it is more subject to his control than any of the others. The highly leached soils of the humid tropics are almost always very low in the mineral nutrients needed in large amounts by plants, so they usually need heavy applications of fertilizers to make them productive. Sandy soils in any climate are low in nutrients, but in semiarid climates loams and clays are usually well supplied with all nutrients except nitrogen.

Fertilizers - General

The need for using fertilizers varies with many factors, especially the soil type and rainfall. Clay and loam soils in areas of low rainfall (less than 30 inches yearly) usually are high in calcium and magnesium (and in pH), and in potassium and phosphorus, but may be low in available nitrogen. Sandy soils in areas of high rainfall are always low in calcium and magnesium (and in pH), as well as in nitrogen, potassium and phosphorus. Sandy soils always have a low base-exchange capacity (ability to hold added nutrients) unless their content of organic matter is high. Hence, sandy soils are greatly benefitted by addition of large amounts of organic matter. Heavy soils do not need organic matter to help them retain nutrients, but may benefit from it if they are compact and slow draining. Animal manures are often very beneficial to heavy soils, supplying nitrogen as well as improving soil texture, but are usually more satisfactory sources of nitrogen when about half of the needed nitrogen is supplied by them and the other half from commercial fertilizer. On sandy soils in humid regions, manures may not prove satisfactory for tree growth.

The nutrient elements usually needed in largest amounts are nitrogen, potassium, magnesium, and phosphorus. Nitrogen is likely to be needed on any soil type for tree growth sooner or later. If chemical analysis shows more than 10 ppm of nitrate in early spring, no response to nitrogen application is likely to be obtained. Few soils do not eventually need nitrogen, however. Certain organic sources of nitrogen are much more expensive than inorganic sources, and their use is ordinarily justified only if their effect on soil texture and on resistance to leaching are important. On heavy soils a single annual application of nitrogen, timed to be readily available for the spring flush, is often satisfactory practice. On sandy soils, where leaching is so much more a problem, it is usually desirable to make 3 applications a year. Basin irrigation gives much better movement of nitrates into the root zone than furrow irrigation. If their effects on soil reaction are not important, all sources of nitrogen are about equally effective in tree and fruit growth.

Potassium is retained well by clay and loam soils but leaches readily from sandy ones. Some heavy soils may show no response to potassium applications or none for many years, especially in arid regions. Heavy applications of good quality manure may supply all the potassium needed on heavy soils in humid areas. On sandy soils potassium fertilizers are needed in amounts similar to nitrogen needs.

Magnesium fertilizer need is related to rainfall, as all soils in areas of heavy rainfall are deficient in this element. Use of dolomitic limestone for pH control tends to provide adequate supplies of magnesium.

Phosphorus is needed by fruit trees in much less amount than the three preceding elements, and unlike them it accumulates even in acid, sandy soils. In arid regions phosphorus will benefit trees only if cover crops show a marked response to its use. In humid regions phosphates may be more beneficial for their role in holding magnesium in soil than for any direct effect on trees. Usually its use can be discontinued after applications have been made for 10 years.

Calcium is rarely needed as a fertilizer element because this need will automatically be covered if soil reaction is controlled. Soils with pH values above 6.0 already have adequate supplies of calcium; soils below pH 5.0 need liming to raise the pH so that minor elements will be available.

Sulfur is an essential element, but rarely must it be considered in fertilizer programs. Most soils have adequate supplies, and much sulfur is often applied for non-fertilizing purposes.

The minor or micronutrient elements are zinc, iron, copper, manganese, boron, and molybdenum. These are equally as important to plants as the elements previously discussed, but are needed in very minute amounts only.

SOILS AND SOIL MANAGEMENT

Paradoxical as it may seem, the soil, which should be the first thing to receive the attention of the prospective fruit grower, is sometimes the last — or does not receive his attention at all. How many acres of land have been planted to bananas in tropical America which, because of bad texture, or too much acidity, or low-lying and wet, ~~have been planted to bananas which~~ were not suited to this crop? How many citrus orchards have been foredoomed to failure because they were planted on fine-textured clays which could never be adequately drained? How many avocados have been planted on wet clays where the root-rot caused by *Phytophthora cinnamomi* wiped them out by the time they were five to 10 years old?

Especially for the guidance of the inexperienced horticulturist I wish to offer the following notes. To technically-trained men, some of them will seem ~~very~~ elementary. But I believe they are basic. Some of them – especially those regarding the management of tropical American soils, ~~will~~ may not be valid ten or twenty years from now, when more experience has increased our knowledge along many lines.

In the first place, I wish to emphasize, in a general way, the superiority of young soils, as against old, worn, leached-out soils. To bring home this point, I have often said that when I bought a farm in Tropical America, I wanted one with an active volcano on it. ~~What I mean is this~~: Stand back and ask yourself this question: Are not many of the richest and best lands) ~~those which owe their origin to recent, or relatively recent (speaking geologically)~~ those which are found in volcanic areas, all the way from Mexico to Peru? Compare these with the llanos (plains) of eastern Colombia, or the great Amazon basin, where rainfall may be heavy, ~~but~~ and leaching throughuntold centuries has reduced fertility to a low level.

But to come down to ~~immediate~~ our problems: In some instances, the horticulturist will greatly benefit by the published reports of soil surveys of his general region. Many Cuban agriculturists have told me that they had found invaluable Bennett and Allison's "The Soils of Cuba (   ) in which are set forth, in text and map, the results of a painstaking study of the soils of that Island. Since their time, the work of soil surveying and mapping has been extended to parts, at least, of numerous other countries, by numerous well-trained workers, and it will continue. But obviously, large scale soil surveys, which are the only kind which can be carried out when the object is to map / and classify as distinct "types", the soils of a large area, do not meet all the needs of the horticulturist who contemplates the development of ten, a hundred, ~~10, 100,~~ or even a thousand acres. He will have some-one make for him, or he himself will make, a detailed survey of the area.

I say "he himself will make" because any horticulturist with ~~average intelligence~~ good experience and a little preliminary study, can do this. He must classify his soils, at depths up to 3 feet (this is enough in most instances) as to texture, ~~and to~~ To learn what he most needs to know, he does not have to respect the refinements of classification which can only be attained with the ~~use of a microscope~~ aid of laboratory analysis which ~~enables him to evaluate the size of~~ measures the exact size of even the smallest particles. ~~It is sufficient for him~~ He only needs to classify the samples he takes, right in the field, as he goes along making borings with his soil auger. If his land is "spotty" he may have to make borings at intervals as close as 25 to 50 feet; if sudden changes in texture are rare, 100 feet is sufficiently close.

A simple soil auger is inexpensive and can be made almost anywhere. It is only necessary to buy a "greenwood auger bit" of 3/4 or 1 inch bore, and about 5 feet of ordinary 1/2 inch galvanized iron pipe-

Any ironworker can solder this bit into one end of a ~~three~~ five? foot length of pipe: at the other end he threads the pipe, ~~[illegible]~~ uses a coupling, and makes a handle about 15 inches long which is used to turn the auger into the ground. It is well to file or grind off the screw at the end of the auger bit, to avoid possible damage to ones hand when he draws the auger out of the soil, twirls it ~~anti~~ slowly clockwise, and holds his thumb between the threads to let him catch the soil in his hand, where he looks at it, and ~~perhaps~~ rubs it between his fingers to ascertain the texture. It may be mentioned that very dry, sandy soil obviously will not cling to the bit, which makes it difficult to do a soil survey ~~until~~ unless the land is ~~wet~~ moist; ~~and~~ One may also have trouble with ~~on the other hand,~~ ~~in~~ stiff clays for it is hard work/ withdrawing the auger from a depth of two or three feet.

As the auger goes down, it is withdrawn after each 8 or ten inches, and if there are changes in texture, which is often the case and is a most important point, these are noted and are used in making the soil map, if one is to be prepared.

Recognition of five textures is usually adequate to meet the needs of the practical horticulturist. These are, proceeding from the coarsest to the finest: sand, sandy loam, clay loam, coarse-textured clay (often called light clay) and fine-textured clay, which popularly is ~~often called~~ ~~termed~~ called heavy clay, a term modern technicians do not favor because, *in sensu strictu*, it refers to weight, not texture.

Include description of methods of determining texture

In addition to texture, it is essential to know—at least for some fruit trees (e.g., the lychee)—the approximate degree of acidity or alkalinity of ~~acidity of~~ the soil. This is commonly referred to as the pH value. It should be ascertained every now and then, as one proceeds with his study, by means of a simple, easily obtainable kit which can be used right in the field. A tiny sample of soil is placed in the small porcelain pan, or the waxed paper, which comes with the outfit. A small amount of the accompanying liquid is poured over this and the resulting color (hence the name colorimetric method) is compared with the color chart which also comes with the outfit. A very simple, and sufficiently accurate, operation.

need verb

Coarse sands are, ~~of course~~, practically useless from the horticultural standpoint - unless we are talking of soils containing plenty of better material as well. ~~But~~ Many fruit trees are ~~grown~~ successfully on soils with a ~~very~~ high percentage of fine sand, as witness the thousands of acres of Citrus fruits grown on such soils in Florida. ~~Such~~ These soils, obviously enough, require the liberal use of fertilizers, containing not only the major mineral elements, nitrogen, phosphorus, and potassium, but also, in many instances, several minor elements as well. The work done by Florida scientists in determining the nutrient requirements of Citrus trees on sandy soils ~~in that State~~ may be pointed out as an outstanding example of the benefits to be derived from intensive horticultural research.

Sandy loams are usually excellent soils, and, fortunately, are abundant in many parts of tropical America. In some instances they may be slightly less desirable than good clay loams, which in my opinion are just about the best banana soils in the world. This may be because a moderate proportion of fine (clay) particles increases the water retaining capacity of the soil — (not an advantage in regions of high rainfall, naturally enough) — and seems also to result in longer productive life of the land.

Clays, so abundant in many regions, ~~often~~ commonly require more skillful management than ~~the~~ others ~~sandy soils~~. Soils with a clay content up to 80 or even 85%, if granular in structure, often prove to be excellent banana lands. On the other hand, soils of much lower clay content may be extremely hard to drain satisfactorily if the clay is plastic or "sticky" in character.

Some of the most ~~recalcitrant~~ difficult soils in tropical America are plastic clays, even when they ~~these~~ contain ~~it~~ a good percentage of coarse sand ~~and~~ or gravel. Thousands of acres of such land, even under a rainfall of 35 to 45 inches annually, are conspicuous for the ~~xerophytic~~ desert-like vegetation ~~vegetation~~ with which they are covered.

Drainage

Fortunate indeed is the horticulturist who does not need to pay much attention to problems of drainage. Less fortunate is he who lives in a flat, low-lying area subjected to heavy rainfall during even part of each year, -

or in a region where irrigation ~~a par~~ is an indispensable part of his program, ~~but~~ if his soils are fine-textured clays, and the surface of his land, ~~within an area of each acre or two, shown~~ is characterised by ~~slight~~ differences in elevation. ~~which might pass unnoticed were it not for serious differences in the behavior of his trees.~~

To approach the general problem of drainage logically, I believe we may do well to consider the three major factors in the following order: (1) Outlet, (2) deep drainage, and (3) run-off.

Outlet means that excess water from the area under cultivation has some place to go and some way to get there. ~~If~~ If the horticulturist ~~who~~ is contemplating the establishment of a banana farm, or an orchard of fruit trees, ~~to~~ in a low-lying area with higher land all around him, he would in most instances do well to get rid of the property and move to a more favorable location, one where he can channel the excess water into a near-by stream or some other place where it will do no harm. ~~he can go ahead provided the cost of excavating the necessary canal to carry the water to such a place is not expensive~~.

<u>Deep Drainage</u>. This means the provision of drains or

ditches, excavated to such depth and spaced at such distances one from the other, as to keep free water at all times below the ~~essential~~ root zone of the trees. It does not matter, of course, if a few of the roots go down to free water, in fact this may be desirable to a certain extent, but the zone from which the tree gets its nourishment must never be too wet ~~be kept in~~ over long periods of time for, ~~such condition, that air can get into the soil,~~ ~~that~~ ~~and~~ the feeding roots to ~~can~~ develop and operate effectively. ~~freely under favorable conditions.~~

But how is the horticulturist to know what spacing to use between drains, and how deep to dig them? Many trees have been lost, ~~and~~ or on the other hand money has been wasted, because the horticulturist did not know.

Test wells are ~~usually the~~ the best answer. This does not mean digging holes with a ~~sto~~ spade or a post-hole auger, ~~for one~~ to determine where the water-table (free water in the soil) ~~exists~~ stands at the moment. We ~~should~~ must know from week to week, throughout the year, ~~and~~ We can ~~only~~ best get this information by setting 4-inch or 6-inch clay (or cement, if preferred) tubes in the ground, extending to a depth which we consider to be somewhat below the root zone of our trees. Perhaps 4 to 6 feet. Once a week we measure the depth at which free water stands in the test-well, ~~using the~~ starting from surrounding surface of the land. ~~as the starting point.~~ zero feet.

In some instances these records may be all we need; in others, to ~~secure~~ avoid wasting land by not having ~~ditches~~ drains spaced closely enough, or more important, to make sure that the water table is kept down to the necessary level in the area between ~~ditches~~ drains, we have to start by considering the texture of the soil, ~~using our judgment to suggest possible spacings~~, then dig a few experimental drains ~~some ditches and~~

at different spacings, perhaps 25, 50, or even 100 feet. We then set test wells in a line between each two drains.

~~spacing the wells perhaps 12, or 25, or even 50 feet apart, depending upon the character of the soil.~~ ~~We will find~~ observations will usually show that the ~~height of the~~ water table is ~~higher~~ nearer to the surface at the center of the area between ~~ditches commonly~~ drains. ~~considerably higher~~ than in the ~~ditches~~ drains themselves (if they are carrying water)]. ~~or at least~~ In any event, higher than it is in the test wells close to the ~~ditches~~ drains, This because, as Everyone knows, ~~that the~~ movement of water in the soil

? is much greater vertically than horizontally.

All this sounds like a lot of work, and is a lot of work ~~has been mentioned~~, ~~is not always necessary~~, but where doubts exists it eliminates them.

¶ Finally, it should be mentioned that it is customary in many regions to give open drains ~~ditches - which more properly be called drains~~ - a side slope of one in four. This usually suffices to attain the ~~an~~ "angle of repose", which means that not much soil will fall into the drains from time to time, ~~to~~ blocking ~~blocking~~ the free movement of water. The side-slope, however, may ~~should~~ vary somewhat, in accordance with ~~in depending on~~ soil texture.

~~Run-off.~~

Run-off. This third and last factor

in the drainage program is the easiest to handle, but at the same one which can cause serious and expensive losses if ignored. ~~Run~~ Good run-off means simply that there are no low spots where water can stand for several days ~~at least~~, with resultant damage to ~~the trees~~ the ~~roots of the~~ root systems of our trees ~~affected~~. Prompt and effective run-off is particularly important if the soil is clay, or there is clay or hard-pan in the layers close to the surface.

Many years ago, when we were attempting to find some way to grow bananas successfully on 80% clays in Honduras, I wrote Professor F. S. Earle, who founded the agricultural Experiment Station at Santiago de las Vegas near Habana, Cuba, and later was instrumental in saving the sugar cane plantations of Puerto Rico from ~~destruction~~ the mosaic disease. I asked him, "How can we drain these 80% clay soils"? He replied "Dont try to pull the water out of clay soils, slide it off the top."

Irrigation.

I have advised many of my students who

were heading for agricultural careers but had not decided ~~did not~~ in what particular branch they wished to specialise, to go in for agricultural engineering. There are vast areas in tropical America where drainage and irrigation are the keys to successful farming. They have already received merited attention in numerous countries ~~many regions~~, but undreamed-of possibilities are still ahead of us. And what an interesting field it is, for it involves expert knowledge of the chemistry, structure and texture of soils, relationships between soils and climate, topographical surveying, the plant-water relationships of many different crops, and finally the problems of soil management, including, among other things, drainage, irrigation and fertilizers, though some people will argue that the latter do not really belong in the realm of agricultural engineering.

What are the principal things which the fruit grower should know, if irrigation is an essential part of his program? He must know when to irrigate, how much water to use, and how to apply it to the land. When, how, and how much.

There are those who ~~espouse~~ voice the thesis that the soil throughout the root zone should be kept moist at all times. There are others who argue that water should not be applied until the wilting point is reached, that is, until the leaves of your trees begin to droop a bit, and look thirsty. "When doctors disagree, who shall decide?" Much depends, perhaps, on the crop we are considering. I would keep the soil under banana plants moist at all times. But not so wet as to preclude the entrance of air into the soil. On the other hand, Citrus trees may profit by allowing the soil to dry out to a somewhat greater degree between irrigations. If this is true, it also means that ~~???~~ the costs connected with irrigation are kept to the minimum.

The Spaniards have a saying, "el ojo del amo engorda el ganado" - "the watchful eye of the master fattens the cattle". By this same token, frequent use of the soil auger, in the hands of the experienced horticulturist, gives the best control of irrigation.

As regards ~~app~~ the application of water, overhead irrigation, now standard practice on many large banana plantations in tropical America, and beginning to be used on other crops as well, seems to be ideal from several points of view. With this method, the quantity of water applied can be controlled with great accuracy, and it is spread evenly over the entire surface. It is economical of manual labor. The expense of installation places it out of the reach of many fruit growers/ who operate on a small scale. Then there is the cost of pumping, but this may be offset by the saving which results from the elimination of much hand labor. Sprinkling increases evaporation and promotes leaf diseases (fungus)

Fruit growers whose plantings are not large resort to one of the three traditional methods of application, - flooding, basins, and furrows. Flooding consists in covering the entire surface with water, its spread being controlled by the use of "checks", narrow ridges ~~out~~ of soil six or eight inches high, which are placed at convenient intervals. Water is brought into the orchard by means of small temporary "field ditches" and dumped onto all of the areas controlled by checks.

Basin irrigation - a popular method - differs from flooding in one major respect: Instead of covering the entire surface, water is applied only to areas which are occupied by the feeding roots of the tree, and can therefore be utilized by the latter. The spread of the tree is taken as the guide. Basins made by raising ridges of soil, again six or eight inches high, are prepared around each tree, usually just outside the reach of its branches, ~~and~~. As in the case of flooding, these basins are filled from field ditches, temporary in character. Obviously, basin irrigation is more economical of water than flooding.

Furrow irrigation is practiced in many important fruit-growing regions. Shallow furrows, ~~are plowed~~ spaced perhaps two feet apart, are plowed down the centers between the tree rows, ~~and~~ There must be sufficient slope so that water will run, but not rapidly, from one end of the row to the other. The mistake is sometimes made of having the "runs", that is the furrows, too long, ~~or perhaps~~ the slope ~~is not~~ may not be sufficient for water to move at the right speed from one end of the furrow to the other. Three hundred feet is often considered the greatest advisable length. If longer, ~~the~~ too much water may go into the soil near the point of intake, too little at the farther end of the run. If the slope is too steep and water moves too fast, adequate penetration may not be obtained anywhere along the line, while on the other hand, if the slope is not steep enough and more especially if the soil is clay, water may stand in the furrows too long, involving - in very dry climates - a considerable loss by evaporation. ~~as well as "puddling" of the soil~~.

The question, ~~of~~ How much water to apply? can only be answered in terms of general principles. Every farmer who lives in a semi-arid region, watches the skies with an anxious and hopeful eye for the ~~appearance of~~ onset of the rainy season. The first showers may not wet the soil ~~to the depth of more than~~ deeper than a few inches. When applied to dry soil, water will penetrate only to the depth ~~required to~~ ~~which the~~ where quantity ~~meets the~~ can no longer fill it to "field capacity". Below that depth, the soil is not wet until more water is applied.

Rewrite

F.C. = amt of water soil will hold against pull of gravity – constant % for a given soil

The purpose of irrigation is, or should be, to wet the entire root zone to field capacity, or perhaps it is more correct to say, the zone in which there are rootlets capable of absorbing water required by the plant. If more water is used than the amount required to ~~meet the field capacity of the soil~~ [do this,], an unhealthy condition is the result, not to mention ~~the~~ another important ~~result~~ [point]: water which penetrates beyond the root zone ~~never can be brought back,~~ ~~and may~~ represent a considerable economic loss to the horticulturist. This feature is particularly important where water is scarce or expensive. also leaching of nutrients

How is a man to know when the root zone has been ~~m~~ moistened to field capacity?

The soil auger will tell him. And just how far down does the root zone extend, any-way? The feeding roots of coffee and bananas are mostly within the first foot or two of soil. Many trees work somewhat more deeply than that. Horticultural literature will often provide helpful guidance in this connection. The texture of the soil, however, may influence strongly the extent of the zone from which the plant draws water, and nutrients in solution, hence the wise horticulturist carefully excav-ates around a few trees, to see for himself just what is going on down below.

root room

Redundant to title at beginning of chap.

SOIL MANAGEMENT

Here, indeed, we are in grave danger of rushing in "where angels fear to tread." Even in the Temperate Zone where we have behind us many years of scientific investigation, there exist several very distinct schools of thought regarding soils and fertilizers, all the way from the advocates of "organic gardening" who ~~t~~ believe that carrots (and other vegetables of course) which are grown with chemical fertilizers are highly injurious to human health, to those farmers (few in numbers) who hold that the surface of the land should never be touched by any implement which disturbs ~~the surf~~ it at all. Plowing or even disk-harrowing is anathema. to this latter group,

These are extreme views, but if there is not universal agreement in the Temperate Zone, how can we expect it in the Tropics? We have relatively little experience, relatively few carefully-conducted experiments, to guide us. The problems are numerous, often complex, and ~~may~~ vary from place to place, in accordance with differences in soil and climate.

Speaking in general terms, it seems that the tendency, in many regions, is away from deep plowing, except on fine-textured sugar-cane lands - stiff, often sticky, clays - or when breaking pasture lands to bring them under more intensive cultivation. The disk harrow, which breaks up the soil to a depth of only 3 or 4 inches, is gaining popularity among fruit growers.[7]

The late Louis Bromfield, who ~~for years~~ preached the gospel of shallow cultivation, organic manures, and mulching, some 15 years ago spent ten days with us at the Escuela Agricola Panamericana in Honduras. I had been led to think of him as an extremist;

follow thru on Bromfield

I was ~~disillusioned~~ mistaken. We had been for some years keeping our soils in what we considered to be good tilth by disk-harrowing. We used all the organic manure we could get from our dairy and stables. It was by no means enough, ~~We~~ so we also used commercial fertilizers in quantity.

I feel sure tropical horticulturists agree that animal manure is the ideal fertilizer in most instances. Years ago, when I was assisting A. D. Shamel and P. H. Dorsett in a study of citrus culture in that fascinating home of the Navel orange, Bahia, Brazil, we noticed that quite a few orange growers also operated dairies. Finally we asked Colonel da Costa, "Which pays you best, your dairy or your orange grove?" Without hesitating he replied, "Oh, I don't make any money out of the dairy. But I need the manure for my trees."

This may be the place to mention an interesting experiment which was commenced by Pedro Cofiño some twenty years ago on his coffee plantation "La Retana" in the valley of Antigua, Guatemala. He had been ~~carrying out~~ following the standard practice of that region. Once a year laborers with heavy hoes scraped the soil away from ~~around~~ the bases of the coffee bushes, ~~and~~ ~~windrowed it for~~ leaving it in windrows six or eight inches high down the centers between the rows. The primary ~~purpose~~ objective was to destroy the weeds.

This "finca" was on sandy loam of recent volcanic origin, and the coffee was grown under shade of *Grevillea robusta*, as is customary in the Antigua valley. After leaving the soil in windrows for a year it was ~~sea~~ hoed back around the coffee. Thus an inch or two of topsoil was shifted in position at least once a year.

Walking through the finca one day, just after new windrows had been formed, Pedro and I noticed that they were full of chopped-up, fine white feeding roots. "This won't do" we agreed, "we are cutting off the feeding roots just as fast as they are produced."

So Pedro switched to a new system. He eliminated the hoes, leaving the surface undisturbed. When necessary, laborers cut with machetes the few weeds that grew.

¶ Then Pedro started making compost. He used all the leaves and other vegetative material he could get from his farm, and he bought all the stable manure he could get in town. He spread manure and compost over the finca as fast as he could ~~develop the material~~ get them.

Results were so satisfactory that after the experiment had been carried on for ~~a few~~ two or three years, coffee growers came from places as far distant as Costa Rica to see "La Retana".

This brings us ~~logically~~ to a brief discussion of mulching, which I think will be used more and more by tropical American fruit growers. Aside from its benefits, it has the advantage that it is often much easier to get material for mulching - rice straw, sugar cane leaves, even grass - than it is to get stable manure. Mulching goes especially well in combination with basin irrigation. Three or four inches of dry leaves or straw or grass retain moisture, keep the soil in the basin cool and in good condition, and gradually supply a little organic matter.

I do not mean to say that mulching should be limited to orchards where basin irrigation is practiced. In dry climates it can profitably be used under many different conditions.

But what about green manures, so popular in many northern countries? It may be too early to reach definite conclusions, but my own experience with them in Central America and the West Indies has not been very encouraging. For example, in Jamaica we planted cowpeas under young bananas, several crops of them in rapid succession. When each crop came into bloom, we disked it into the soil and planted another. We got no significant increase in fruit weights, while at the same time we were getting eight pounds per bunch in adjacent plots, through the application of nitrate of soda.

Cover-crops, used to keep undesirable types of vegetation under control and to protect the surface of the land from too much sun, have been profitably used in many regions. It should be mentioned that cover crops and green manures are sometimes considered to be one and the same thing, because when planted primarily with the object of increasing soil fertility, green manures also serve, at least temporarily, to suppress weeds and protect the soil from over-heating and erosion, while legumes in particular, when used as cover crops, may enrich the soil through the leaves which fall and ~~and~~ supply organic matter as well as nutrients to a limited degree. Unfortunately, it seems to be true that the addition of vegetative ~~The season for~~ material to the soil, through incorporating green manures or cover crops, does not give the results ~~which~~ obtained in the North, ~~seems to be that their they are oxidized~~ because decaying organic matter is oxidized so much more rapidly under tropical conditions. ~~than they are in cooler climates~~.

If experience in the banana plantations of ~~tropical~~ central America is any guide, a ground cover ~~the presence~~ of soft broad-leaved herbaceous vegetation ~~or~~ (as opposed to grasses) is ~~desirable~~ ~~useful~~ beneficial, if kept within bounds by cutting it down to a height of one foot, more or less, whenever necessary. But low-growing matted grasses, such as Bermuda, are among the worst enemies of the ~~g~~ fruit grower, first because they compete for nitrogen with the trees (and usually win out) and secondly, because they are hard to eliminate. Few indeed are the orchards in tropical America ~~is not~~ where grass is not a problem; few indeed are the orchards (especially the small ones) where grass, because it is allowed to develop uncontrolled, does not ~~retard the~~ appreciably affect the growth of the tree and its productiveness. An interesting exception is the mango, which, when young, will not grow as rapidly, ~~when~~ surrounded ~~with~~ by grass, as it will under clean cultivation, but ~~which~~, when mature, often produces excellent crops right in the center of a lawn.

The subject of fertilizers is too vast and too complex to be discussed in detail here. A few generalities may not be out of place. The citrus fruits, in comparison with certain others, seem to thrive on a well-rounded fertilizer program. Bananas are tremendous consumers of nitrogen; on the well-balanced alluvial soils of Central America this seems to be practically the only nutrient which must be supplied, ~~but~~ though on residual soils in many ~~regions~~ countries this is not the case. Pineapples are

Qualify

rather specialised plants, not rank feeders like the banana. Avocados need a good deal of nitrogen - on some soils - in addition to other elements. Mangos, when the trees are of mature size, must be fertilised very sparingly, else the result will be vegetative growth at the expense of fruit production.

~~To terminate this Appendix, I would like to make a prophecy (didn't I begin by speaking of "rushing in where angels fear to tread?").~~

The use of fertilizers, in connection with tropical agriculture and horticulture, is growing apace. Fertilizer factories are becoming more numerous every year. The potentialities of the future are tremendous, particularly because the source of nitrogen, perhaps the element of which the largest quantities are needed, is inexhaustible - the air.

We read these days about "exploding populations" (they are not exploding, they are just increasing rapidly); we read about the danger of world-wide starvation within another century or two. We do not read so much about improved techniques of tropical soil management, the development of crop varieties of greater productivity or higher food value than some of those which are grown today, and the astonishing results which will be obtained from the more ~~abundant~~ extensive use of fertilizers.

Perhaps it is because these subjects do not excite the imagination to the same extent ~~that~~ as "exploding populations" and "world starvation" ~~do~~.

Rainfall for the year 1969 at Casa Popenoe,
Antigua Guatemala

April	2.85	inches
May	7.10	
June	8.55	
July	6.54	
August	12.30	
September	16.62	
October	2.45	
	56.41	inches

No precipitation worth recording in other months. The total of 56.41 inches is higher than average rainfall for recent years as far as I know.

Abril	Mayo	Junio	Julio
285	710	855	654

Agosto	Sep	Octubre
1.230	1.662	245

285
710
855
654
1230
1662
245
5.641