DISTRIBUTION OF ABSORBING ROOTS OF COFFEE (*Coffea arabica* L.) AND RUBBER (*Hevea brasiliensis* Muell. Arg.) IN MIXED PLANTINGS IN TWO ECOLOGICAL ZONES OF COSTA RICA

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To my father and mother
and to my brothers.

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AUTHOR'S BIOGRAPHY

The author was born in Mexico City, Mexico, in February, 1938.

He carried out his secondary school studies at St. Andrew's College, Ontario, Canada, and his university studies at Kansas State University, where he obtained the degree of Bachelor of Science in Agriculture, with a major in Horticulture.

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INTRODUCTION

The mixed planting of permanent commercial crops in the tropics has long been a topic of interest to investigators and agriculturists, especially from the point of view of it being one of the possible solutions to the ever-growing problem of adequate land use in the tropics. Mixed planting of permanent crops seems a promising system for tropical agriculture in the future because it makes more complete use of the cultivable land than the systems used up to now. Furthermore, it offers protection to the farmer by diversifying the risk of price drops or low production.

Interplanting of coffee and rubber has been used in the East Indies for a long time and was introduced to America in 1950 when trial plantings were established by the USDA Cooperative Rubber Program in Costa Rica.

However, due to unfortunate circumstances, these trial plantings were not kept up for a number of years. Nevertheless, data recently obtained (50) indicate that this system is proving highly satisfactory.

There are a great many problems and unknowns involved in this system. One of the most important of these is the root picture. Knowledge of the underground situation is of great value in solving problems such as those of adequate fertilizer application, proper cultural methods and spacing of plants.

By determining quantitatively the distribution of the absorbing roots of coffee and rubber growing in mixed plantings in two ecological zones of Costa Rica, as was done in the investigation described in the following pages, valuable knowledge was acquired concerning the underground situation in this system. Not only was information gained about the root distribution of *C. arabica* and *H. brasiliensis* growing under different environments, but also of the two species growing together, and the degree to which their absorbing roots intermingle, indicating the possible occurrence of root competition for nutrients, water, and space. Furthermore, information was acquired about the effect of soil conditions on the distribution of absorbing roots of the coffee-rubber complex in the two ecological zones studied.

REVIEW OF THE LITERATURE

1. Basis of the interplanting system:

One of the main problems faced today by agriculturists in tropical countries is that of land utilization. The rapidly increasing population, together with the overproduction and consequent price drop of the main crops grown, such as coffee, rubber, cacao, bananas, etc., has made the extensive plantation system unsatisfactory. The need has arisen for the development of new agricultural systems for the tropics which will make possible higher incomes from smaller extensions of land. One system which has been suggested by various investigators and which seems to be a promising solution is that of interplanting permanent crops, simulating the natural vegetation.

Holdridge (41) states that a mixed culture, copying the natural physiognomy of the plant association, is ecologically sound. He indicates that such a system would permit the maintenance of the nutrient cycle permanently with little or no need for commercial fertilizer application, and would eliminate to a large extent the development of insect and disease problems.

Hunter and Camacho (44) support this theory of copying natural vegetation. They point out that in tropical and subtropical forests, various stories or strata occur in the climax vegetation and recommend that this condition be copied when initiating permanent plantations at sites previously under virgin forest. They are of the opinion that such a system would be advantageous, since one can put to maximum use the available land as well as compensate possible losses in one crop with gains in another.

2. Examples of the interplanting system:

A number of investigators in America, as well as in the East Indies and Africa, have become interested in the possibility of interplanting different crops with *Hevea* rubber. Allen (1, 2) recommends the planting of rubber in single and double hedgerows spaced far enough apart to permit permanent intercropping. He lists a number of crops which may be interplanted with *Hevea* in such a system and suggests a number of tentative planting designs which may be used for the different mixed plantings. He recommends combinations with Manila hemp, banana, pineapple, oil palm, kapok, cacao, coffee and a number of fruit and forest trees. However, he stresses the fact that these recommendations are purely theoretical and that a considerable amount of investigation should be carried out on these suggested plantings before recommending them to commercial agriculturists.

In Costa Rica, Morales and others (56) carried out a number of experiments in which rubber was planted with various other crops such as corn, yucca, beans, sugarcane, rice, sorghum, etc. Results indicated that corn and yucca seemed the best intercrops. Profitable returns were obtained with these two crops and it was found that young rubber actually showed better development when interplanted than when grown under the common system of monocultivation.

Work has been done on the interplanting of tree crops with *Hevea*, principally cacao and coffee. Imle and others (45) suggest various different planting systems for rubber and Robusta coffee (*Coffea canephora*) and for rubber and cacao (*Theobroma cacao*) in which the rubber is planted in hedge lines. They are of the opinion that tree crops are more advantageous than annuals because: 1) they are more permanent and have a consequent stabilizing effect on the population; 2) they provide greater conservation of the soil resources; and 3) they involve less risk because tree crops can withstand adverse weather conditions which may be disastrous for annuals.

Nosti (58), reports that on the island of Fernando Po off the coast of Nigeria, Hevea is used exclusively as shade for coffee and cacao.

Hacquart (33) recommends the interplanting of cacao and Hevea, planting the rubber in rows in such a way that it provides shade for the cacao trees; this would result in a more complete use of the land. The author points out that one advantage of this system is the rapid decomposition of the forest debris as well as a more complete ground cover.

According to Cramer (15) interplanting of coffee and rubber has long been a common practice in Indonesia. However, in this region complete elimination of all vegetation other than rubber is recommended when the Hevea trees reach tapping age, the reason being to provide better microclimatic conditions around the tapping panels, especially from the point of view of phytosanitation.

Snoep (75) in his discussion on 'lane planting' of rubber interplanted with coffee, states that "it is possible to establish a permanent mixed culture that continues to yield profit which at least is as great as that derived from plantations consisting of one type of culture only."

3. Plant-soil interrelationships of the interplanting system:

Note should be taken of the fact that although much has been written about mixed planting, most of the information available consists of theoretical discussions dealing with the pros and cons of interplanting rubber with other crops. Suggestions are made by the authors regarding the crops to be planted and planting designs to be used, but emphasis is put on the fact that these suggestions are purely theoretical and should be put to trial before they are applied on commercial scales. In general, investigators point out that there are a great many unsolved problems inherent in this system. Perhaps the most important drawback of the mixed planting systems, pointed out by almost all of the above mentioned investigators, is that of competition - especially root competition. However, these authors only refer to the problem as one which should be studied, but give little evidence that in practice it does occur.

The problem of competition between plants growing on the same piece of land is one to which increasing importance has been given in recent years.

Clements, et al.(14) have reviewed the literature on this subject prior to 1929, and have come to the conclusion that there are five direct factors for which plants compete: light, water, nutrients, oxygen and carbon dioxide. Competition for oxygen and carbon dioxide occurs only under rare conditions of limited supply of soil air. The relative importance of the remaining three factors is stated by the authors to depend on which one "is present in the smallest amount relative to the demand."

The fact that both nutrients and water are absorbed by the plant from the soil make the underground parts of plants of primary importance in any study of competition.

Aaltonen, cited by Clements, et al. (14) states that the "struggle for room is decided by the underground and not the aerial parts of trees."

The importance of competition under the soil level has been demonstrated in a number of experiments carried out with various different species.

Vogdt (88) found that when a group of suppressed pines were freed from root competition of surrounding older trees by means of an encircling trench, the released pines showed a marked increase in rate of growth.

Pessin (65), studying the root system of long-leaf pine seedlings growing in association with grasses and herbs, found that all these plants had the majority of their roots within the upper foot of soil and were therefore in competition with each other. This was proved by the fact that when the grasses and herbs were removed, the pine seedlings made marked progress.

Cross (16), working with alfalfa and pecans, found that although both thrive in the same type of soils, they will not grow together satisfactorily at the same time in the same area. Since both species develop deep root systems, the author suggests that this causes strong competition for water and nutrients.

Garin (24) has inferred that root competition must frequently be the most important factor of suppression and dominance of species in a forest stand.

Surmac (80) carried out experiments with pine seedlings and observed that when competition for water by roots of adult trees was removed by isolating the seedlings with a trench 70 cm deep, the young regeneration flourished.

Walter (89) in Alabama, found that growth of pine seedlings was slowed down by competition with mother stands at distances of 55 ft from the latter; further than the spread of the crowns. Survival of the seedlings at five years increased from 51% close to the border up to 78%, 40 ft away. The diameter of the root collars increased with the distance at the rate of 0.1 in for each 10 ft.

Root competition between rubber trees and other plants growing close to them has been studied to a limited extent.

Van der Veen (85) has observed that when abundant moisture is available, competition is not evident, but in a dry period, competition between Hevea and a cover crop is expressed by a lessened growth of the rubber trees and reduced soil moisture.

Pfaltzer and Vollema (66) report that in Java, young rubber plants grew more rapidly under clean cultivation than with a cover crop of Centrosema pubescens. The cover crop retarded girth growth slightly.

Investigators in Malaya (67) have shown that grasses compete too much to be used as a ground cover under rubber. They indicate that it is more satisfactory to use leguminous creepers or natural undergrowth.

Van der Marel (54) observes that, although the nitrogen content of the soil increases when rubber is interplanted with legumes, nodulation almost ceases. He suggests that the rubber can suffer as a result of root competition.

The above references give ample evidence of the fact that the underground parts of plants are capable of competing with one another for the requirements of the plant and that this competition may affect visibly the growth and development of the plant. However, it is fitting to note that plants are capable of living together, occupying the same volume of soil, without harmfully competing with each other.

Woodhead in 1906, cited by Clements et al. (14) has described such a situation occurring in mixed communities of Scilla, Holcus and Pteris. In this case, these species were living together without competing, forming what he called a 'complementary society', that is, "the underground parts occupying or tending to tending to occupy definite and different layers."

Sherff, also cited by Clements et al. (14), indicates that a "number of species may live together without competing with each other when 1) their underground parts lie at different depths and their roots are thus produced in different layers; 2) they make unlike demands on the soil, even though the roots lie at the same depth." He also points out that a plant community may be 'edaphically' competitive despite being complementary as to the aerial parts, and vice versa.

Whether the relationship between plant communities living together is competitive or complementary depends on a number of factors acting at the same time under specific conditions. That is to say, whereas competition will occur under a certain situation where these factors are involved, the same plants may live in a complementary relationship when one or more of the affecting factors varies.

Kharitonovich (48) has observed that in steppe plantations in the USSR, oak (Quercus robur) is suppressed by certain other species such as robinia (Robinia pseudoacacia), birch, common ash, elm, and boxelder. On the other hand, oak is not affected by species such as lime, pear, hornbeam, and Acer campestre, that is, it sustains a complementary relationship. In some cases, oak will suppress other species such as *Fraxinus pennsylvanica*.

Lysenko (53) claims that while competition between different species is a powerful ecological factor, intra-specific competition does not exist. However, his views have been repudiated by Karpov (47) who found that tree stands suppressed young growth of the same species by reducing soil moisture to values near the wilting coefficient. Moreover, no material difference in intensity was found between interspecific and intra-specific competition.

4. Root distribution:

The importance of root distribution from the view point of competition has already been discussed. However, in order to understand how root competition occurs, a certain knowledge of the rooting habits of plants and the factors that affect root distribution is necessary.

Andersson (3) has described root competition as a race in which the 'first comer' to a fresh source of moisture and nutrients may make it unavailable to other root systems. He points out that "hence, specific or individual differences in rate of root growth are important."

There are a number of factors which are responsible for the distribution of roots in the soil. According to Weaver and others (91, 92), these factors can be divided into two main groups: hereditary and environmental. Hereditary factors, according to these authors, give some species certain characteristic features in their usual habitat and are responsible for the type and degree of reaction of the root system to modification by environmental factors. Environmental factors, such as moisture, nutrients, oxygen, temperature, soil structure and texture, light and gravity have a marked influence on root development. They have been proved capable in many cases of dominating genetic factors and greatly modifying the conformation of plant root systems.

The influence of hereditary factors on the root distribution has been demonstrated in corn by Weaver (93), who found that certain strains had a much more limited root system than others.

Spence (76) has concluded from observation of the root systems of a number of important range plant species that "each species has a definite root pattern from which individual specimens deviate but little." He grouped the root systems into four distinct classes according to the distribution of their roots: fibrous, semifibrous, semi-taproot, and taproot systems.

Gursky (31) attributes differences in depth and spread of root systems entirely to species and climatic conditions. He states that species growing under dry conditions have deeper and more intensive root systems, whereas those growing in forest regions with higher rainfall have shallower and more extensive root systems.

Gerasimenko (25) has brought attention to the fact that oak tends to develop many small roots in the deep layers of the soil from an early stage of development. Oak is claimed to produce less roots in the 0 - 50 cm, and particularly in the 0 - 25 cm layers of the soil profile than other species.

Donelly (20), describing the root system of avocado, infers that this species has a certain root distribution which is fairly constant under the various soil conditions studied. Soil conditions affected the root system quantitatively rather than qualitatively.

A study involving 31 species of trees and shrubs in North Dakota carried out by Yeager (95) indicated that trees having little resistance to drought have a greater tendency to form deep, penetrating vertical roots in most locations, than do most drought-resistant species. Furthermore, known drought-hardy trees, such as oak and choke cherry, which tend to have relatively deep root systems, were found to differ from non-drought-hardy species in that the deep roots were distributed in a manner characteristic of these species, regardless of moisture conditions.

Although the above mentioned investigations have ample evidence that plants in general have a natural tendency to develop their root system along certain patterns characteristic of each species, note should be taken of the tremendous influence of environmental factors. These factors in many cases modify the root distribution to such an extent that the natural tendencies of the species are lost and their root distributions vary according to the limiting environmental factor or factors.

Domokos (18) indicates from investigations carried out on fruit trees, that the physical and chemical character of the soil, together with the position of the water table, are the limiting factors to root growth. Root conformation varies according to genetic characteristics only within these wide limits.

Reyneke and Van Niekerk (70) suggest that in order to obtain a uniform root distribution, it is necessary to know the principal factors which encourage and inhibit root development. They state that the most important of these factors are water supply, soil texture and structure and nutrient supply.

Hopkins and Donahue (43) studied the roots of trees in three different types of forest, and correlated their findings with soil characteristics. They found that although response to soil conditions varied slightly between species, there was a strong correlation between root distribution, moisture equivalent and organic matter content of the soil.

A study made by Butijin (11) of root distribution of fruit trees on profiles showing a thin clay layer over sea sand, indicated superficial root system development. This was attributed to the low percentage of porosity of the sand together with a low nutrient content and an unfavourable water supply.

Till (82) claims that roots grow in the direction of the soil water supply and suggests that the zones of highest available water supply can be determined by observing where the greatest concentration of roots occurs. Ballantyne (5) has correlated root growth to water supply. He states that root systems of fruit trees may be expected to develop in the direction of the available water supply. Thus "the method and amount of watering will alter the general shape of the root system, making it either a deep or a shallow one."

Hardy (35) has expressed his opinion based on studies made of cacao root systems in Trinidad, that the distribution of roots of cacao as well as of forest trees, is ruled mainly by soil features such as nutrient status, physical properties, and water supply. In his opinion the 'physiological depth' of a soil is determined by the "degree of aeration of successive soil layers of the profile; it may be limited by a high water table, ... but is otherwise determined by soil structure." In a study of the root distribution of sugar-cane in Trinidad (35), the same author observed that "vertical root distribution appears to be controlled by fluctuations in ground-water level which impress certain distinctive features on the soil-profile, and may be estimated by soil-profile examination."

Chemical features of the soil exert a powerful influence on the development of root systems. The pH and exchangeable Ca have been correlated with root development (90) with results showing that a pH of 4.8 almost totally inhibits root growth. Roots grow well at pH over 5.0.

Bergmann (6) observed that the presence of $CaCO_3$ favourably affected the longitudinal growth of roots and mitigated the toxic effects of temporary carbon dioxide concentrations in the soil. Calcium phosphate was found to have a beneficial effect on root development.

An investigation on grass-root distribution in Nebraska (22) showed that low exchangeable calcium and low nitrogen content in surface layers was closely correlated with a limited root development. On the other hand, high levels of soluble phosphorus were correlated with unrestricted root growth. Deep rooting was observed in profiles with ample supplies of nutrients throughout the profile.

The physical properties of the soil, as proved by various investigators, are of great importance in determining root distribution in the soil profile.

Karatskheliya (46) demonstrated that in soils with good structure the root system of tung trees extended throughout the profile, in some cases reaching the parent rock. In podsols, humic soils and sandy soils lacking structure, however, roots were limited to the surface layers.

Matjuk (55) indicates that there are marked differences in rooting behaviour of trees and shrubs according to the texture of the various soil horizons. Considerable changes of root development occur in passing from one layer to another of different texture.

Perhaps the single soil property which has the greates influence on root system development is the pore space.

Salter in 1940 (73) pointed out that the available water capacity and the permeability to water and to air of a soil are determined to a large extent by the volume and size distribution of the soil pore spaces. He stressed the importance of this factor which tends to impede or favour the spread and permeation of roots in the soil.

Veihmeyer and Hendrickson (86) working with two subsoils which exhibited peculiar water holding capacities, compacted these soils under laboratory conditions to a density similar to that in the field. In one case, roots were unable to penetrate the compacted sample when the apparent specific gravity was 1.8 or above.

Two years later, the same authors (87) described a similar experiment with nine different soil types compacted to various densities. It was possible to obtain higher densities with sandy soils than with clays, although the threshold densities above which roots did not enter were higher for sands (1.75) than for clays (1.46). In no case were roots found to occur in soils having densities of 1.9 or above. Failure of roots to penetrate compacted soils was attributed to the small size of pores rather than to lack of oxygen as it was found that roots penetrated saturated non-compacted soils from which the air had been expelled by heating.

According to Hardy (38) the size of the pores determines the ease of penetration of the soil by plant roots. He states that "root tips, protected by root caps, have definite dimensions, ranging from 0.1 to 0.5 mm. or over." Hence pores must have similar dimensions in order to permit root penetration.

Lugo-López (52) related pore size and apparent specific gravity or bulk density of clay soils to root development of three grasses. Results indicated that, in Para and Bermuda grasses, the combined effects of bulk density and small pores reduced root development. Guinea grass, however, was able to send roots through relatively dense layers of soil having high microporosity, presumably because of the small size of its root-tips.

Zimmerman and Kardos (96), working under laboratory conditions, observed a highly significant negative correlation between bulk density and degree of root penetration by soybeans and sudan grass. Sudan grass roots penetrated compacted soil cores more readily than soybean roots, probably also, as in the last case, because of the smaller size of its root-tips.

Evidence has shown that soil temperatures can have an effect on root development. Proebsting (69) attributed a lack of roots in the superficial soil layers of a California orchard to high summer soil temperatures. Experiments with peach trees showed that excessively high (95ºF) or low (45ºF) temperatures had a negative effect on root development. Optimum development was found at medium temperatures (75ºF). In Japan (57) it was found that optimum root development of peaches occurred at a soil temperatures of 24ºC and stopped at 35ºC.

Cartter (13) has shown that in soybean, the temperature of the root environment plays an important role in the development of the plant.

In summary, the above literature shows that variation in the environment of the root occupation zone is the most important cause of variation in the configuration of the root system. The degree to which this variation in the soil environment affects the root distribution of different plants is dependent on the inherent response of each species to the various environmental stimuli and will determine the development of the root system and its distribution within the soil profile (77).

5. Methods of studying root systems:

The size, variability, and complexity of plant root systems, together with the fact that in order to observe or make quantitative studies of them, the roots must first be separated from the surrounding soil, has made it extremely difficult to devise a method of studying roots which is precise or accurate. However, through years of investigation, a number of methods have been suggested and used which give a reasonable degree of accuracy and provide at least a picture of the root situation.

The methodology used in root studies of mature plants can be divided into two main groups:

1. The direct observation methods.
2. The quantitative sample methods.

The direct observation methods consist basically of exposing the root system of the plant studied *in situ* and reproducing what is observed either by photographs (32, 40, 93) or by plotting the exposed roots to scale (51, 84, 94). Exposure of the roots is made either by mechanical methods with hand tools or by washing away the soil with jets of water or air. This method is reasonably accurate but extremely time-consuming.

The quantitative sample methods of root study consist essentially of extracting soil samples of a known volume from the root occupation zone at varying depths and distances from the plant under study. After extracting the samples, the roots are separated from the soil and measured quantitatively.

Most investigators making quantitative root studies follow the same basic method outlined above. However, researchers vary in the way they approach the three essential steps of the method.

1) Extraction of samples: Some workers have used the 'soil-block method', whereby blocks or prisms of soil of precise dimensions are cut out throughout the root occupation zone until the whole or a representative part of the root system is extracted (7, 10, 23, 28, 83). Another method commonly used is the 'soil-core method', in which soil cores are extracted by means of steel cylinders or Veihmeyer tubes (4, 27).

2) Separation of roots from the soil: Basically, two methods are commonly used for this step: a) the 'dry method', consisting of separating the roots manually or by sieving (7, 28); and b) the 'wet method', whereby roots are washed through sieves (79) or soaked in water for a certain length of time and the soil is allowed to separate from the roots.(8, 12).

3) Measurement of the root concentration in each sample: The majority of workers making quantitative root studies, have measured the root concentration in their samples by weighing them

oven dry (23, 29). However, other investigators, such as Bloodworth et al. (8) maintain that, by determining the number and size of roots rather than their weights, a better comparison is obtained of root distribution in the various horizons. A number of methods have been suggested for determining the total length, area, volume and number of roots in the soil profile (17, 49, 59).

It is fitting here to call attention to Pavlychenko's method of root study (64) by which the entire root system is extracted in one block. The soil is washed away and the root system is placed in a large tank. The root system is then determined by measuring the individual roots.

A very interesting and recently devised method of measuring root distribution is one involving radioactive tracers (9, 34, 71). The use of this method has been limited, and it presents a number of difficult problems, but investigators who have used it indicate a number of advantages over the traditional methods.

6. The root system of coffee and rubber:

In view of the fact that the present investigation deals with the root systems of *Coffea arabica* L. and *Hevea brasiliensis* Muell. Arg. growing together, it has been thought convenient to review the existent literature concerning their individual root systems in order to obtain some idea of the root pattern of these trees when not in competition with each other.

a) Coffee. The root system of this genus has been amply studied in various parts of the world. Nutman (60, 61, 62) studied the root systems of 67 *C. arabica* trees in Kenya, East Africa. By discarding:

1) "those trees showing signs of abnormality in their above-ground portions" and 2) "any trees in situations which offer obvious reasons for considerable modification" (e.g. where downward root penetration is inhibited, or where a pan of rock occurs and stops downward growth), this investigator maintains that a 'normal' root system of Coffea arabica can be defined. He describes the 'typical' root system of arabica coffee as follows:

1) A TAP-ROOT consisting of a stout central root often multiple, tapering more or less abruptly and rarely extending more than one foot from the surface.
2) AXIAL ROOTS: commonly 4 to 8 in number; running vertically downward below the tree trunk. They may originate in the forking of the tap-root but are frequently of lateral origin. They penetrate vertically 8 or 9 feet, branching in all directions at all depths.
3) LATERAL ROOTS:
    a) Surface-plate roots: running more or less parallel to the soil surface to a distance of 4 to 6 feet from the trunk.
    b) Laterals not in the surface-plate: roots which "do not run parallel to the surface but ramify evenly in the soil and sometimes become verticals, branching in all planes."
4) FEEDER-BEARERS: roots "of varying length, evenly distributed about one inch apart on the permanents, showing a slight tendency to be shorter and more numerous in the surface-soil
5) FEEDERS: roots "borne uniformly on the feeder-bearers at all depths but are slightly more numerous in the surface-soil."

The same author goes on to mention that hard-pan has little effect on root development, and that lava, mud-stone, gravel strata, and a high water table inhibit root penetration "to a greater or lesser degree". The acid limit of optimum feeding-root growth is stated by this investigator to be pH 5.8 to 6.0.

Guiscafré-Arrillaga and Gómez (28, 29, 30) concluded from studies in two clay soils in Puerto Rico that: 1) 95 percent of the roots of the coffee trees studied occurred in the top 12 inches of soil; 2) there is no fixed ratio of tops to roots in coffee trees; 3) there is a close positive correlation between trunk diameter at the soil line and the extent of the root system; and 4) the coffee tree root system has the shape of an inverted cone, but this can be greatly modified by soil conditions.

Thomas (81) in Uganda, made root studies of *C. canephora*, *C. excelesa*, *H. brasiliensis* and other tropical plants and concluded that their root systems are usually superficial but their distribution is greatly dependent on soil conditions.

Franco and Inforzato (23) in Brazil studied the root system of coffee in different soils of São Paulo State. They concluded that there is no 'typical' root system of coffee, but rather one that is characteristic of a certain soil, since physical and chemical properties of the soil modify root distribution.

Hatert (39) carried out a study of the root system of *C. canephora* trees aged 1, 3½, 7 and 14 years. He makes little mention of the influence of soil conditions, and describes the root system of Robusta coffee as follows:

"- a straight taproot, sometimes forked, which may be 90 cm deep.
- lateral roots with a tropism almost exclusive for superficial horizons.
- many secondary and absorbing roots forming a dense mat which is distributed uniformly around the trunk over a surface of at least 7 to 8 square meters."

Suarez de Castro (79) observed in Colombia that coffee roots in the soil studied were superficial and their development was determined by the thickness of the superficial soil layer. Furthermore, root concentration decreased progressively from the trunk to the periphery.

In Costa Rica, Bermudez (7) investigated the root system of coffee trees in five different soils. His results indicated that "a good root system develops when the drainage is adequate and the "A" horizon is deep, of medium texture, and granular in structure." High root concentration was closely related to organic matter content and total porosity. A high water table limited root penetration and modified lateral distribution. Most of the roots occurred in the upper 30 cm of soil.

In Angola, Trancoso (83) found no correlation between soil chemical and physical properties and the distribution of _C. canephora_ roots. He describes the root systems of both _C. canephora_ and _C. arabica_ as superficial, having 65 percent of their roots in the top 30 cm of soil and negligible amounts below the 1 m. level.

b) _Rubber_. Very few studies have been made on the root system of _Hevea brasiliensis_.

Thomas (81) mentions that although Para rubber trees have a well marked tap-root, very few feeding roots are found below 16 cm.

Research in Malaya (68) has shown that, in general, there is little variation in the concentration of surface feeder roots with distance from the tree in mature rubber. Emphasis is placed, however, on the fact that this situation is subject to variations due to factors such as soil moisture, type, aeration, and cultivation. Further excavations demonstrated that both tap and lateral roots were strongly developed. Lateral roots were by no means confined to the surface layers of soil, a large number having been found in the lower horizons.

Investigations in Indonesia (26) showed that under favourable soil conditions, Hevea develops a deep tap root with strong laterals branching off at all depths. This feature can be greatly modified by mechanical resistance and water content of the soil. Dryness in the top soil will result in a downward growth of the laterals. As a whole, the root system of rubber is extremely susceptible to variations in soil conditions.

Otoul (63) made a detailed study of the root systems of Hevea plants ranging in age from germination to 14 years, in different soils in the Belgian Congo. Observations led him to conclude that "Hevea has, in general, a well-developed root system, predominantly superficial and 'humus-loving' in character, with the majority of its absorbing roots situated within the top 30 cms. of soil."

MATERIALS AND METHODS

The investigation consisted in the determination of the spatial distribution of the absorbing roots of interplanted coffee and rubber trees in two ecological zones of Costa Rica. For the purposes of this study, a diameter of 1.5 mm was chosen arbitrarily as the dividing line between absorbing and non-absorbing roots. The choice was made on the basis of the criterion held by a number of investigators (7, 12, 21) who believe that it is from the rootlets of approximately this diameter that the majority of the root hairs (generally considered to be the main absorbing organs of plant root systems) originate. Consequently, quantitative determination of roots with diameters less than 1.5 mm is in fact a measurement of the absorbing or 'active' root surface of the plants involved. With this in mind, note should be taken of the fact that from this point on throughout the following pages, the terms: 'absorbing roots', 'rootlets' and 'feeder roots' refer to those roots with a diameter of 1.5 mm or less.

By determining quantitatively the absorbing roots of each species studied at varying depths and distances from the tree trunks, an attempt was made 1) to discover the volume of presumably active or absorbing root occupation by each and both of the two species studied under the prevailing conditions; 2) to show the spatial distribution of the active roots of coffee and rubber in the environments studied; and 3) to find out to what degree and where in the root occupation zone the active roots of the two species intermingle when growing together in the two zones studied.

The soil conditions which are generally considered to play a possible limiting role in controlling root development were determined in order to aid in the explanation of the results obtained from the root distribution studies.

Location of the study:

The study was carried out at tow locations: 1) the 'La Hulera' experimental station of the Inter-American Institute of Agricultural Sciences at Turrialba, Costa Rica; and 2) the Costa Rican Government's tropical experiment station 'Los Diamantes' situated in Guápiles on the Atlantic Coast of Costa Rica. Physiographical data of the two locations are as follows:

	Turrialba	Guápiles
Mean annual rainfall	2606 mm	4419 mm
Mean annual temperature	22.8º C	24.6º C
Altitude above sea level	610 m	300 m
Ecological formation (according to Holdridge (42))	Very humid Subtropical forest	Very humid Tropical forest

The trees selected for study were located in the 'Coffee-Rubber' section of the coffee-rubber and cacao-rubber intermixed demonstration plantings. (Turrialba Test 14, and Los Diamantes Test 20).

Selection of the trees:

La Hulera

For each of the four replications, a pair of trees (one of coffee and one of rubber) was chosen which was representative of the population at the site. Selection was made on the basis of general external aspect, height, and vigour of both the coffee and the rubber trees. In previous investigations on the root system of coffee (28) a direct relationship has been pointed out between trunk diameter at the soil-line and the extent of root distribution. For this reason, trunk diameter at the soil-line was also taken as a basis for selection of trees. (See tables 1 and 2)

Unfortunately, at the time of initiation of the study, the trees were in a poor state of development and neither the coffe nor the rubber trees could be considered exemplary speciments (Fig. 1). However, since this plot was the only available coffee-rubber interplanting at this location, it became necessary to disregard the condition of the trees in general and select speciments which were representative of the plot population. Eight trees were selected: four Coffea arabica var. 'Typica'; and four Hevea brasiliensis. The rubber trees were of the three component type, consisting of a trunk from a high yielding Eastern clone top-budded with a SALB-resistant top clone and with a rootstock of unknown genetic origin.

Planting design in the plot studied followed the 'mixed lane' planting system in which two permanent crops are planted in alternate lanes. The rubber trees are planted 6 x 10 feet in two-row lanes with 90 feet clearance between lanes where the coffee is planted in 5-row plots at three different densities. The distance between coffee and rubber is twelve feet (3.65m). At the time of initiation of root extraction (June, 1961) all trees at this location were eleven years old.

Los Diamantes

Due to limitation of time, only three trees of each species were sampled at this location. The same criterion was followed here as in La Hulera for the selection of the trees. However, at Los Diamantes, both

TABLE 1

Diameter at the soil-line of coffee and rubber trees sampled at La Hulera and Los Diamantes

Location	Tree pair nº.	Diameter at soil-line (cm) Rubber	Coffee
La Hulera	T - 1	20.3	14.3
"	T - 2	24.4	10.4
"	T - 3	22.8	10.9
"	T - 4	21.3	11.5
Los Diamantes	X - 1	26.2	13.1
"	X - 2	34.2	11.7
"	X - 3	23.9	12.3

TABLE 2

Average height of coffee and rubber trees in the areas sampled at Los Diamantes and La Hulera

	Average tree height (meters)	
	La Hulera	Los Diamantes
Rubber	10.0	9.0
Coffee	2.5	3.3

Fig. 1. Sampling site at La Hulera. Note the poor development and lack of foliage of the coffee trees which showed heavy infection by Mycena citricolor.

Fig. 2. Sampling site at Los Diamantes. Note the vigorous development of both coffee and rubber trees.

coffee and rubber trees had a much healthier aspect than at La Hulera, and consequently representative specimens of the plot population were truly good representatives of the species as well. Both the rubber and the coffee trees were found to be free of disease, and showed vigorous development (Fig. 2). Trunk diameters at the soil-line and average height of the trees are given in tables 1 and 2.

Coffee trees were of the 'Villalobos' variety of C. arabica. Rubber trees were of the three component type similar to those at La Hulera. Planting design at the 'Los Diamantes' sampling location is similar to that in 'La Hulera', with the difference that at Los Diamantes, the rubber trees are planted at varying distances in single-row lanes. The coffee trees in the rubber interlane are planted at different densities. Distances between trees studied are as follows: rubber to rubber, 2.5 m; rubber to coffee, 3.0 m; coffee to coffee, 2.5 m. At initiation of sampling at Los Diamantes (January 1962) the age of the trees was: 9 years for rubber, and 7 for coffee.

Determination of chemical and physical properties of the soils studied:

At Los Diamantes, soil samples were taken within the root sampling area at depths of 0-10, 10-20, 20-40, 40-60, 60-80, 80-100, 100-120, and 120-140 cm. At La Hulera, this sequence of depths could not be followed exactly because of interference to sampling by rocks and stones. Hence sampling depths here varied among themselves, but were generally representative of equal strata of the soil profile. After extraction, soil samples were analyzed in a laboratory in order to determine certain chemical and mechanical properties which were thought to be the most important to the development of the root system.

Chemical analysis:

pH. Active and potential pH were determined by the method recommended by Sáiz del Río and Bornemisza (72) using a Beckman 'Zeromatic' pH meter. For the 'active' pH determination, the soil was mixed with water at a ratio of 1:1. 'Potential' pH was measured by mixing the soil with an 0.01 M solution of $CaCl_2$ at a ratio of 1 part of soil to 2 parts of solution.

Mechanical analysis:

Apparent specific gravity. For this determination, undisturbed soil core samples were taken by inserting brass cylinders, having a volume of 81.5 cc into the soil at varying depths in the soil profile. These were then dried in an oven at 103ºC, allowed to cool, and weighed. Apparent specific gravity, or bulk density, was calculated by dividing the oven-dry weight in grams of the samples by the volume of the cylinder, in cubic centimeters, namely, 81.5.

In a number of cases, (especially in the La Hulera soil) the presence of small stones in the core samples caused a large error in the bulk density determinations. This was eliminated to a certain degree by separating the stones from the soil, washing, drying and weighing them, and then subtracting their weights from those of the oven-dry core samples. The volume of the stones from each sample was determined by water displacement, and was subtracted from the volume of the sampling cylinder.

Extraction of root samples:

The method used for the extraction of the root samples was a modification of the trench method used by Franco and Inforzato in Brazil

(22) and by Bermudez in Costa Rica (7). The same method was used for each replication.

First a trench was dug at a right angle to the direction of the rubber lanes, 15 cm away from the central axis of the rubber tree trunk and extending all the way to the coffee tree trunk - a distance of 3.65 m. at La Hulera, and 3.0 m at Los Diamantes. The width of the trench was approximately 1 m (enough to permit two workers to move freely) and the depth was 1.50 m.

Next, the volume to be sampled was delimited. A strip of land was marked off 20 cm wide (10 cm on either side of a straight line connecting the central axes of the two trees) and extending from the base of the coffee tree to the base of the rubber tree. Due to the fact that the area between the coffee and the rubber trees was never flat, a taut wire was strung from the soil line of the coffee trunk to the rubber tree and set horizontal with a spirit level (Fig. 3). The purpose of this wire was to serve as a base level to which the layers of samples at varying depths would be parallel and consequently uniform in all the replications. Starting from the wire, 20 cm layers were marked in a direction perpendicular to the wire and parallel to it along the face of the trench mentioned before. Maximum depth to which these layers were marked was 1.40 m. which was the depth at which practically no roots of either tree were found.

Thus, a sampling volume was delimited consisting of an imaginary parallelepipedon 20 cm wide, 360 cm long, and 140 cm deep, extending from the rubber tree to the coffee tree. This volume of soil was divided into cubes 20 x 20 x 20 cm. Note should be taken of the fact that the topmost layer of soil which is referred to in the following pages as the 'superficial layer', consists of a layer of soil 20 cm wide, of variable thickness, and extending along the entire length of the sampling volume. The lower limit of this layer is the datum-line 20 cm down from the wire base-line described above, and parallel to it. The upper limit of the superficial layer is referred to as the 'soil-line'.

From each of these 8,000 cc cubes, a one-liter subsample was extracted with a cylindrical core-estractor. One-liter volume was obtained by inserting the steel tube 8.14 cm in diameter, to a depth of 19.2 cm (Fig. 4). Once inserted, the sampling tube was dug out with a knife, taking care not to lose any part of the soil-core inside the tube. Each soil core thus extracted was then placed in a polyethylene bag, labelled and taken to a separating room for separation of roots from the soil.

After extraction of the soil-cores from each of the 80 dm^3 cubes in a layer, the soil was levelled down to the next layer and the procedure repeated until a maximum depth of 1.40 m was reached.

Separation of roots from the soil:

After being partially air-dried, the core soil was passed through a 2 mm sieve from which the large roots and a large portion of the smaller roots were extracted. The remaining soil was then spread on a table and the smaller rootlets picked out with tweezers. After this, the soil was again passed through a series of sieves and the remaining fine roots picked out.

Identification of roots:

In order to enable accurate separation of coffee from rubber roots, it was first necessary to learn to identify them. This was done

Fig. 3. Second layer of the sampling profile ready for extraction of soil cores. Note marked area which is at a depth of 20 cm from the taut base-line wire.

Fig. 4. Method used for the extraction of one-liter core samples from the soil profile.

by observing a large number of roots of varying sizes taken from various depths of the soil. Most of the roots were distinguishable at first sight, rubber roots being generally yellow in colour, long, flexible, and for the most part, larger in diameter than coffee roots. The latter were white, highly branched and smaller in diameter. In a number of cases, however, these characteristics were not sufficiently distinctive and observation under a dissecting microscope was necessary for proper identification. Through repeated observation, the following characteristics were noted:

Coffee roots:

A hard white cylindrical xylem is found under a brown succulent layer of phloem which in turn is wrapped in various layers of a soft white, large-celled gauze-like rhytidome.

Rubber roots:

These have a simple, thin, parchment-like phellogen. Between the phellogen and the xylem there is a layer of latex tubes which are easily identifiable, as upon drying, they break down and appear as an amorphous paste-like substance which is dark red in colour.

On the basis of these characteristics, rubber roots were separated from coffee roots.

Classification of roots:

In view of the fact that this study is primarily concerned with the absorbing roots of each tree, roots were divided into two classes (absorbing and non-absorbing) according to diameter. As explained earlier in this chapter, roots with diameters less than 1.5 mm were considered absorbing and those with diameters greater than 1.5 mm were classified as non-absorbing. The reasons for this classification are obvious. Larger roots, the function of which is primarily support and conduction, cannot be included in the absorbing root volume. Secondly, root concentration is expressed in grams dry weight per liter of soil; a lack of classification of roots would thus give misleading results, since larger roots would weigh more, but have less surface area than roots of smaller diameter.

After classification and separation, root samples were dried for 96 hrs in an oven at 70ºC and their dry weight determined.

RESULTS

The Soil Aspect:

I. At La Hulera:

The soil at the Turrialba location is of the Institute Clay type, described by Dóndoli and Torres (19) as "a fluvio-lacustrine alluvial soil occupying a low area across which runs the Turrialba-La Suiza Highway."

Relief of this area is predominatly flat to undulating with a hummocky mocro-relief. Variable coarse sandy, gravelly and stony deposits underly the humic topsoil which is about 40 cm deep, dark brown in colour when moist, and grey brown when dry.

The topsoil is described as follows: granular or crumby and fairly strong in structure; texture clayey to fine silty with only a small amount of sand or none; 'fairly high' permeability and consistency "plastic and sticky when wet, hard when dry." The subsoil is yellower in colour, with permeability diminishing with depth, possibly due to formation and accumulation of clay minerals within the saturation zone.

The water table is said to vary in level and in some places, to occur above 75 cm depth during the wet season.

The quantity of round stones, as well as the depth at which the underlying sandy or gravelly sediments occur, varies greatly.

The characteristics observed in three profile pits at La Hulera come quite close to those described above. The humic topsoil is 10 YR 3/4 in colour and the subsoil 10 YR 5/4, according to the Munsell colour chart. Structure shows a remarkably strong aggregation. Throughout the humic and non-humic layers of the profile, the soil consists of a 'pseudosand' which, despite the use of mechanical apparatus and dispersing agents such as sodium carbonate, is extremely difficult to disperse. By dry sieving samples of topsoil and subsoil, it was found that each contained 46 percent of pseudosand aggregates of very coarse and coarse sand sizes (2.0 - 0.5 mm), and 26 percent of finer aggregates of medium sand size (0.5 - 0.2 mm). The high pseudosand percentage of this soil partly explains its high permeability, at least in the surface layers of the profiles examined.

Mechanical analysis, following drastic dispersion, showed the coarse pseudosand (2.0 - 0.5 mm) to consist of equal parts of fine sand (0.2 - 0.02 mm) and silt plus clay (0.02 mm). The sand consists mainly of mineral grains of augite, labradorite, magnetite and some ferruginous concretions.

A. Physical Features

1. Apparent specific gravity or bulk density:

Results of this determination are shown in the following table:

TABLE 3

Apparent specific gravity data (corrected values) from two profiles (T - 1 and T - 2) in La Hulera

Profile T - 1										
Depth of sample (cm)	5	15	-	25	35	50	70	90	110	130
App. sp. gr.	0.73	0.57	-	0.64	0.65	0.64	0.61	.63	0.79	.73
Profile T - 2										
Depth of sample (cm)	5	10		25	35	40	90	110	115	130
App. sp. gr.	0.69	0.62	0.56	0.56	0.52	0.46	0.67	1.03	0.83	2.37

Note should be taken of the fact that these data are of little reliability due to the occurrence of numerous small stones in the core samples. This caused considerable error which has been taken into account in table 3 (See under Materials and Methods).

Furthermore, as can be seen in Figure 5, in profile T - 1, the humic layer dips down to a depth of approximately 1.50 m, which results in values for apparent specific gravity not being characteristic of the soil profile of the zone due to the humic soil compacting less with increase in depth than the subsoil.

Nevertheless, data from this profile are important in that they help to explain differences between root distribution of the trees at this site ($T\text{-}1_c$, $T\text{-}1_r$, $T\text{-}4_c$.& $T\text{-}4_r$) and trees growing at other sites where this 'intrusion' of humic soil into subsoil layers does not occur.

Profile T - 2 is a better representation of the general profile in the area, and analytic results thus give a better picture of the true situation in the area sampled. Hence, more importance is given to this profile when discussing the soil characteristics of La Hulera as a whole. Profile T - 1 will be discussed only with regard to the effect of its characteristics on the two pairs of trees that were sampled in it.

The most striking feature of profile T - 2, and deductively of the La Hulera sampling site, is the extremely low apparent specific gravity values within the first 90 cm.

Figure 6 shows a slight decrease of apparent specific gravity values with depth increase down to 90 cm, from which point these values increase until a top value of 2.37 is observed at the maximum sampling depth of 125 cm. However, this slight decrease is considered to be of

Fig. 5. Soil profile T - 1 The irregular white line marks the limit between humic and non-humic soil layers. Rectangles are 20 x 40 cm and their top limit is 20 cm below the original soil-line.

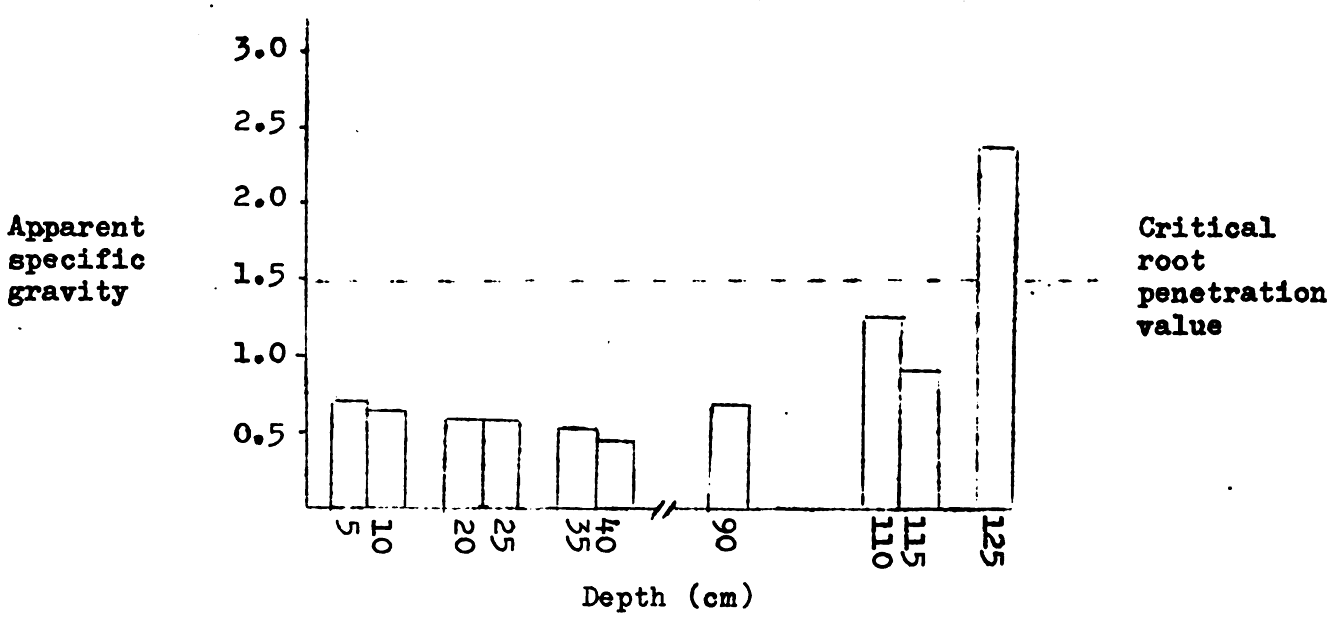

Fig. 6. Apparent specific gravity of La Hulera soil (Profile T - 2) in relation to profile depth

little importance from the viewpoint of root penetration, since all the values down to a depth of 90 cm are well below 1.5 which is generally accepted as the critical value for root penetration.

The increase in bulk density from the 90 cm depth down is important, since the values approximate and surpass the critical 1.5 value, indicating severe drainage impedance, and probable root growth restriction, resulting from increasing compaction and decreasing permeability.

The evidence previously adduced shows this profile to consist of a highly permeable, well-drained layer approximately 90 cm thick underlain by an impermeable compacted layer. The change in permeability is visually evident by the appearance of reddish mottling on a slightly grey, though still dark soil layer.

Mention should be made at this point of the fact that the profile pits studied were dug at different points on a slight slope, T - 2 profile being at the lowest point, T - 1 in the middle, and a third profile T - 3 (which was not sampled for porosity) at the highest point. As would be expected, this resulted in the pervious layer of soil being deeper in the top-most profile (T - 3) where no mottling was observed at the maximum root sampling depth (1.50 m) and shallowest in the lowest profile (T - 2) in which mottling and evidence of waterlogging was found at a depth of 1.4 m. Profile T - 1 was intermediate between the two extremes showing a slight degree of mottling at the floor of the sampling trench (1.50 m).

2. Porosity:

La Hulera soils were found to have an average true specific gravity of 2.27. Using data from table 3, the volume percentage of total pore space can be calculated from the following formula:

$$\text{Pore space (vol. percent)} = \frac{\text{True specific gravity-Apparent sp. gr.}}{\text{True specific gravity}} \times 100$$

In this way the porosity percentage of profile T - 2 down to a depth of 90 cm was shown to be 75 percent. According to the literature, and 'ideal' soil should have a pore space volume of approximately 66 percent. High values of 75 percent such as that given by the La Hulera soil, are exceptional and are confined to certain kinds of senile latosols (37). The average porosity of the La Hulera subsoil below the 90 cm depth is 38 percent. At a depth of 125 cm porosity was calculated to be 4 percent, corresponding to an apparent specific gravity of 2.37 and a true specific gravity of 2.46. This value is low enough to cause markedly impeded drainage.

3. <u>Capillary and non-capillary pore space</u>:

Attempts were made to determine capillary pore space by measuring moisture content of the soil at the sticky point, which measures approximately colloidally-bound water occurring in moist clay soils. However, this was unsuccessful, due to the extremely stable aggregate structure of the Institute Clay. The pseudosand aggregates proved too strong to yield to the hand kneading process involved in the sticky point determination.

4. <u>Root room</u>:

This is the most important of the six ecological soil factors which determine plant growth and crop production, namely, (i) root room (ii) water supply (iii) air supply (iv) nutrient supply (v) harmful factors, and (vi) soil temperature. Root room is defined as "the effective volume of soil in which root penetration is easy and in which water and air relations are completely satisfactory for the unrestricted growth of plant roots." (37) It depends not only on structure of the soil, but also on the presence or absence of a water table, hard pan, or impermeable compact soil layer which limits downward penetration of roots. Since plant roots will penetrate rigid porous media only when the diameter of the pore spaces is commensurate with that of the root tips (which mostly vary in diameter from 0.1 to 0.5 mm), apparent specific gravity values may be employed as an approximate though reliable measure of root penetrability of a soil.

As has been mentioned in the literature review, various investigators have pointed out that at soil bulk densities numerically less than 1.5, root penetration is usually not impeded, and at apparent specific gravity values lower than 1.00, soils offer little or no resistance to root penetration. Since at the La Hulera sampling sites apparent specific gravity values are numerically well below 1.00, normally around 0.62, it can be assumed that root penetration, as regards mechanical impedance, is completely unrestricted down to a minimum depth of about 1.2 m.

B. Chemical Features

Soil reaction (pH value):

Soil reaction data of the three profiles studied at La Hulera are presented in table 4. Scrutiny of this data shows that active and potential pH values in profile T - 3 are constantly lower than those in the other two profiles which are similar to each other. This may be due to the fact that profile T - 3 is situated at a higher point on the slope than profiles T - 1 and T - 2, hence it has a deeper pervious soil layer, is more strongly leached, and is consequently more acid in reaction throughout the depth sampled. However, all three profiles show the same tendency to increase in pH value (decrease in acidity) with increasing depth. These values increase one pH unit in 150 cm of vertical distance, which implies a ten-fold decrease in acidity from soil surface to a depth of 150 cm. This tendency may be due either to accumulation of bases brought down by leaching, or to proximity to the less-weathered and actively-weathering parent volcanic materials.

TABLE 4

Soil pH of La Hulera profiles.

Profile T - 1										
Lower depth (cm)	10	20	40	60	80	100	120	140		
pH value in water	5.3	5.4	5.8	5.8	6.3	6.5	6.5	6.8		
pH value in $CaCl_2$	5.0	4.9	5.2	5.2	5.5	5.7	5.9	6.2		
Profile T - 2										
Lower depth (cm)	8	15	23	30	38	45	68	90	120	150
pH value in water	5.4	5.6	5.9	6.1	6.4	6.2	6.3	6.5	6.6	6.6
pH value in $CaCl_2$	5.1	5.1	5.2	5.5	5.6	5.8	6.0	6.1	6.3	6.3
Profile T - 3										
Lower depth (cm)	10	20	40	60	80	100	120	140		
pH value in water	4.9	4.9	5.1	5.5	5.4	5.7	5.8	5.9		
pH value in $CaCl_2$	4.5	4.6	4.7	4.9	5.0	5.2	5.4	5.5		

Base status:

Consideration of the low pH values discussed above, together with data given by F. R. Sands concerning the exchangeable base contents of Institute Clay (74) yields information about the base status of La Hulera sampling site soil (table 5).

TABLE 5

Base status of the two superficial foot layers of Institute Clay

pH	Exch. cap. (meq/100gm of soil)	Exch. Ca.	Exch. Mg. (meq/100gm of soil)	Exch. K	Degree of saturation.
			Top foot (0 - 30 cm)		
5.3	31	9.1	1.8	0.62	37 %
			Second foot (30 - 60 cm)		
5.4	29	7.0	1.8	0.89	33 %

As is evident from table 5, the degree of base saturation of this soil is low, mainly because of the low exchangeable calcium and magnesium contents. Under optimum conditions of base saturation, the exchangeable calcium content of the upper 30 cm layer of soil should be around 12.0 meq per 100 gm of soil, and for exchangeable magnesium and potassium, 3.0 and 0.35 meq per 100 gm of soil respectively. Hence it can be deduced that the La Hulera soil is deficient in exchangeable calcium and magnesium, though well supplied with exchangeable potassium.

II. At Los Diamantes:

There is no detailed description as yet available of the soils at the Los Diamantes sampling site. Hardy (37) has described the soil of this area as "a colluvial-alluvial soil developed over Pleistocene to Recent detritus washed down from the northern slopes of the Cordillera Central of Costa Rica which comprises several large volcanoes that were active in geologically recent to historic times. The parent material therefore consists of only slightly weathered volcanic fragmental rocks comprising agglomerates, sand and ash."

The topsoil is dark greyish-brown in color (10 YR 3/2) and the subsoil pale yellowish-brown (10 YR 4/3). It is sandy in texture, becoming coarser with depth. Mechanical analysis of a sample of subsoil showed it to contain equal amounts of coarse, medium and fine sand with only a small amount (about 5 percent) of silt plus clay. The soil is underlain by gravelly boulder beds which vary in depth(Figs. 7 & 8). The humic layer varies in depth from 15 to 45 cm and merges gradually into the sandy subsoil indicating heavy leaching and good drainage (Fig. 7). Permeability is high throughout the profile. The consistency is friable but neither plastic nor sticky when wet, though hard and brittle when dry.

No evidence was found of the water table at the maximum sampling depths, (1.50 m) in any of the profiles observed. Relief at the Los Diamantes Experiment Station is predominantly flat with slight undulations.

A. Physical Features

1. Apparent specific gravity:

The following data were obtained from two profiles at Los Diamantes (X - 1 & X - 3).

TABLE 6

Apparent specific gravity data from two profiles (X - 1 & X - 3) in Los Diamantes

Depth of sample (cm)	5	15	30	50	70	90	110	130
Profile X - 1	0.80	0.76	0.76	0.87	0.92	1.02	-	1.28
Profile X - 3	0.71	0.84	0.75	0.91	1.07	1.15	1.11	1.33

Fig. 7. Soil profile X - 3. Note the absence of a defined limiting line between humic and non-humic layers. Also note the absence of stones throughout the profile.

Fig. 8. Soil profile X - 2 (not sampled for soil analyses). Note size and amount of boulders. This profile is scarcely 10 m away from profile X - 3, above.

As in the La Hulera soils, bulk density tends to decrease with increasing depth in the soil profile down to the 30 cm level and from this point down, increases with depth increase (Fig. 9); presumably a result of considerable subsoil compaction or clay mineral formation. Above the 70 cm level, none of the bulk density values approach the critical 1.5 value for root penetration. This profile differs from the La Hulera profiles in that apparent specific gravity values in no case reach the critical root penetration value of 1.5.

2. Porosity:

True specific gravity of the Los Diamantes soil was found to be 2.53. Hence total pore space down to a depth of 70 cm was shown to be 68 percent in profile X - 1 and 66 percent in profile X - 3. These values are extremely high, making the soil 'ideal' as regards porosity. Total pore space below the 70 cm level is 55 and 53 percent for profiles X - 1 and X - 3 respectively. These values are not low enough to result in impeded drainage.

3. Capillary and non-capillary pore space:

Moisture content at the sticky point was not measured for Los Diamantes soils because the moist kneaded cakes, being sandy, fell apart on drying. If a value of 26 percent by volume is assumed (this being the value for film and wedge water for moist coherent sands) for the sticky point, the following values can be calculated* for non-capillary pore space of the Los Diamantes sampling site soils:

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* Non-capillary pore space = Total pore space - capillary pore space

Profile X - 1 (0 - 70 cm) : 68 - 26 = 42 percent by volume

Profile X - 1 (70-130 cm) : 56 - 26 = 30 percent by volume

Profile X - 3 (0 - 70 cm) : 67 - 26 = 41 percent by volume

Profile X - 3 (70-130 cm) : 54 - 26 = 28 percent by volume

Since these values for non-capillary pore space are in all cases well above the critical value for satisfactory root respiration (10 percent), commonly accepted by plant physiologists, it is evident that the soil of the Los Diamantes sampling sites is more than adequately aerated for optimum root development.

4. Root room:

Bulk density values well below 1.5 in Los Diamantes soils give evidence that, at this location, root room is more than adequate throughout the profiles studied down to the full depth of sampling (1.4 m).

B. Chemical Features

Table 7 shows the results obtained from reaction determinations of Los Diamantes soils. The data in this table show somewhat higher pH values for Los Diamantes than is the case with La Hulera soils.

An interesting feature of Los Diamantes profiles is that soil pH values increase with depth down to a certain level (80 cm in profile X - 1, and 120 cm in profile X - 3) and from there down show a tendency to decrease with depth. That is, soil acidity decreases with depth down to a certain point in the profile, after which it increases with further depth increase. A possible explanation of this phenomenon is that intense leaching within the humic and partly humic layers of the profile results in the accumulation of leached bases at the lower limit of these layers.

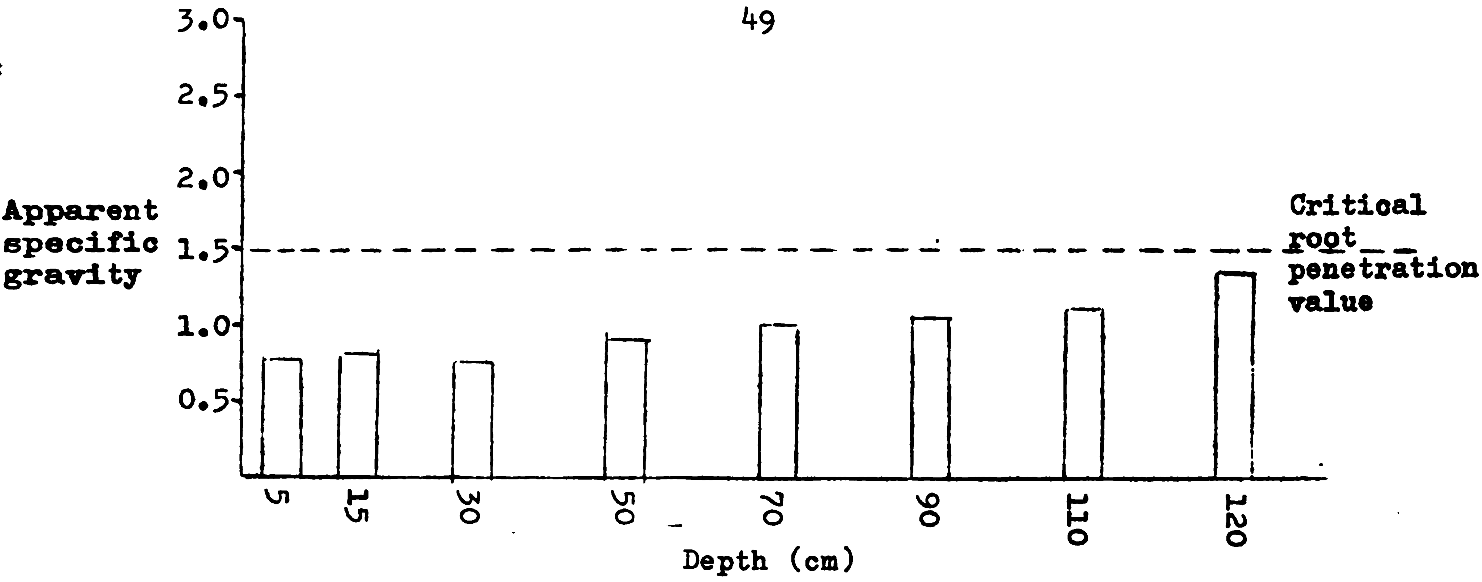

Fig. 9. Average apparent specific gravity of Los Diamantes soil (profiles (X - 1 & X - 3) in relation to profile depth

TABLE 7

Soil pH of Los Diamantes profiles

	Lower depth (cm)							
	10	20	40	60	80	100	120	140
Profile X - 1								
pH value in water	5.9	5.9	6.4	6.8	7.0	6.5	6.5	6.4
pH value in $CaCl_2$	5.2	5.3	5.4	5.5	5.6	5.7	5.8	5.7
Profile X - 3								
pH value in water	6.0	6.1	6.3	6.9	6.9	6.9	7.2	6.7
pH value in $CaCl_2$	5.5	5.5	5.6	5.8	5.9	6.1	6.2	6.0

Below these humic and semi-humic strata the soil is more susceptible to heavier leaching and soil acidity increases.

As a whole, the Los Diamantes soil reaction data seem to suggest a higher degree of base saturation than the soil at La Hulera. However, sufficient evidence from chemical analyses is lacking to support this supposition.

The Root Picture: *

A. Distribution of absorbing roots of coffee

I. La Hulera:

Data for the four coffee trees sampled at La Hulera ($T\text{-}1_c$, $T\text{-}2_c$, $T\text{-}3_c$, and $T\text{-}4_c$) are presented in tables 8, 9, 10 and 11.** Table 20 shows the averaged data from the four trees. The total weights of samples per depth layer and per column distant from the trunk of the tree are also shown in these tables, and are illustrated in graphic form, expressed as percent of the total sample weight, in Figures 10 through 13, with Fig. 14 illustrating the average values for the four trees.

A general look at the data in these tables brings to note the large variability that occurs between trees as regards the distribution of their absorbing roots. This variability between individual trees justifies a description of each tree, and a corresponding discussion thereof.

Coffee tree $T\text{-}1_c$:

From the data in table 8, it is evident that in tree number $T\text{-}1_c$, the largest majority of the absorbing roots lies within the top 40 cm of

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* The following notes describe the findings based on scrutiny of the tables and diagrams.

** Tables 8 - 25, and Figs. 31-38 appear in the Appendix.

soil (Fig. 10). In this part of the soil profile, more than 70 percent of all the absorbing roots of this tree are found. Below this 40 cm depth layer, feeder root concentration drops rapidly and, in the next 40 cm depth layer, only 5 percent of the total absorbing roots occur and these do not extend beyond 60 cm distance from the tree. At a depth of 80 cm in the soil, rootlet concentration rises sharply to 15.6 percent from which point it diminishes with depth down to the maximum sampling depth (140 cm). The last two 20 cm layers contain 5 and 3 percent of the total absorbing roots in the sampling volume respectively. As regards rootlet distribution and distance from the trunk, sample weights show that concentration rises from 20 to 40 cm distance, and then diminishes gradually with increase in distance up to 1.4 m. Approximately 74 percent of the absorbing roots in the volume sampled are in the 60 cm closest to the trunk. Distribution is fairly even within the next 80 cm, the rate of decrease being slight.

The total coffee feeder-root sample weight is greater in tree number $T\text{-}1_c$ than in the other trees, except $T\text{-}2_c$, despite the fact that in this case, the volume occupied by the coffee rootlets is smaller than in any other tree. This in all probability is due to the fact that this was the first tree sampled and consequently, through inexperience on the part of the investigator, a larger number of rootlets were lost during separation from the soil. Furthermore, a certain lack of experience in the identification of rootlets, possibly caused a number of coffee roots to be classified as rubber roots, and vice versa.

Tree $T\text{-}2_c$:

As can be seen in table 9 and Fig. 11, tree number $T\text{-}2_c$ has a great majority of its roots within the surface 40 cm of soil, in which layer

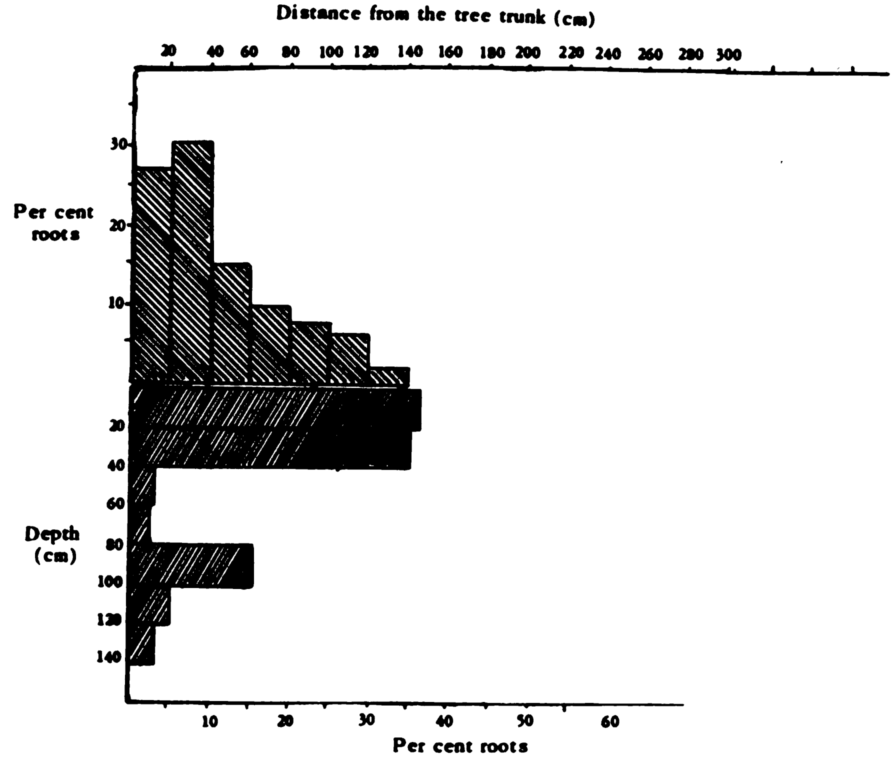

FIGURE 10 Absorbing root distribution of coffee tree T1c (La Hulera)

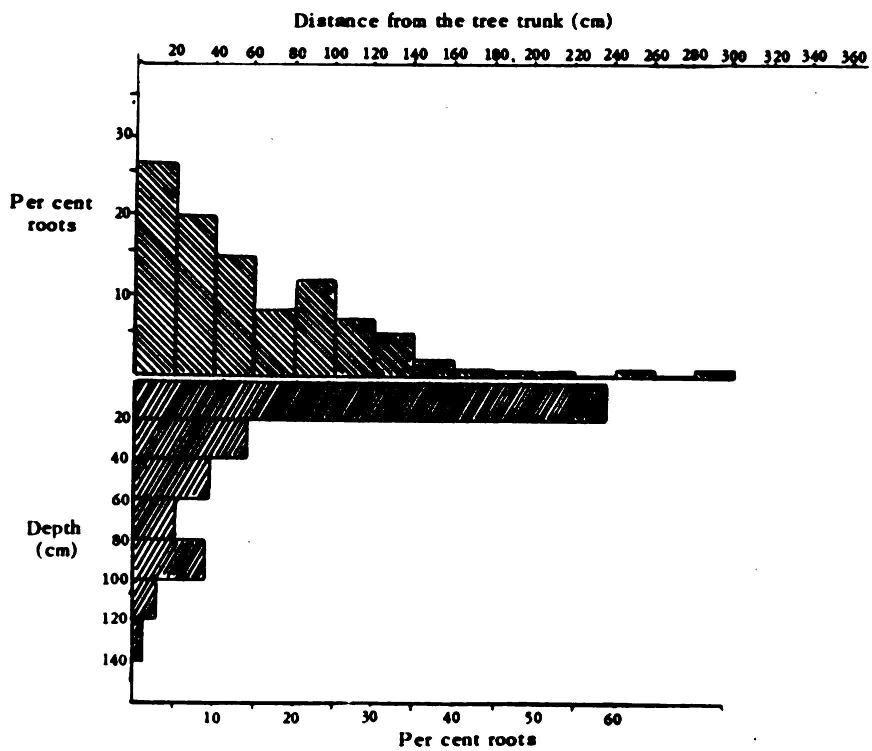

FIGURE 11 Absorbing root distribution of coffee tree T2c (La Hulera)

are contained 72 percent of the absorbing roots in the volume sampled, and of these, 58 percent occur within the first 20 cm of soil. From a depth of 40 cm down to 80 cm, feeder-root concentration decreases gradually at the rate of about 4 percent for every 20 cm depth increase. At the 80 cm level, absorbing root content increases slightly from 5.3 percent to 8.7 percent. From this point downwards, there is a sharp decrease in rootlet concentration until the maximum depth of sampling is reached, at which point only 1.2 percent of the total absorbing root volume occurs. In regard to distance from the tree trunk, table 9 shows that feeder-root concentration is highest closest to the trunk and diminishes gradually for a distance of 80 cm from the tree trunk. At this point there is a slight increase in absorbing root content, but from there on there is a tendency of rootlet concentration to decrease gradually with increase in distance up to 3.0 m where the feeder-root concentration is 0.47 percent. In general, absorbing root distribution in this tree is in the shape of an upright bell having two zones of high concentration; one at the apex, and another one less marked, at a depth of 80 cm from the soil surface. These zones of high rootlet concentration seem to indicate that the root system has developed in two main strata out of which rootlets develop and distribute themselves through the profile away from the tree on the horizontal plane and downward on the vertical plane.

Tree $T\text{-}3_c$:

Absorbing root distribution in tree number $T\text{-}3_c$ is somewhat similar to that in tree $T\text{-}2_c$ (table 10 & Fig. 12). Fifty (50) percent of the total coffee feeder-root weight in the profile occurs in the surface layer. There is a sharp decrease from this topmost layer to the next one where only 13 percent of the absorbing roots occur. From this 40 cm layer, the absorbing root contents of the strata below show a general tendency to diminish gradually with depth, although slight increases are noted at the 80 and 120 cm levels. Forty-three (43) percent of the rootlets occur within the 40 cm closest to the tree trunk. From this distance outward toward the periphery, rootlet concentrations fluctuate from distance to distance showing an overall tendency to decrease as the periphery is approached. Very few feeder-roots are found beyond a distance of 2.7 m from the tree trunk, and none at all beyond 3.2 m. The total weight of rootlets found between 2.2 and 3.2 m distance, amounts to only 2.1 percent of the total. As a whole, this tree shows the same bell-shaped distribution as T-2_c, with the large majority of absorbing roots in the soil-line-to-datum-20 layer. There are two strips of relatively high feeder-root concentration; one at the 60-80 cm layer, and the other at the 100-120 cm depth.

Tree T-4_c:

This tree (table 11 & Fig. 13) presents a panorama of absorbing root distribution which at first sight seems somewhat different from the other three trees. The principal feature which distinguishes the absorbing root picture of this tree from those of others at the same location is the apparently even distribution of feeder-roots throughout the profile. However, a closer scrutiny of the data shows that the bulk of the rootlets is distributed in a manner similar to that found in other trees at La Hulera. The actual weights of rootlets found in other parts of the profile are low and their value in relation to the whole of the feeder-root weight in the profile is also low. Tree number T-4_c has approximately 62 percent

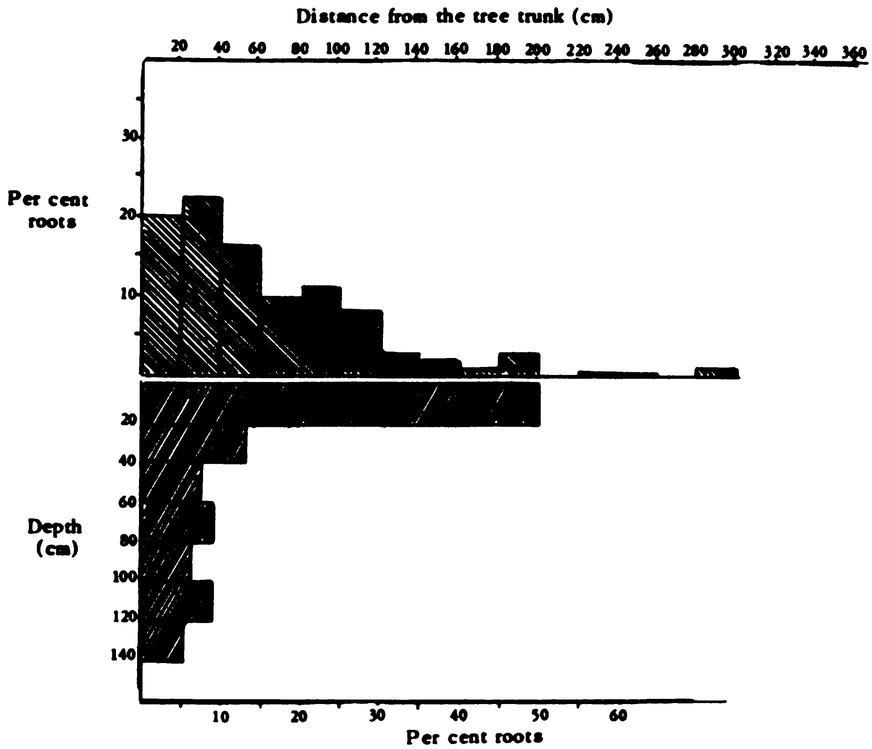

FIGURE 12 Absorbing root distribution of coffee tree T3c (La Hulera)

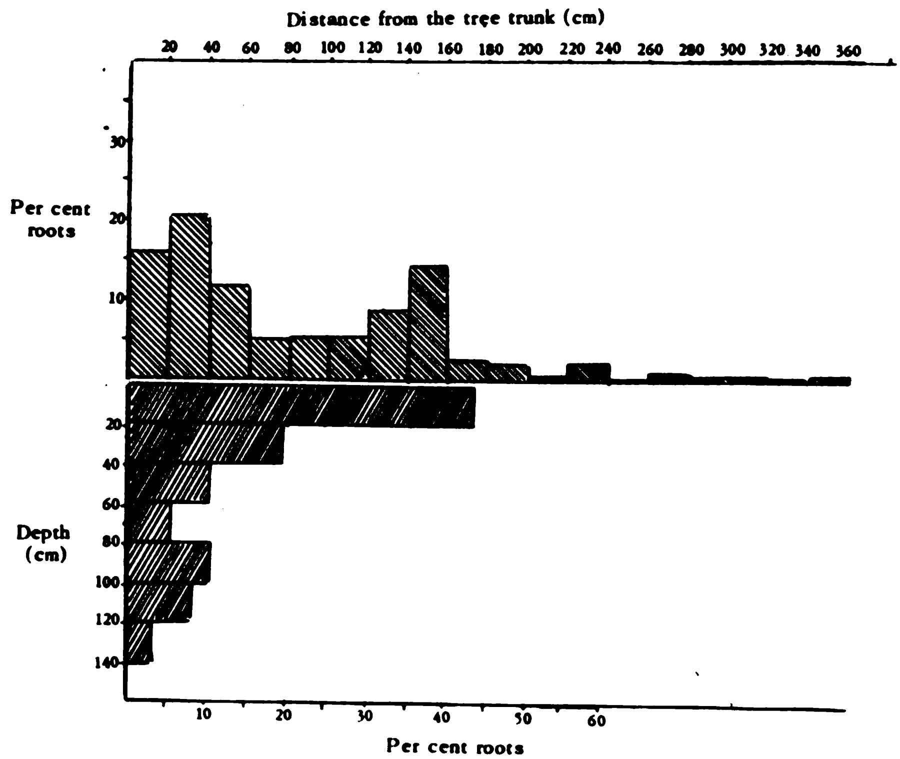

FIGURE 13 Absorbing root distribution of coffee tree T4c (La Hulera)

of its absorbing roots within the 40 cm top layer. From this level downwards, concentration decreases rapidly with depth increase to the 80-100 cm layer, where an increase in absorbing root content is evident.

As in the other trees sampled, T-4_c has the largest feeder-root concentration in the 20 cm closest to the trunk, wherein more than 37 percent of all the feeder-roots are found. Absorbing root percent diminishes gradually with increase in distance from the trunk up to 160 cm where concentration rises to 15 percent and continues to decrease in the subsequent distances. The limit to which significant rootlet weights were found is 2.4 m from the coffee tree trunk. From this point on toward the periphery, values were found to be very low and of little significance in relation to the total weight of absorbing roots in the profile. As in trees T-1_c, T-2_c, and T-3_c, in the deepest stratum sampled (1.2 - 1.4 m), rootlets only extended horizontally to a distance of 1 m from the trunk line, with small amounts of absorbing roots occurring at 1.6 and 2.0 m from the tree trunk.

Mean results: Table 20 and Fig. 14 show the average absorbing root distribution of the four coffee trees sampled at La Hulera. In general, the same distribution pattern is shown by the average data as by each of the individual trees. That is, absorbing roots are distributed in a bell-shaped pattern with the highest concentration in the topmost 40 cm of soil (68 percent) and a tendency to diminish with depth from the superficial layer down to 80 cm. Below this stratum, feeder-root concentration increases due to the presence of a strip of soil high in rootlet content stretching as far as 30 cm from the rubber trunk-line. From this layer down to the maximum sampling depth (140 cm), absorbing root concentration

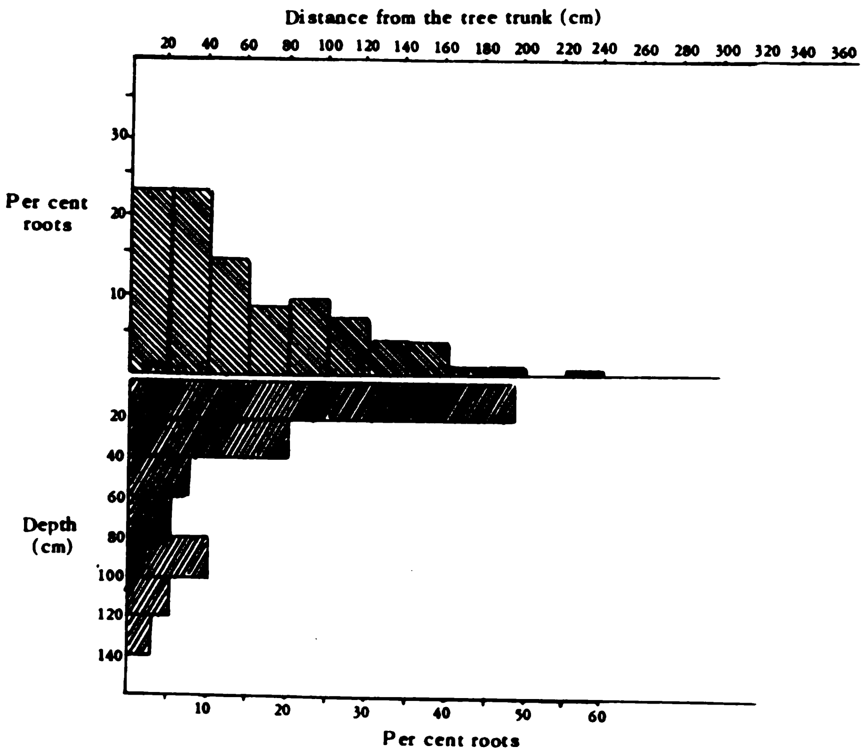

FIGURE 14 Average absorbing root distribution of trees T1c, T2c, T3c and T4c (La Hulera)

diminishes with depth. Weight of feeder-root samples decreases with distance from the trunk-line up to the 1 m line, at which point it increases slightly and then continues to diminish gradually with distance. This slight increase at the 1 m distance is caused by increases at that distance in the topmost and in the 80-100 cm layers; coincidentally, the layers from which an increase in depth is accompanied by a decrease in sample weight.

II. Los Diamantes:

Data for the three coffee trees sampled at Los Diamantes (X-1_c, X-2_c, and X-3_c) are shown in tables 12, 13 and 14, and represented graphically in Figs. 15, 16 and 17, in the same manner as the data from La Hulera. Table 15 and Fig. 18 present averaged data of the three trees.

Tree X-1_c:

Scrutiny of the data in table 12 reveals that 52.6 percent of the feeder-roots from this tree occupy the surface layer of soil which varies in depth from 20 cm in the middle of the sampling area to less than 5 cm on either side of the middle ridge (Fig. 36). Below this stratum, absorbing root concentration falls rapidly to 16.5 percent in the next 20 cm layer, but rises to 18.4 percent in the third stratum. From this level to the next one below it (60-80 cm), absorbing root content decreases suddenly down to 5.3 percent, remains at that value through the next soil stratum, and then decreases sharply in the last two layers.

Rootlet concentrations vary considerably from sample to sample, showing a general tendency to diminish with distance from the coffee trunk-line(Fig. 15). Within the first four depth layers, rootlets extend all the

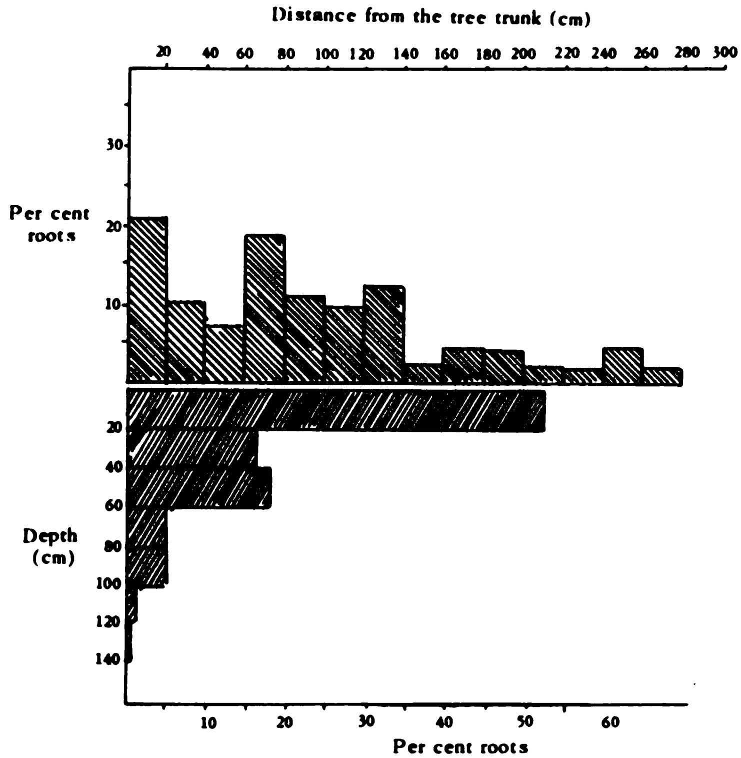

FIGURE 15 Absorbing root distribution of coffee tree X1c (Los Diamantes)

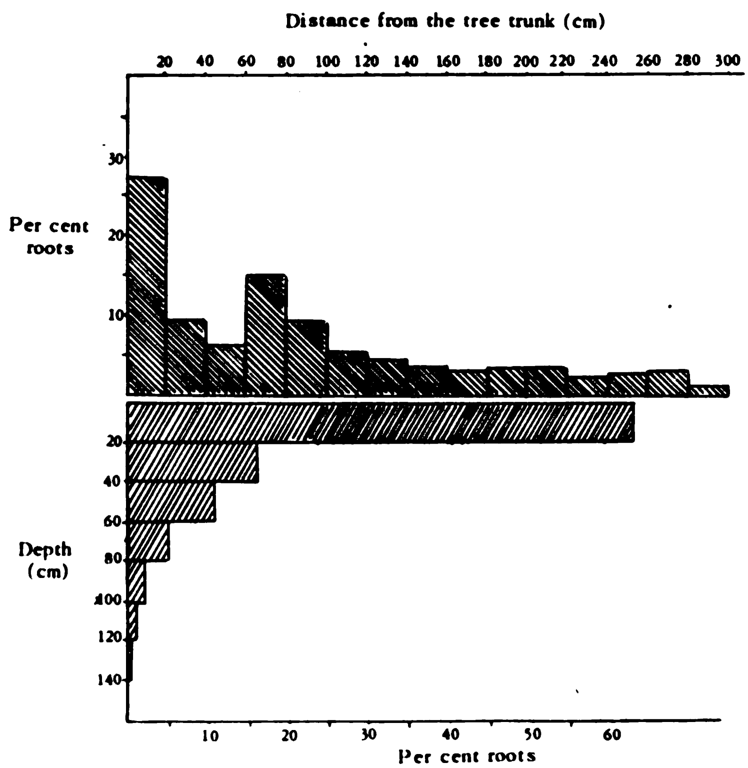

FIGURE 16 Absorbing root distribution of coffee tree X2c (Los Diamantes)

way to a distance of 2.8 m from the coffee trunk. In the fifth and sixth depth layers, feeder-roots are distributed in pockets, leaving spaces without rootlets at different distances from the tree. The deepest layer contains very few absorbing roots and these occur within the 40 cm closest to the trunk-line.

Tree X-2_c:

Data from tree X-2_c are shown in table 13 and represented in Fig. 16. As can be seen in Fig. 37, the soil-line in this site is very irregular, making the samples in the surface layer vary greatly in volume. Despite this fact however, table 13 shows that 63 percent of the total absorbing coffee root occur in the surface layer.

The second depth layer contains 16 percent of the roots sampled and from here downwards, rootlet concentration per layer decreases with depth (Fig. 16), the deepest stratum containing only 0.68 percent of the total absorbing roots. Rootlet distribution is also very variable in this tree, but somewhat more uniform than in tree X-1_c. In the first three layers, rootlets extend all the way to the rubber trunk-line (3 m away from the coffee trunk-line) with only a slight tendency to diminish with increasing distance from the coffee trunk-line. Very few absorbing roots are contained in the last three layers (approximately 9 percent altogether), and these tend to concentrate close to the coffee trunk-line, rapidly decreasing as distance from the tree trunk increases. Beyond a distance of 1.8 m from the trunk-line, only pockets of low rootlet concentration occur. As depth increases, so does the horizontal extension of the absorbing root area. As a whole, the total rootlet concentration tends to diminish with increasing distance from the tree trunk. Rootlet

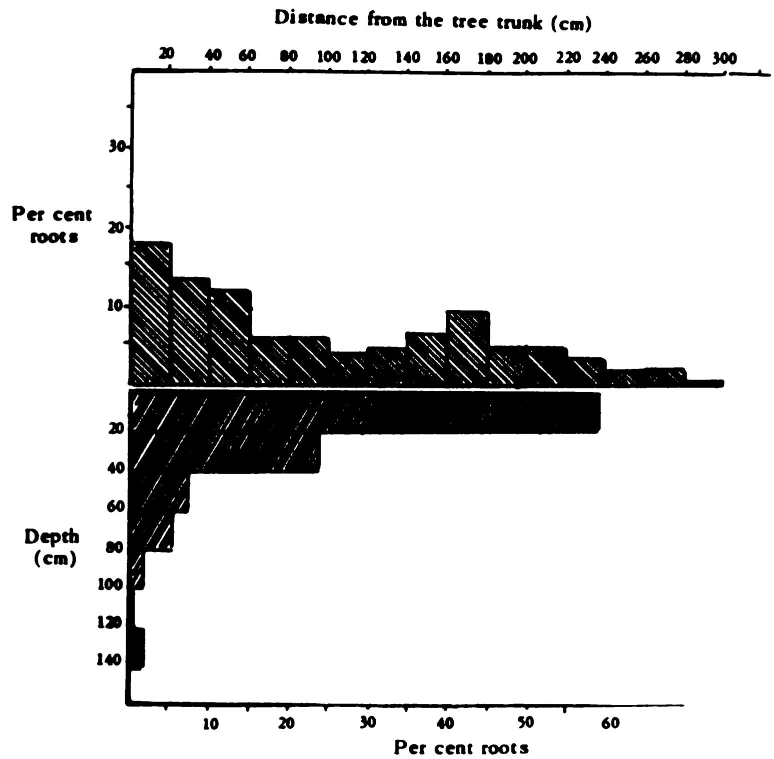

FIGURE 17 Absorbing root distribution of coffee tree X3c (Los Diamantes)

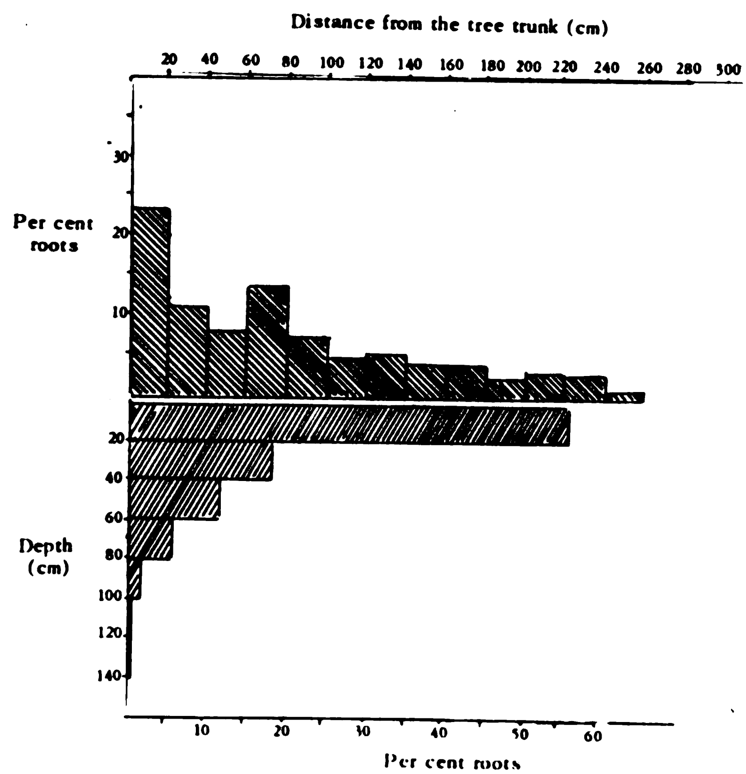

FIGURE 18 Average absorbing root distribution of coffee trees X1c, X2c and X3c (Los Diamantes)

percentage rises slightly at the 80 cm distance but then continues to show a decreasing tendency towards the periphery.

Tree X-3_c:

Data from table 14 and Fig. 17 show that coffee tree X-3c has a distribution similar to X-2_c. That is, a high percentage of rootlets in the surface layer (59.2 percent) and a tendency to decrease feeder-root concentration with depth increase is noted. Furthermore, a marked horizontal extension of the absorbing roots in the top layers, and a recession of the limit of horizontal extension accompanying increase in depth, is evident.

As in tree X-2_c, the surface layers exhibit a marked irregularity of rootlet content from sample to sample in each layer. A characteristic feature of this profile is the increase in absorbing root percentage and horizontal extension from the 1.2 to the 1.4 m strata.

Mean results: Table 15 and Fig. 18 summarize the results obtained in the three trees samples, as they describe the average feeder-root distribution for these trees. Approximately 60 percent of the absorbing roots were found in the surface layer despite a great irregularity of the soil-line. Rootlet percentage decreases with depth and to a slight degree with increase in distance from the tree. Horizontal extension of absorbing roots is marked in the top layers and recedes with depth increase, with regions of low feeder-root concentration occurring in the lower strata. Absorbing root weights in the surface layers vary markedly from sample to sample.

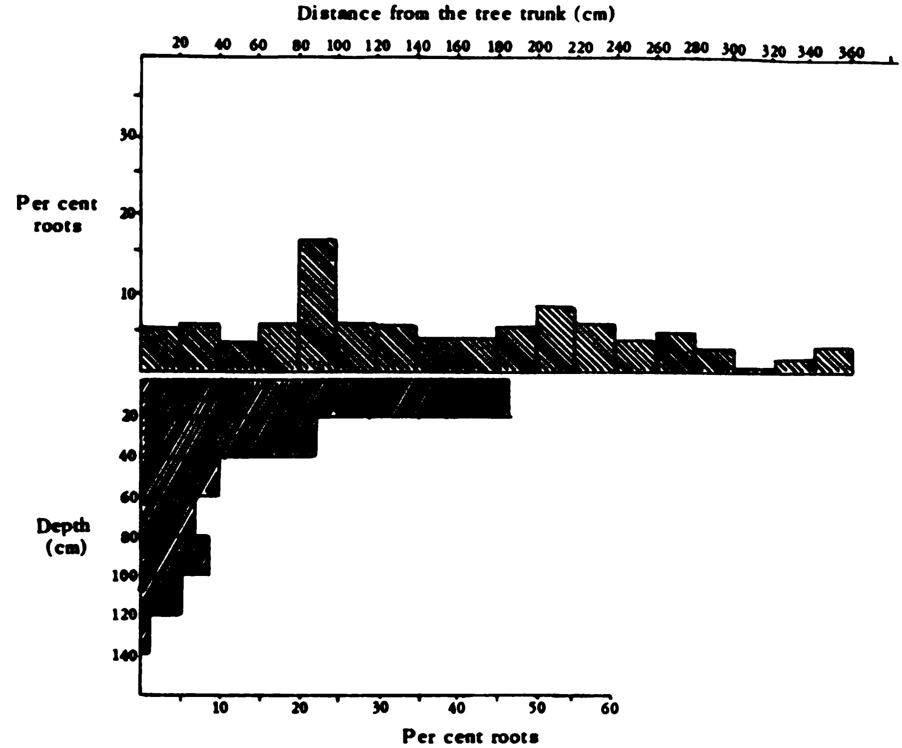

FIGURE 19 Absorbing root distribution of rubber tree T1r (La Hulera)

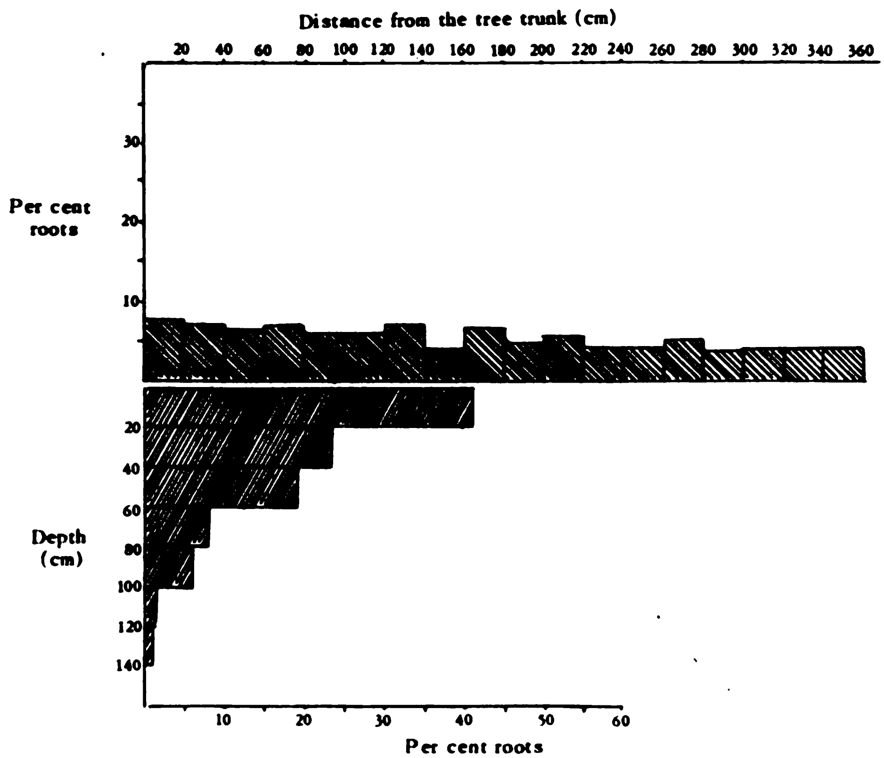

FIGURE 20 Absorbing root distribution of rubber tree T2r (La Hulera)

B. Distribution of absorbing roots of rubber

I. La Hulera:

Data for the four rubber trees ($T\text{-}1_r$, $T\text{-}2_r$, $T\text{-}3_r$, and $T\text{-}4_r$) in the La Hulera coffee-rubber interplanting, are presented in tables 16 through 19, and expressed graphically in figures 19, 20, 21 and 22. Table 21 and Fig. 23 present the average values for data obtained from the four trees sampled.

Tree $T\text{-}1_r$:

The most striking feature of rubber tree number $T\text{-}1_r$, as is evident from the data on table 16, is the occurrence of varying rootlet concentrations throughout the profile down to the sixth depth layer (1.2 - 1.4 m). A marked tendency of feeder-root concentration per depth layer to decrease with increase in depth is noticeable down to the 80-100 cm depth layer at which depth a slight increase occurs, followed by a decreasing tendency (Fig. 19). The soil in the two surface layers contains 68.1 percent of the total absorbing roots in the profile with 46.4 percent in the surface layer.

There is a tendency in all layers to exhibit zones of root proliferation, in most cases between 1.0 and 1.4 m distance from the rubber tree trunk. This is especially marked in the surface and second layers in which there is a sharp increase in feeder-root content from the 80 cm distance to the 100 cm distance after which rootlet concentration continues fluctuating along the entire length of the sampling profile. The seventh or deepest layer of sampling shows scant 'pockety' distribution with the pockets coinciding roughly with the above mentioned zones of rootlet increase in the upper layers of soil.

<u>Tree $T\text{-}2_r$:</u>

Table 17 and Fig. 20 show that on the vertical plane as well as on the horizontal plane, absorbing root distribution of rubber tree $T\text{-}2_r$ is similar to that of $T\text{-}1_r$. The two superficial layers contain 64.7 percent of the roots in this profile, with 41 percent in the topmost one. Decrease in feeder-root concentration with depth increase is steady and rapid. Rootlet concentration fluctuates from layer to layer with a number of peaks occurring at various distances and a very slight overall tendency to diminish with distance from the trunk. Very few rootlets occur in the seventh or deepest layer, and these are found far apart from each other in regions of low rootlet concentration.

<u>Tree $T\text{-}3_r$:</u>

Data for the distribution of rubber absorbing roots in profile T - 3 are given in table 18 and in Figs. 21 and 33. Forty-nine (49) percent of the absorbing roots in the profile sampled are contained in the surface layer which varies greatly in depth. The second layer contains 21 percent of the roots, making a total of 70 percent for the first 40 cm of the soil profile. Within the surface layer, feeder-roots are unevenly distributed, pockets of high rootlet concentration occurring throughout the layer at varying distances from the trunk. Rootlet concentration per depth layer diminishes rapidly from the surface to the bottom of the sampling volume from 49.2 percent at the surface, to 2.7 percent in the deepest layer. Horizontally, absorbing root concentration is very variable from sample to sample with rootlets extending throughout the profile in the topmost 80 cm depth. Within the next three 20 cm strata, feeder-root distribution is spotty with a number of unoccupied spaces occurring at

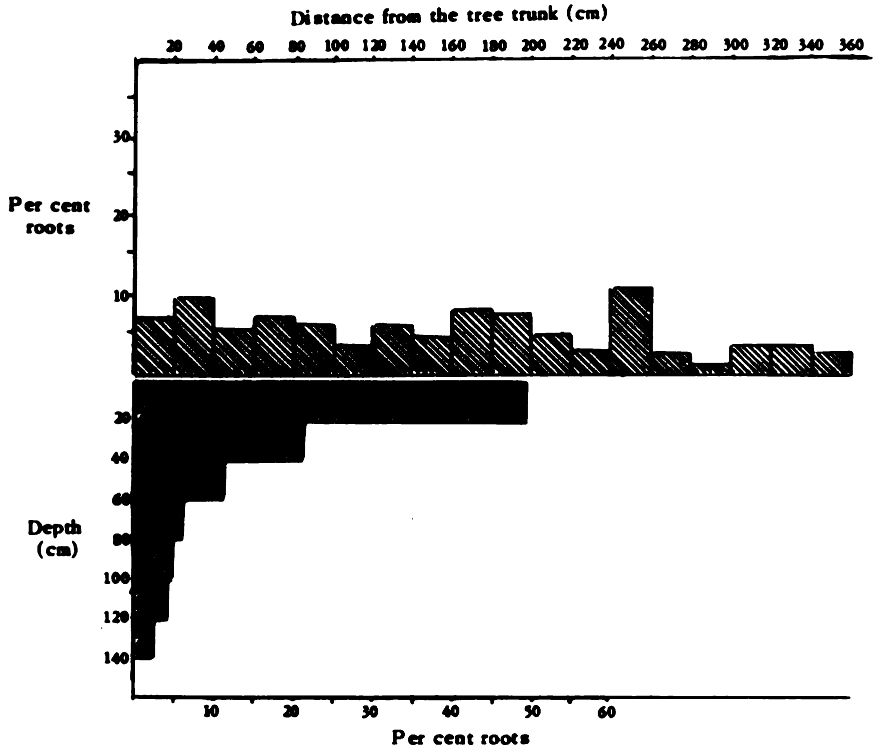

FIGURE 21 Absorbing root distribution of rubber tree T3r (La Hulera)

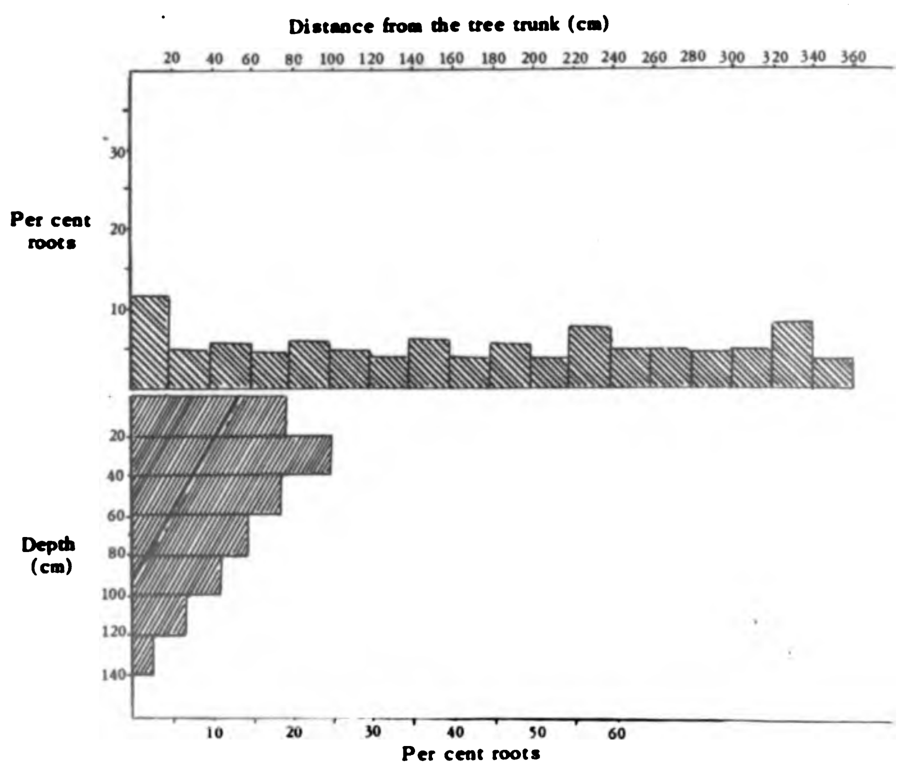

FIGURE 22 Absorbing root distribution of rubber tree T4r (La Hulera)

different distances from the trunk. In these three layers, rootlet concentration tends to diminish with increasing distance from the rubber trunk.

<u>Tree T-4_r</u>:

Tree number T-4_r shows an absorbing root distribution somewhat different from that of the other three trees sampled in this location - (see table 19 and Figs. 22 and 34). The main difference occurs in the vertical plane, which does not show a decrease in feeder-root concentration with increasing depth. There are less rootlets in the surface layer (19.5 percent) than in the 20-40 cm layer (25.2 percent). From the second layer downwards, however, a characteristic decrease in absorbing root concentration with depth is evident throughout the profile; here pockets of moderately high rootlet concentration exist, and the majority of these occur in the superficial layers. The maximum depth layer sampled shows relatively few rootlets and these are scattered in pockets of low feeder-root concentration along the length of the layer. In general, along the horizontal plane, the highest absorbing root concentration occurs in the 20 cm closest to the tree trunk, generally diminishing toward the middle of the sampling area and then increasing slightly toward the periphery.

<u>Mean results</u>: Scrutiny of the averaged data from the four rubber trees sampled at La Hulera (Fig. 23, table 21) reveal that, in general, the absorbing root system of rubber interplanted with coffee in La Hulera is distributed fairly evenly throughout the soil profile to a depth of approximately 1.4 m. The majority of the rootlets seem to occur in the superficial two 20 cm layers which contain more than 46 percent of the absorbing root total in the sampling volume. Feeder-root content per depth layer

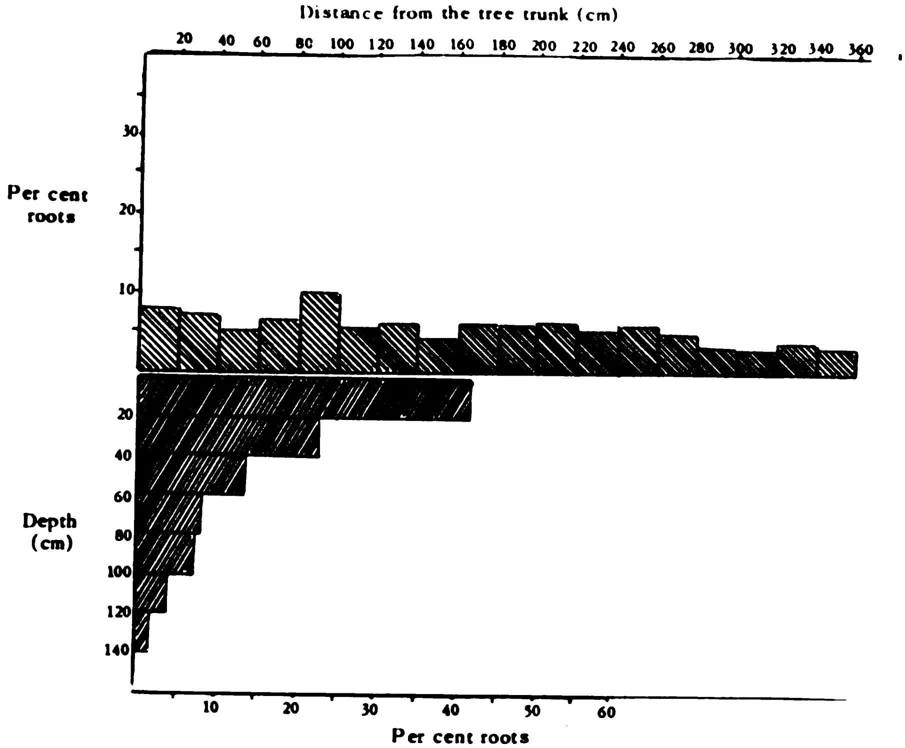

FIGURE 23 Average absorbing root distribution of rubber trees T1r, T2r, T3r and T4r (La Hulera)

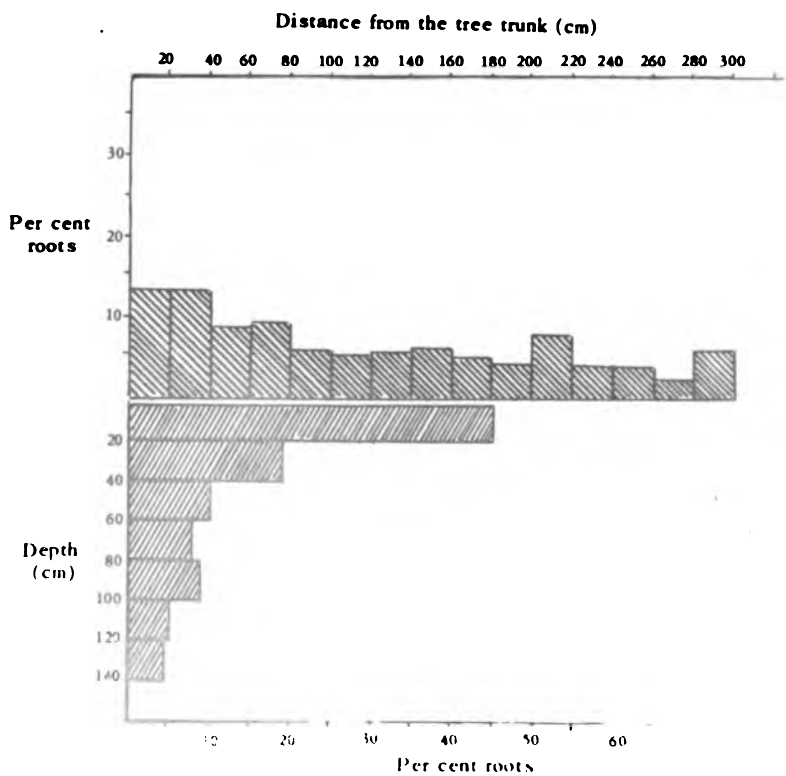

FIGURE 24 Absorbing root distribution of rubber tree X1r (Los Diamantes)

decreases steadily from 41.7 percent in the surface layer to 1.5 percent in the deepest layer sampled.

On the horizontal plane, absorbing root concentrations fluctuate from sample to sample at different distances from the trunk-line, with the greatest concentration (10.4 percent) occurring at a distance of 1.0 - 1.2 m from the tree.

II. Los Diamantes:

Data obtained from the extraction of rubber absorbing roots in the Los Diamantes mixed planting are shown in tables 22, 23, and 24, and expressed graphically in Figs. 24, 25 and 26. Average values for absorbing root weights of the three trees sampled at this location ($X\text{-}1_r$, $X\text{-}2_r$, and $X\text{-}3_r$) are shown in table 25 and Fig. 27.

Tree $X\text{-}1_r$:

From data in table 22, it is evident that absorbing roots of rubber tree $X\text{-}1_r$ occupy the entire profile to a depth of 80 cm and from there downwards, to the maximum sampling depth (1.4 m) they are contained in pockets at varying distances from the trunk-line. Forty-five (45) percent of the total absorbing roots occur within the superfical soil stratum. A decrease in rootlet concentration per depth layer occurs from the soil-line to the 80-100 cm stratum. At this depth, root concentration increases slightly and then continues to decrease with depth down to the maximum sampling depth. Within the surface layer (which shows a great variability in depth) highest feeder-root concentration occurs within the 80 cm closest to the tree trunk. A pocket of relatively high concentration occurs at a distance of 2.0 - 2.4 m from the trunk-line (Fig. 36). In general, absorbing root concentration tends to diminish toward the periphery with increases occurring at distances of 2.0 - 2.2 m and 2.8 - 3.0 m from the trunk (Fig. 24).

Tree X-2_r:

Table 23 and Fig. 25 present data from rubber tree X-2_r which show the absorbing root system of this tree to spread throughout the entire sampling profile. Forty-two (42) percent of the absorbing roots in the profile are contained in the surface layer which varies considerably in depth due to the irregular soil-line (Fig. 37). Pockets of markedly high rootlet concentration occur in this layer within the first 60 cm distance from the tree, and at a distance of from 2.2 - 2.4 m from the rubber tree.. As depth increases, the percentage of feeder-roots in each layer decreases down to the 120 cm layer. At the lowest depth stratum, a marked increase in rootlet concentration occurs which ocrresponds to the presence in this layer of a strip of root proliferation which stretches along the entire length of the sampling profile. Horizontally, the highest rootlet concentration occurs in the 40 cm closes to the tree trunk. Feeder-root percentage decreases with distance from the trunk-line as far as 1.4 m. From this point toward the periphery, feeder-root concentration in the profile rises and falls at different distances from the trunk-line.

Tree X-3_r:

Rubber tree X-3_r (table 24 and Fig. 26) exhibits the majority of its absorbing roots (71.8 percent) in the two superficial depth layers (0 - 40 cm). Rootlet percentage within the top layer shows pockets of high concentration at the 20 - 60 and 220 - 260 cm distances. Within the next four depth strata (40 - 120 cm) feeder-root content is low (15 percent)

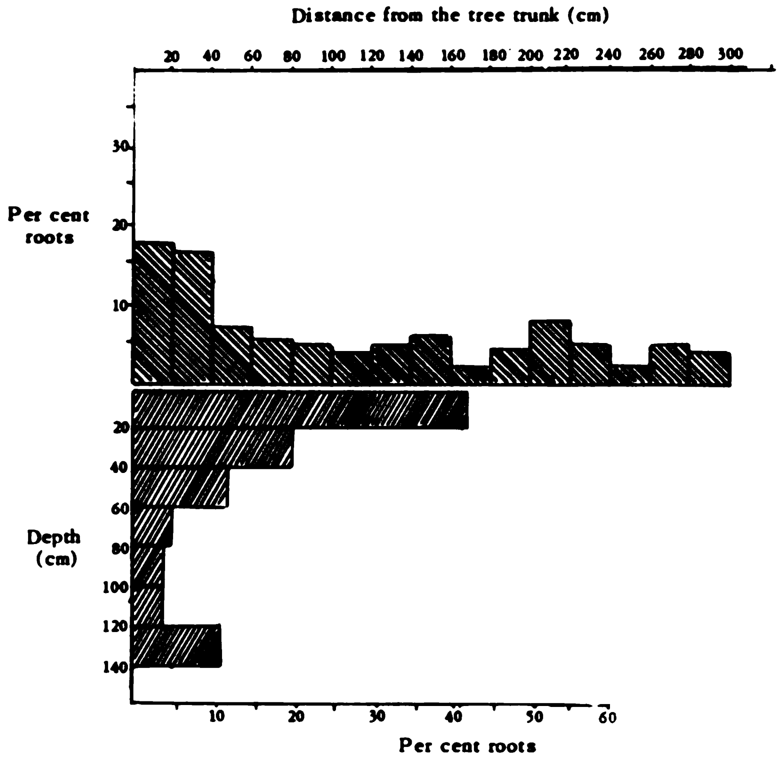

FIGURE 25 Absorbing root distribution of rubber tree X2r (Los Diamantes)

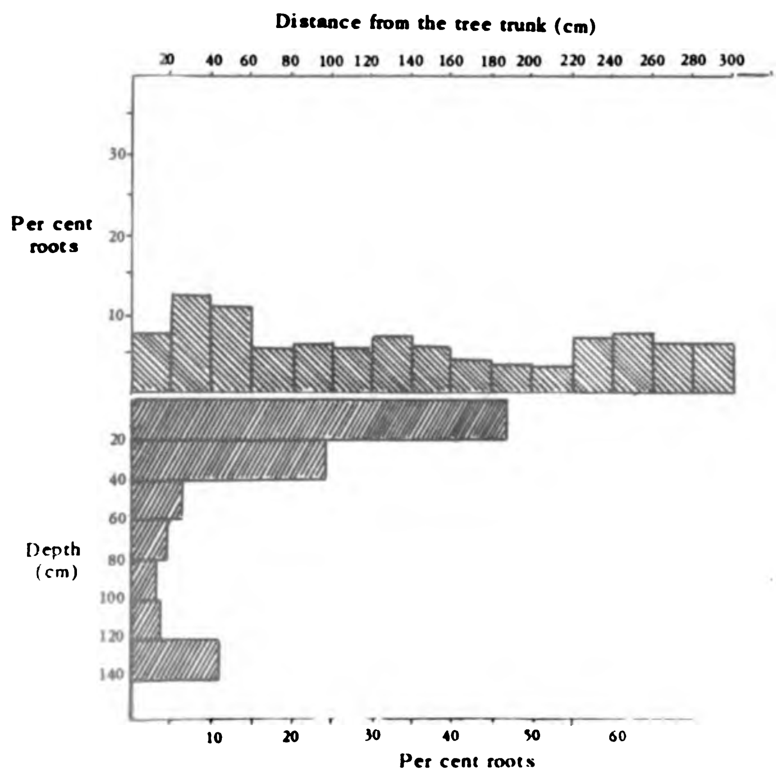

FIGURE 26 Absorbing root distribution of rubber tree X3r (Los Diamantes)

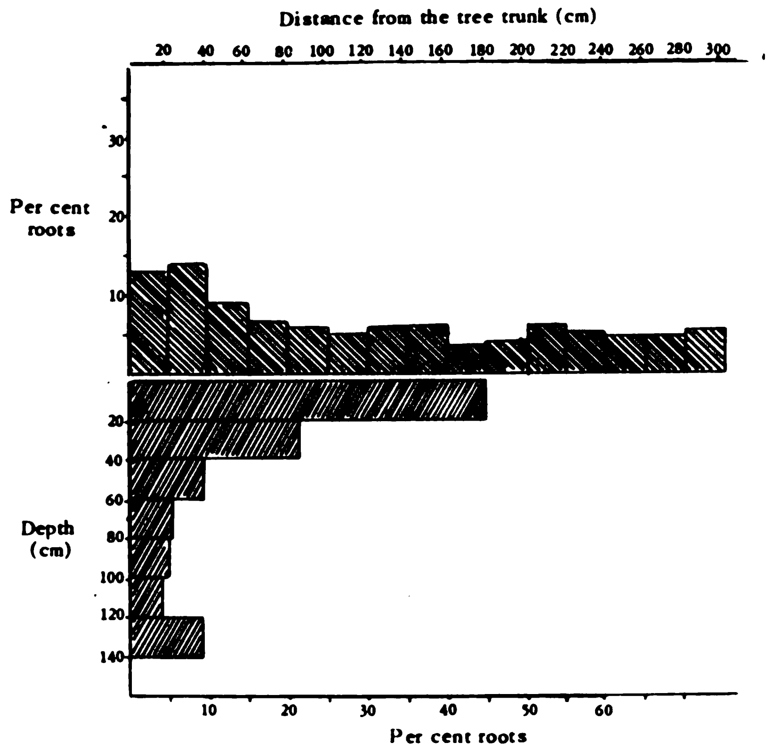

FIGURE 27 Average absorbing root distribution of rubber trees X1r, X2r and X3r (Los Diamantes)

although spread out over the whole length of the profile except for small spaces where no rubber rootlets occur. Absorbing root content in the deepest layer (120 - 140 cm) is relatively high with rootlet concentration values varying considerably from one place to another along the radius from the trunk-line, the highest values occurring in the first three distances (0 - 60 cm). Absorbing root percentage is highest at the 20 - 60 cm distance column.

Mean results: Average data for the three trees samples at Los Diamantes are shown in table 25. From this data a general idea can be formed of the absorbing root distribution of rubber at the Los Diamantes site (Fig. 27). Absorbing roots extend throughout the sampling profile; the highest percentage occurring in the superficial layer (45 percent) and a decrease with depth layer being noted down to the 1.2 m layer. The deepest stratum (120 - 140 cm) shows an increase in feeder-root content indicating root proliferation at this level. On the horizontal plane the highest absorbing root content is found in the 40 - 60 cm distance column (14.1 percent). From this point out toward the periphery, feeder-root percentages per distance column vary markedly between each other, but show a general tendency to diminish with increasing distance from the trunk-line.

Non-absorbing Root Distribution of Coffee and Rubber at the Two Sites Studied

Knowledge of the non-absorbing root picture of the rubber-coffee interplantings in the two sites studied, is of importance to the present investigation, not only because of the important role that these roots play in the growth and development of the plants, but also because it is from these larger roots that the smaller absorbing roots originate.

The sample weights of the non-absorbing roots from the two locations studied were originally intended to be included in this dissertation. However, the large variability in root diameters, together with the fact that representative samples of the larger roots (diameters larger than 2 cm) could not be taken with the core-sampler used, resulted in the distribution of non-absorbing roots as presented in the weight sample data, **not being** really representative of the true situation occurring in the field. Hence the weights of those parts of the samples which were considered non-absorbing roots, were disregarded.

By exposing with jets of water the remainder of the root systems of sampled trees after sampling, an attempt was made to observe the general distribution of the main non-absorbing roots of these trees.

The following was observed at La Hulera (Fig. 28):

a. Coffee non-absorbing root distribution:

i) A short tap-root extended down to a depth of approximately 50 cms. and ended abruptly.

ii) Axial roots spread out in all directions from the axis of the tap-root.

iii) Lateral roots spread out in all directions branching out from the tap-root at a minimum depth of about 15 cm.

b. Rubber non-absorbing root distribution:

i) The topmost lateral roots occurred at about 30 cm below the soil-line.

ii) All lateral roots showed a strong positive geotropic response and tended to wrap themselves around the tap-root making what seemed to be a forked tap-root.

iii) Tap-roots showed a tendency to be long and tapering with depth, but obstruction by stones caused them to fork out and vary greatly between trees.

iv) In no case did the tap-root reach a depth greater than 2 m (presumably due to the high degree of compaction of the soil below this depth).

v) Lateral roots with diameters greater than approximately 15 mm were not found to occur at a distance of more than 1 m from the tree trunk.

At los Diamantes, the non-absorbing roots of the trees studied were not uncovered due to a lack of time and labour. However, the roots of some of the trees were partially uncovered with metal tools so a general idea could be formed of the distribution of the main non-absorbing roots of the trees at this site. Observation showed that in general at this location the tap-root of rubber trees penetrated to a depth of about 1.6 m and was greatly forked in all cases due to obstruction by stones and boulders (Fig. 29). Thick lateral roots (diameter greater than 4 cm) were observed to occur at varying depths starting at two or three cm from the soil surface (Fig. 30). Coffee non-absorbing roots were found to be distributed in much the same pattern as those in La Hulera, although the laterals and axials seemed to be deeper and more extensive at Los Diamantes (Fig. 2).

Fig. 28. Root system of coffee and rubber trees at La Hulera.

Fig. 29. Lower limit of a rubber tree tap-root at Los Diamantes. Note obstructions by the boulder and the root proliferation above this point.

Fig. 30. Partially exposed root system of a rubber tree at Los Diamantes.

DISCUSSION AND CONCLUSIONS

Perhaps the most important point which must be brought to bear before discussing the results obtained in this study, is the large amount of error involved in the measurement of root yields. There is no known method of quantitative root stody which will ensure 100 or even 90 percent recovery of all the roots contained in a given volume of soil sampled.

Furthermore, the large number of factors which affect the distribution of plant roots in the soil result in an equally great variability occurring between identical plants under seemingly identical conditions. Thus, there are two main factors which limit the obtaining of accurate data in quantitative root studies: 1) the variability between plants; and 2) the difficulty involved in the recovery of roots from the soil.

The former difficulty can be overcome by suitable replication of sampling; and the latter by extreme care in the separation of <u>all</u> roots from the soil to which they have adhered. Unfortunately, both steps involve a large amount of time and labour which in most cases (due to cost and the relative value of the accuracy to be obtained) make their execution impractical or impossible.

The method employed in this study was designed to obtain the highest degree of accuracy possible under the conditions in which it was carried out. It has proved successful in revealing certain tendencies in the root distribution of the plants studied and the results of individual samples show enough similarity amongst themselves to permit them to be judged as being representative of the populations of which they formed a part. However, when discussing the data obtained in this study, it is important to have constantly in mind the error factor which, in a number of cases, is responsible for some of the peculiarities observed in the data for individual trees.

An example of the error factor in this study is the case of coffee tree T-1_c at La Hulera, Data for this tree indicate an absorbing root distribution which is somewhat different from that of other trees in the same location and rather similar to the 'inverted cone' distribution of coffee roots described by Bermudez (7). However, closer scrutiny of the data for this tree reveals the fact that the weights of the terminal samples along the horizontal plane are relatively high and diminish abruptly. Comparison of this abrupt ending of horizontal extension with the gradual decrease with distance noted in other La Hulera coffee trees, suggests that in reality, coffee rootlets did occur in the T - 1 profile at distances from the coffee tree which were greater than those observed in tree T-1_c. However, the investigator is conscious of the fact that a number of rootlets were lost during the separation of the roots from the soil, due to inexperience on his part. This indicates that the absorbing root distribution of tree T-1_c as presented in table 8 is somewhat different from the actual picture occurring in the field which in all probability is similar to that of the other three trees sampled at La Hulera.

Absorbing root distribution of coffee interplanted with rubber La Hulera:

Data obtained at this location reveal the fact that although the weights of individual root samples in the soil profile exhibit considerable variability from one sampling site to another, the distribution of these weights and their relative value with regard to the total weight of absorbing roots in each profile studied show great similarity amongst themselves. Hence it can be deduced that at the La Hulera coffee-rubber interplanting, the absorbing roots of coffee are distributed in the following manner: A bell-shaped pattern with approximately two thirds of the total absorbing roots contained in the superficial 40 cm on the vertical plane and horizontally within the 80 cm closest to the coffee trunk. Rootlet concentration diminishes with depth from the superficial layer down to approximately 80 cm, at which depth feeder-root concentration increases along with horizontal extension. From this stratum down to the deepest layer sampled, rootlet concentration diminishes with increase in depth and horizontal extension recedes toward the coffee tree trunk. On the horizontal plane, absorbing root concentration shows a strong tendency to diminish with increasing depth in all strata except the superficial layer in which pockets of relatively high rootlet concentration occur at varying distances from the tree trunk.

Los Diamantes:

The similarity of the absorbing root distribution of each of the trees sampled at Los Diamantes with that of the general average for this location indicates the similarity between individuals and hence the fact that sample rootlet distributions are representative of the population studied in Los Diamantes. In general, the absorbing root distribution of coffee in Los Diamantes can be described from the data obtained as follows:- an irregular distribution of rootlets throughout the profile with the large majority (60 percent) contained in the surface layer and distributed fairly evenly along the entire length of the profile. Pockets of high absorbing root concentration occur at varying distances from the tree which coincide with dips in the soil-line. This indicates that within the surface layer, a large percentage of the rootlets occur within the upper 10 cm. A slight tendency of the absorbing root concentration to diminish with distance from the trunk is evident. Concentration decreases rapidly with increasing depth down to the maximum depth sampled (1.4m). In the lower strata, regions of low feeder-root concentration occur with spaces between them which become larger as depth increases.

As can be seen, the coffee absorbing root system at La Hulera differs considerably from its counterpart at Los Diamantes. The occupation of the soil profile by coffee absorbing roots at Los Diamantes is much more extensive horizontally and only slightly less extensive vertically than is the case at La Hulera. Furthermore, more rootlets are produced by coffee trees at Los Diamantes than at La Hulera, as can be judged by comparing the total weights of the averages in both zones. This may be due to the poorer general growing conditions of the La Hulera trees, or to varietal differences between trees in the two zones.

On the other hand, absorbing root distribution of coffee at the two places is similar in that at both locations it seems to be superficial in nature, occupying the surface 40 cm with more than 60 percent of the total absorbing roots in both cases. This is in agreement with observations made by Trancoso in Angola (83) and Suárez de Castro in Colombia (79), who found that coffee root systems at these locations were superficial in nature, and in the latter case, was determined by the thickness of the superficial layer.

Absorbing root distribution of rubber interplanted with coffee

La Hulera:

As is the case with the coffee trees at this location, there are marked differences between the abosrbing rubber root concentration of individual samples from site to site. However, the relative rootlet concentration values are similar enough to the general average of the four trees sampled representative of the actual distribution of the absorbing roots of rubber trees at La Hulera.

The absorbing root system of rubber at La Hulera has been shown to be fairly evenly distributed throughout the profile. Approximately 46 percent of the absorbing roots in the soil profile occupy the upper 40 cm of soil. Vertically by layers, the absorbing root concentration decreases markedly with depth increase while horizontally it remains reasonably even, with fluctuation occurring from sample to sample but with a slight overall tendency to decrease with increasing distance from the tree trunk.

Los Diamantes:

As in the La Hulera sites, rubber absorbing roots at Los Diamantes extend throughout the soil profile. A similar tendency to vary in sample concentration along the horizontal plane occurs at Los Diamantes, as at La Hulera, although in the former location, absorbing roots of *Hevea* show a constant tendency to produce a large number of rootlets at a distance of about 40 - 60 cm from the trunk. Vertically, rubber rootlets diminish as depth of the soil increases down to the 1.2 m depth layer, at which depth root concentration rises again slightly.

Observation of the data for the rubber absorbing root distribution in both zones studied shows it to be similar in both cases to that observed by investigators in Malaya (68) who state that little variation was observed in the surface feeder-roots with distance from the tree.

Comparison of the sums of the average root sample weights at the two locations studied (tables 21 & 25) shows that at La Hulera, Hevea trees have a proportionately greater absorbing root surface than their counterparts at Los Diamantes. This can be attributed to genetic or age differences between trees at the two sampling locations, as soil environmental factors do not seem to play a limiting role in relation to root development at either of the two zones.

The combined absorbing root distribution of the coffee-rubber complex

In view of the fact that this study is primarily concerned with the root distribution of the coffee-rubber complex as a whole and not that of each species individually, the discussion of the results obtained in this investigation should be made from the point of view of the whole complex as it was studied in the field, and not of each species individually.

Scrutiny of Figs. 31 through 39, together with a consideration of the information gathered from the individual treatment of the species involved in these combined plantings, gives an idea of the root pictures of the coffee-rubber interplantings as they actually occur in the field at the two locations studied.

1. La Hulera:

Data from tables 20 and 21 show that, at this location, the average weights of absorbing coffee roots in the sampling profiles add up to a total of approximately 16 g. This represents 41 percent of the total weight of rubber and coffee feeder-roots in the profiles sampled. Summation of the average rubber absorbing root weights totals 23.3 g, representing 59 percent of the grand total of coffee plus rubber average weights in the profile. These data give evidence that, at La Hulera sampling sites, the profiles sampled contain approximately 18 percent more rubber absorbing roots than coffee feeder-roots. This is to be expected, since it has been shown in a previous analysis of data from La Hulera that, at this location, rubber absorbing roots tend to extend themselves throughout the sampling profile both in vertical and horizontal directions, whereas coffee absorbing roots occupy only a portion of the profile, leaving parts of it free of invasion. A large part of the profile however, is occupied by roots of both species, resulting in their intermingling, and a consequent possibility of competition between the rubber and the coffee trees.

More detailed observation of the data in tables 20 and 21, as well as the graphic representation of this data in Fig. 31, reveals important facts with regard to where and to what degree intermingling occurs within the sampling profile.

Both coffee and Hevea have around 65 percent of their absorbing roots in the two surface layers (soil-line to 40 cm) with coffee showing a slightly higher percentage in the surface layer than rubber. This would lead to the assumption that root intermingling is very marked in the top layers. This is only partly true, however, because coffee root occupation of the superficial soil layers is mainly restricted to the 2.0 m closest to the coffee tree, leaving the remaining 1.6 m unoccupied for the free development of the rubber roots. On the other hand, a considerable amount of rubber roots extend into that portion of the two surface strata occupied by high concentrations of coffee rootlets. In general, however, although intermingling of rootlets from the two species does occur in the surface layers to a higher degree than in deeper strata, it is not as high as would be expected from the data on feeder-root concentration per depth layer (tables 20 & 21). A further reason for this is that rubber roots tend to diminish in concentration with increase in distance from the rubber tree, especially when reaching those parts of the soil profile heavily occupied by coffee roots. This last feature may be due to a filling up of the pore space by coffee roots which possibly made the soil 'uninvadable' to rubber roots by restricting air or water supply, or both.

In the lower strata there seems to be very little if any intermingling of coffee and rubber roots; coffee feeder-roots being predominant in the soil volume close to the coffee tree and this fact coinciding with the low rubber root concentrations shown to occur in this volume of soil. It is fitting to note here that rubber absorbing roots are generally larger in diameter than coffee absorbing roots and consequently their weights signify less root surface than equal weights of coffee absorbing roots. Hence it is still more evident that rubber root invasion of the coffee root occupation zone, to the relatively small degree it occurs, has little probability of harmfully affecting the coffee absorbing root system. Inversely, the fact that coffee absorbing roots invade to a very low degree the zones of high rubber absorbing root concentration, gives further indication that coffee and rubber seem to live together favourably without their root systems harmfully interfering with each other at the La Hulera mixed planting.

2. Los Diamantes:

The sum of the average weights for absorbing coffee roots at Los Diamantes is 21.7 g. The corresponding sum of the average sample weights of rubber at the same location is 16.5 g (see tables 15 & 25).

These weights represent 57 and 43 percent respectively, of the total of the average absorbing root weights in the profiles studied at this location. This indicates that, at the Los Diamantes sampling location, the profiles studied contain approximately 14 percent more coffee rootlets than rubber absorbing roots.

Consideration of the data for individual trees at Los Diamantes reveals that the higher percentage of coffee rootlets is not unexpected. In this location, coffee absorbing root distribution extends throughout the topmost 80 cm of soil, diminishing gradually from the surface layer to a depth of 80 cm. Horizontally, coffee absorbing roots extend all the way to a distance of 2.8 m in all of the three topmost 20 cm soil strata. Rubber rootlets do not permeate the surface layer of the soil so thoroughly as coffee, but show higher concentrations than do coffee rootlets in the lower soil strata. When considered together as they occur in reality in the profiles studied, the two distribution patterns are observed to intermingle to a high degree; especially in the surface soil layer, which contains relatively high feeder-root concentrations of both species. The degree of intermingling diminishes with increase in depth with the ratio of coffee to rubber gradually changing from values above unity to values well below unity as depth increases and proximity to the rubber trunk line is approached.

Observation of Figs. 36, 37 and 38 indicates that extremely marked intermingling of coffee and rubber feeder-roots occurs in the surface layer in isolated pockets. These pockets present high absorbing root concentrations of each species which coincide with each other and with depressions in the soil-line.

Attention should be given to the fact that at these points a marked increase in both rubber and coffee absorbing root concentrations occurs in conjunction with a depression in the soil-line or rather, an increase in the shallowness of the extracted core sample. With this in mind, it becomes evident that the root distribution of the plants studied at this location is extremely superficial in habit, as evidenced by the fact that where these pockets of high rootlet concentration occur, they are surrounded by samples having similar root concentrations and varying only in thickness. Hence the conclusion can be reached that in the Los Diamantes sampling location, a great percentage of the absorbing roots of both coffee and rubber are contained within a very thin layer of soil close to the surface. This finding implies that, at this location, absorbing root distribution is extremely superficial, roots showing a strong response to a negative geotropism.

Considerable differences have been observed between the absorbing root distributions of the coffee-rubber associations in the two ecological zones studied. These differences may be caused by hereditary, and / or environmental factors. As little is known about the degree to which varietal and clonal differences affect the root distribution of Coffea and Hevea, the environmental factor alone has been taken as the basis for the following discussion.

According to Hardy (37) the chief soil environmental factors which play a decisive role in determining the growth and production of plants are: (i) root room (ii) water supply (iii) air supply (iv) nutrient supply (v) harmful factors, and (vi) soil temperature.

Laboratory data have shown that in the two locations where the study was carried out, the physical conditions of the soils are such that root penetration down to a depth of at least 1.4 m is entirely unrestricted. It is evident that the features of the root distribution patterns in these two profiles are not governed directly by soil physical features. Thus, root room, the first and most important of the six soil ecological factors outlined above as determining plant growth and production, can be disregarded as a limiting factor determining differences between the absorbing root distributions of the coffee-rubber complex in La Hulera and Los Diamantes. Hence, roots in the two soils are free to extend in any direction in the profiles to a minimum depth of 1.4 m at La Hulera, and deeper at Los Diamantes.

Air supply also seems to be more than adequate in both soils and is probably not a limiting factor as far as differences in the two root systems are concerned. The low apparent specific gravity values observed in both soils indicate extremely high porosity which, in turn, implies ample air space throughout the sampling volumes at the two locations.

Soil temperature was not determined, but this factor was not considered to be important in this study, as there was no evidence at either location of the occurrence of extreme temperatures which would noticeably affect root distribution. On the basis of the pH data, nutrient supply seems not to be a limiting factor in determining the root distribution in these soils. The pH values were found to increase with depth in both soils studied, indicating a high degree of leaching, and a higher exchangeable base content at lower depths than in the superficial layers. At both sampling locations, rootlets showed a tendency to concentrate in the superficial layers. Hence it is not believed that nutrient status of the soils is responsible for the differences observed between the absorbing root distribution of the coffee-rubber complex in the two soils studied. Further evidence in support of this supposition is the low base status reported by Sands (74) for Turrialba soils.

Water supply seems to be therefore, the decisive factor in determining the absorbing root distribution of the coffee-rubber complex at La Hulera, as well as at Los Diamantes. Although no data are available concerning the moisture gradient in either soil profile, it can be deduced from secondary data such as the pH gradient (which indicates severe leaching), porosity percent, and climatic data for the two zones studied. The high porosity, severe leaching and high rainfall prevalent in both zones, points toward a moisture gradient at Los Diamantes and at La Hulera which diminishes with depth. At Los Diamantes this gradient is reflected in the absorbing root distribution of the coffee-rubber complex. The root systems here of both coffee and rubber trees show a similar tendency to be extremely superficial in habit. This could be explained by the fact that high moisture content is retained in the superficial humic soil, causing the rootlets of both coffee and rubber to respond to positive hydrotropism. The increase in absorbing root concentration of rubber trees which was observed in the bottom sampling layer may be caused by proximity to the water table in this profile. It may also be attributed to the high soil compaction and consequent reduction of aeration occurring below this depth; a situation which would logically result in roots proliferating along the horizontal plane as their vertical penetration into the soil is restricted.

The absorbing root distribution of the coffee-rubber complex at La Hulera is also a predominantly superficial one and is evidently determined by a moisture gradient which decreases with depth. However, this profile is characterized by a water table which varies in level considerably. This variable water table would appear to be responsible for the layer of root proliferation at a depth of approximately 80 - 100 cm, which was characteristic of the coffee trees in the La Hulera soil profile. The more intense permeation of the deeper soil layers by rootlets of coffee and rubber in this profile, as compared with the marked superficiality of root distribution at Los Diamantes, may well be attributed to the variable water table in the La Hulera soils. In other words, a positive hydrotropic response of the roots seems to cause root development to vary with the water table.

The preceding considerations seem to indicate that the coffee-rubber association maintains a competitive relationship under the conditions at Los Diamantes, and a complementary one under the La Hulera conditions. However, it must be stressed that this conclusion is based only on the degree of intermingling observed between the absorbing root systems of coffee and rubber under the conditions studied. In order to arrive at a conclusion as to whether root competition does or does not occur between the two species in the interplantings studied, a great deal of further information must be made available. First it must be determined conclusively whether harmful competition does or does not exist under the conditions of the present study. This can only be determined by recording yields and observing growth and development of the mixed plantings over an appropriate period of years. If harmful competition is found to occur, it will then be necessary to determine what plant and environmental factors play the decisive roles in this competition. Only after these unknowns have been answered, will it be possible to make recommendations for the use of the coffee-rubber mixed planting on a commercial scale.

Hence the information obtained in this investigation will not achieve its full value until it has been complemented by further experimental information regarding the characteristics and affecting factors of the coffee-rubber interplanting system.

SUMMARY

The absorbing root distribution of mature interplanted coffee and rubber trees was studied in two ecological zones of Costa Rica.

The method used was a modification of the trench method employed by Bermudez. Soil-core samples were extracted from a sampling volume located between rubber and coffee trees. After separation from the soil, roots of each species were classified according to their diameter as absorbing ($<$ 1.5 mm) and non-absorbing (1.5 mm) roots and their dry weights determined.

Average results of four pairs of trees sampled at La Hulera experiment station at Turrialba, and of three pairs sampled at Los Diamantes experimental station at Guápiles, indicate the following:

1. Absorbing roots of coffee interplanted with rubber at La Hulera are distributed in an upright bell-shaped pattern with 68 percent of the absorbing roots contained in the top 40 cm of soil and having a diminishing tendency with depth down to approximately 80 cm at which depth a layer of increased rootlet concentration occurs. Horizontally, absorbing root concentration diminishes with increasing distance from the trunk.
2. At Los Diamantes the absorbing roots of coffee show an extremely superficial distribution with 60 percent of the total absorbing roots occurring within the 20 cm of the soil closest to the surface. Rootlet concentration diminishes rapidly with depth increase. Horizontally, absorbing root concentration shows a tendency to decrease with distance from the trunk.

3. Absorbing roots of rubber at the Turrialba location show a fairly even distribution throughout the sampling profile, the maximum depth of which was 1.4 m. The majority of the absorbing roots occur in the superficial 20 cm of soil (46 percent). Rootlet concentration diminishes with depth. On the horizontal plane, absorbing root concentration fluctuates at different distances from the rubber tree trunk, but the overall tendency is to decrease with increase in distance from the trunk.

4. Rubber absorbing root distribution in Los Diamantes mixed planting is mainly superficial, with 45 percent of the total absorbing roots in the superficial layer. A decrease in rootlet concentration with depth occurs down to a depth of 1.20 m, where concentration increases slightly, and then continues a diminishing tendency down to the maximum sampling depth (1.4 m). On the horizontal plane, highest absorbing root concentration occurs at a distance of 40 - 60 cm from the rubber tree trunk. From this point outward, toward the periphery, rootlet concentration varies from distance to distance, but shows an overall general tendency to diminish with distance from the trunk.

5. At La Hulera, total absorbing root weight of rubber is 18 percent greater than the total weight of coffee absorbing roots. The degree of intermingling of coffee and rubber rootlets is relatively low, resulting from the fact that where high rubber feeder-root concentrations occur, coffee rootlet concentration is low, and vice versa.
At Los Diamantes, the degree of rootlet intermingling is presumed to be high since the absorbing root systems of both species occur mostly in the superficial soil layers.

6. Differences between absorbing root distributions of the coffee-rubber associations at La Hulera and Los Diamantes, is attributed to the moisture gradients of the two soil profiles studied. Other environmental factors such as root room, air supply, nutrient supply, etc. do not seem to play a limiting role at either of the locations of this study. Not much attention is given to the possible influence of genetic factors in this study, since little is known about the degree to which inter-varietal and inter-clonal differences affect root distribution of coffee and rubber.
7. The intermingling of absorbing roots of the two species seems to indicate marked competition at the Los Diamantes sites, but not at the La Hulera sampling sites. However, emphasis should be placed on the fact that considerable further information is necessary before it can be concluded whether harmful competition does or does not occur between coffee and rubber trees interplanted under the conditions of this investigation.

RESUMEN

Se estudió la distribución de raíces absorbentes de árboles adultos de café y hule en cultivos intercalados en dos zonas ecológicas de Costa Rica.

El método utilizado consistió en una modificación del método de trinchera usado por Bermudez. Se estrajeron muestras de suelo con un perforador cilíndrico, de un volumen de muestreo localizado entre un árbol de hule y uno de café. Después de separar las raíces de cada especie del suelo, éstas se clasificaron según su diámetro como absorbentes (< 1.5 mm) y no-absorbentes (> 1.5 mm), y se determinó su peso seco.

En promedio, los resultados de cuatro pares de árboles muestreados en la estación experimental 'La Hulera' en Turrialba, y de tres pares muestreados en la estación experimental 'Los Diamantes' en Guápiles, mostraron lo siguiente:

1. Las raíces absorbentes de café interplantado con hule en La Hulera se distribuyen en forma de una campana erecta con el 68 por ciento de las raíces absorbentes encontrándose en los 40 cm superficiales del suelo. Es evidente una tendencia de estas raicillas a disminuir con profundidad hasta los 80 cm, donde ocurre un incremento en concentración de las mismas. Horizontalmente, la concentración de raíces absorbentes disminuye según incrementa la distancia del tronco.
2. En Los Diamantes, los raíces absorbentes de café muestran una distribución extremadamente superficial, encontrándose el 60 por ciento del total de las raíces absorbentes dentro de los 20 cm de suelo más cercanos a la superficie. **La concentración de raicillas disminuye rápidamente con el incremento en profundidad. Horizontalmente, la concentración de**

raíces absorbentes muestra una tendencia a disminuir según incrementa la distancia del tronco.

3. Las raíces absorbentes de hule en La Hulera muestran una distribución bastante pareja a través del perfil de muestreo cuya profundidad máxima fue de 1.4 m. La mayoría de las raíces absorbentes se encuentran en los 20 cm superficiales del suelo (46 por ciento). La concentración de raicillas disminuye con aumento de profundidad. En el plano horizontal, la concentración de raíces absorbentes fluctua a diferentes distancias del tronco del árbol de hule, pero la tendencia general es de disminuir con incremento en distancia del tronco.

4. La distribución de raíces absorbentes de hule en la plantación mixta en Los Diamantes es principalmente superficial, con el 45 por ciento del total de raíces absorbentes en la capa superficial. Se nota una disminución en la concentración de raicillas con incremento de profundidad hasta 1.20 m en donde la concentración sube levemente y luego sigue disminuyendo hasta la profundidad máxima de muestreo (1.4 m). En el plano horizontal, la concentración más alta de raíces absorbentes ocurre a una distancia de 40-60 cm del tronco de hule. De este punto hacia la periferia, la concentración de raicillas varía de distancia a distancia, pero muestra una tendencia general a disminuir según aumenta la distancia del tronco.

5. En La Hulera, el peso total de raíces absorbentes es un 18 por ciento mayor al peso total de raíces absorbentes de café. El grado al cual las raícillas de hule y de café se entremezclan es relativamente bajo. Esto resulta del hecho de que donde se encuentran altas concentraciones de raicillas de hule, las concentraciones de raicillas de café son

bajas y vice versa. En Los Diamantes, el grado de entremezcla de los systemas radicales de las dos especies parece ser alto, puesto que ambos se encuentran en su mayoría en las capas superficiales de suelo.

6. Diferencias entre las distribuciones de raíces absorbentes de las asociaciones café-hule en La Hulera y Los Diamantes, se atribuyen a las gradientes de humedad de los suelos estudiados. Otros factores ambientales tales como espacio radical, suministro de agua, nutrientes, aire, etc. no parecen ser limitantes en ninguno de los lugares donde este estudio se llevó a cabo. Se le dió poca importancia al factor genético en este estudio puesto que no se sabe mucho acerca del grado al cual afectan las diferencias interclonales e intervarietales a la distribución radical de hule y café.

7. La entremezcla de las raíces absorbentes de las dos especies parece indicar una competencia marcada en los sitios muestreados en Los Diamantes, pero no en los sitios en La Hulera. Sin embargo, se debe poner énfasis al hecho de que es necesario mucha más información antes de que se pueda concluir que haya o no haya competencia entre árboles de café y de hule intercalados bajo las condiciones de este estudio.

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APPENDIX

TABLE 8. Root Distribution Data for Coffee Tree T-1_c (La Hulera)
(Root weights in Hundredths of a Gram)

DEPTH LAYER (cm)	Distance from trunk (cm)																		Total	Per cen
	20	40	60	80	100	120	140	160	180	200	220	240	260	280	300	320	340	360		
0-20	82	176	83	41	86	90	-	-	-	-	-	-	-	-	-	-	-	-	558	36.
20-40	181	177	70	48	30	6	16	-	-	-	-	-	-	-	-	-	-	-	528	34.
40-60	20	8	16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	44	2.
60-80	3	15	22	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	40	2.
80-100	74	69	35	58	2	-	-	-	-	-	-	-	-	-	-	-	-	-	238	15.
100-120	42	22	7	3	1	2	-	-	-	-	-	-	-	-	-	-	-	-	77	5.
120-140	16	7	3	1	-	-	16	-	-	-	-	-	-	-	-	-	-	-	43	2.
Total	418	471	236	151	119	98	32	-	-	-	-	-	-	-	-	-	-	-	1528	
Percent	27.4	30.8	15.5	9.9	7.8	6.4	2.1	-	-	-	-	-	-	-	-	-	-	-		

TABLE 9. Root Distribution Data for Coffee Tree T-2_c (La Hulera)
(Root weights in Hundredths of a Gram)

DEPTH LAYER (cm)	Distance from trunk (cm)																		Total	Per cen
	20	40	60	80	100	120	140	160	180	200	220	240	260	280	300	320	340	360		
0-20	304	238	202	111	204	100	81	-	-	-	-	-	-	-	-	-	-	-	1240	58.
20-40	108	70	44	27	18	11	8	10	-	-	-	-	-	-	-	-	-	-	296	14.
40-60	80	43	12	12	13	7	14	8	5	5	-	1	-	-	-	-	-	-	200	9.
60-80	13	30	33	-	-	10	1	8	8	1	-	2	7	-	-	-	-	-	113	5.
80-100	38	27	13	17	17	19	7	11	7	2	3	3	8	3	10	-	-	-	185	8.
100-120	10	14	6	3	1	3	2	-	-	4	8	2	2	4	-	-	-	-	59	2.
120-140	14	2	3	4	-	-	-	2	1	-	-	-	-	-	-	-	-	-	26	1.
Total	567	424	313	174	253	150	113	39	21	12	11	8	17	7	10	-	-	-	2119	
Percent	26.8	20.8	14.8	8.2	11.9	7.1	5.3	1.8	1.0	0.6	0.5	0.4	0.8	0.3	0.5	-	-	-		

TABLE 10. Root Distribution Data for Coffee Tree $T\text{-}3_c$ (La Hulera)
(Root weights in Hundredths of a Gram)

DEPTH LAYER (cm)	Distance from trunk (cm) 20	40	60	80	100	120	140	160	180	200	220	240	260	280	300	320	340	360	Total	Per-cent
0-20	143	155	119	75	125	81	9	-	-	-	-	-	-	-	-	-	-	-	707	50.1
20-40	50	45	48	22	4	5	11	-	-	-	-	-	-	-	-	-	-	-	185	13.1
40-60	12	26	19	2	8	11	12	15	-	-	-	-	-	-	-	-	-	-	105	7.5
60-80	21	18	3	15	5	12	3	3	1	35	2	6	4	-	-	-	-	-	128	9.1
80-100	11	19	12	13	10	1	2	10	5	4	-	-	1	-	-	-	-	-	88	6.2
100-120	23	38	11	10	10	12	-	-	5	-	-	-	-	1	15	-	-	-	125	8.9
120-140	28	18	21	3	-	-	-	-	-	2	-	-	-	-	-	-	-	-	72	5.1
Total	288	319	233	140	162	122	37	28	11	41	2	6	5	1	15	-	-	-	1410	
Percent	20.4	22.6	16.5	9.9	11.6	8.7	2.6	2.0	0.8	2.9	0.1	0.4	0.3	0.1	0.1	-	-	-		

TABLE 11. Root Distribution Data for Coffee Tree $T\text{-}4_c$ (La Hulera)
(Root weights in Hundredths of a Gram)

DEPTH LAYER (cm)	Distance from trunk (cm) 20	40	60	80	100	120	140	160	180	200	220	240	260	280	300	320	340	360	Total	Per-cent
0-20	75	83	77	46	36	35	85	107	16	-	-	26	-	7	-	-	-	3	596	43.2
20-40	56	64	27	6	7	15	6	64	11	7	1	-	-	-	-	-	-	3	267	19.4
40-60	15	20	15	11	12	9	19	22	3	1	3	1	2	-	-	2	1	5	141	10.2
60-80	17	19	1	1	-	13	1	4	3	1	-	6	-	6	2	2	1	-	77	5.6
80-100	22	66	21	5	4	3	3	-	-	13	2	1	-	1	1	1	1	1	145	10.5
100-120	30	20	22	3	17	4	7	1	-	3	-	-	1	1	-	-	-	1	110	8.0
120-140	11	17	1	4	2	-	-	5	-	3	-	-	-	-	-	-	-	-	43	3.1
Total	226	289	164	76	78	79	121	203	33	28	6	34	3	15	3	5	3	13	1379	
Percent	16.4	21.0	11.9	5.5	5.7	5.7	8.8	14.7	2.4	2.0	0.4	2.5	0.2	1.1	0.2	0.4	0.2	0.9		

TABLE 12. Root Distribution Data for Coffee Tree X-1_c(Los Diamantes)
(Root weights in Hundredths of a Gram)

DEPTH LAYER (cm)	Distance from trunk (cm)															Total	Per-cent
	20	40	60	80	100	120	140	160	180	200	220	240	260	280	300		
0-20	187	70	25	250	41	43	61	32	32	45	2	17	18	19	-	842	52.6
20-40	92	48	42	6	24	11	14	3	8	4	7	4	1	-	-	264	16.5
40-60	31	22	39	26	27	17	18	6	16	9	21	1	54	8	-	295	18.4
60-80	7	12	4	17	5	4	7	3	5	7	5	1	2	6	-	85	5.3
80-100	10	10	9	5	2	-	8	9	16	11	2	-	1	-	-	83	5.2
100-120	3	-	-	-	-	1	12	2	-	-	-	4	-	-	-	22	1.4
120-140	6	4	-	-	-	-	-	-	-	-	-	-	-	-	-	10	0.6
Total	336	166	119	304	99	76	120	55	77	76	37	27	76	33	-	1601	
Percent	21.0	10.4	7.4	19.0	6.2	4.8	7.5	3.4	4.8	4.7	2.3	1.7	4.7	2.1	-		

TABLE 13. Root Distribution Data for Coffee Tree X-2_c(Los Diamantes)
(Root weights in Hundredths of a Gram)

DEPTH LAYER (cm)	Distance from trunk (cm)															Total	Per-cent
	20	40	60	80	100	120	140	160	180	200	220	240	260	280	300		
0-20	554	190	N.S.*	354	215	96	83	82	51	94	67	39	61	59	26	1971	63.7
20-40	103	46	66	52	24	29	26	25	37	14	28	11	13	29	2	505	16.3
40-60	92	38	55	34	22	19	25	3	1	2	12	7	7	15	4	336	10.9
60-80	59	10	38	11	13	14	4	3	1	-	1	2	2	2	1	161	5.2
80-100	13	8	29	3	4	1	-	-	1	-	-	4	-	-	-	63	2.0
100-120	7	5	6	7	6	-	-	-	7	-	-	-	-	-	-	38	1.2
120-140	17	2	-	2	-	-	-	-	-	-	-	-	-	-	-	21	0.7
Total	845	299	194	463	284	159	138	113	98	110	108	67	83	105	33	3095	
Percent	27.3	9.6	6.3	15.0	9.2	5.1	4.5	3.6	3.2	3.5	3.5	2.0	2.7	3.4	1.1		

* No sample was taken at this point due to the soil line "dipping" to a depth of 20 cms. from the wire base-line.

TABLE 14. Root Distribution Data for Coffee Tree $X\text{-}3_c$ (Los Diamantes)
(Root weights in Hundredths of a Gram)

DEPTH LAYER (cm)	Distance from trunk (cm)																		Total	P c
	20	40	60	80	100	120	140	160	180	200	220	240	260	280	300	320	340	360		
0-20	149	146	139	25	75	36	57	80	116	69	61	49	30	38	12	-	-	-	1082	5
20-40	100	56	38	41	15	32	17	38	51	16	20	7	4	-	-	-	-	-	435	2
40-60	31	20	17	15	13	5	6	4	8	4	5	10	-	-	-	-	-	-	138	
60-80	28	6	17	30	8	5	7	1	1	-	2	-	-	-	-	-	-	-	105	
80-100	15	1	9	1	1	2	-	1	-	-	1	-	-	-	-	-	-	-	31	
100-120	5	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6	
120-140	11	17	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	31	
Total	339	247	223	112	112	80	87	124	176	89	89	66	34	38	12	-	-	-	1828	
Percent	18.5	13.5	12.2	6.1	6.1	4.4	4.8	6.8	9.6	4.8	4.9	3.6	1.9	2.1	0.6	-	-	-		

TABLE 15. Root distribution data for the average of coffee trees $X\text{-}1_c$, $X\text{-}2_c$, & $X\text{-}3_c$. (Los Diamantes)(Root weight in Hundredths of a Gram)

DEPTH LAYER (cm)	Distance from trunk (cm)															Total
	20	40	60	80	100	120	140	160	180	200	220	240	260	280	300	
0-20	297	135	55	210	110	58	67	65	66	69	43	35	36	39	13	1298
20-40	98	50	49	33	21	24	19	22	32	11	18	7	6	10	1	401
40-60	51	27	37	25	21	14	20	4	8	5	13	6	20	8	1	260
60-80	31	9	20	19	9	8	6	2	2	2	13	1	1	3	-	126
80-100	13	6	4	2	2	1	3	3	6	4	1	1	-	-	-	46
100-120	5	2	2	2	2	-	4	1	2	-	-	1	-	-	-	21
120-140	11	8	1	1	-	-	-	-	-	-	-	-	-	-	-	21
Total	506	237	8	292	165	105	119	97	116	91	88	51	63	60	15	2173
Percent	23.3	10.9	7.7	13.4	7.6	4.8	5.5	4.5	5.3	4.2	4.1	2.4	2.9	2.7	0.7	

TABLE 16. Root Distribution Data for Rubber Tree $T\text{-}1_r$ (La Hulera)
(Root weights in Hundredths of a Gram)

PTH AYER cm)	Distance from trunk (cm)																		Total	Per- cent
	20	40	60	80	100	120	140	160	180	200	220	240	260	280	300	320	340	360		
0-20	96	106	57	143	447	94	104	105	84	73	151	101	42	47	29	7	10	33	1729	46.4
0-40	55	12	33	27	84	42	21	25	42	93	76	65	60	70	38	9	27	31	810	21.7
0-60	21	55	33	30	36	6	8	2	14	18	23	44	14	26	19	3	3	8	363	9.7
0-80	18	60	2	20	4	7	30	6	9	11	3	5	13	8	7	3	16	27	249	6.7
0-100	17	1	18	9	15	57	25	27	18	16	61	20	12	13	7	-	6	9	331	8.9
0-120	4	3	2	1	31	25	35	5	4	8	5	2	10	33	15	4	6	7	200	5.4
0-140	9	1	3	-	14	2	-	3	1	2	-	5	2	3	-	-	-	-	45	1.2
tal	220	238	148	230	631	233	223	173	172	221	319	242	153	200	115	26	68	115	3727	
rcent	5.9	6.4	4.0	6.2	16.9	6.3	6.0	4.6	4.6	5.9	8.6	6.5	4.1	5.4	3.1	0.7	1.8	3.1		

TABLE 17. Root Distribution Data for Rubber Tree $T\text{-}2_r$ (La Hulera)
(Root weights in Hundredths of a Gram)

PTH AYER cm)	Distance from trunk (cm)																		Total	Per- cent
	20	40	60	80	100	120	140	160	180	200	220	240	260	280	300	320	340	360		
0-20	90	79	87	80	62	96	120	51	86	52	23	18	26	43	42	27	22	15	1019	41.0
0-40	34	28	22	45	38	26	32	16	30	28	54	34	60	56	23	24	22	17	589	23.7
0-60	22	32	44	23	25	17	11	21	15	20	50	37	16	32	16	31	17	44	473	19.0
0-80	16	25	10	15	13	3	3	2	14	10	9	8	8	3	5	5	36	16	201	8.1
0-100	21	15	5	16	8	9	6	9	13	7	7	13	-	1	5	6	1	9	151	6.1
0-120	3	1	2	1	4	-	1	1	7	-	-	-	1	1	2	-	9	1	34	1.4
0-140	8	-	-	-	-	-	4	-	3	-	-	-	-	-	-	3	-	-	18	0.7
tal	194	180	170	180	150	151	177	100	168	117	143	110	111	136	93	96	107	102	2485	
rcent	7.8	7.2	6.9	7.2	6.1	6.1	7.1	4.0	6.8	4.7	5.8	4.4	4.5	5.4	3.7	3.9	4.3	4.1		

TABLE 18. Root Distribution Data for Rubber Tree T-3r (La Hulera)
(Root weights in Hundredths of a Gram)

DEPTH LAYER (cm)	Distance from trunk (cm) 20	40	60	80	100	120	140	160	180	200	220	240	260	280	300	320	340	360	Total	Per-cent
0-20	60	94	36	66	67	17	71	38	115	64	26	10	161	15	9	14	9	20	892	49.2
20-40	24	43	19	32	18	22	21	17	25	40	12	7	18	25	9	23	22	9	386	21.3
40-60	20	7	12	7	5	16	5	4	9	13	15	12	11	8	2	19	26	12	203	11.2
60-80	4	15	12	14	12	3	3	3	-	5	2	4	3	1	1	12	10	7	111	6.1
80-100	11	15	1	8	10	6	1	2	-	7	11	6	7	1	-	1	2	1	90	5.0
100-120	5	4	10	2	2	3	6	11	3	3	12	14	4	1	-	-	-	2	82	4.5
120-140	3	-	9	-	1	2	5	8	-	6	13	-	-	-	1	-	-	-	48	2.7
Total	127	178	99	129	115	69	112	83	152	138	91	53	204	51	22	69	69	51	1812	
Percent	7.0	9.8	5.5	7.1	6.4	3.8	6.2	4.6	8.4	7.6	5.0	2.9	11.3	2.8	1.2	3.8	3.8	2.8		

TABLE 19. Root Distribution Data for Rubber Tree T-4r (La Hulera)
(Root weights in Hundredths of a Gram)

DEPTH LAYER (cm)	Distance from trunk (cm) 20	40	60	80	100	120	140	160	180	200	220	240	260	280	300	320	340	360	Total	Per-cent
0-20	37	11	17	15	14	6	10	3	12	27	4	16	15	16	3	22	33	6	267	19.5
20-40	26	14	17	12	35	15	8	28	19	13	5	29	22	28	10	18	22	23	344	25.2
40-60	36	16	18	6	7	8	11	17	5	7	22	19	9	12	11	15	20	15		18.6
60-80	23	8	16	11	16	20	6	7	3	1	17	17	15	13	22	-	7	3	205	15.0
80-100	17	2	1	6	4	15	5	22	14	9	-	9	7	2	10	10	21	2	156	11.4
100-120	13	5	7	4	2	2	11	5	-	18	3	13	1	-	4	-	9	1	98	7.2
120-140	6	11	2	10	2	-	-	2	2	-	-	-	-	-	3	5	-	-	43	3.1
Total	158	67	78	64	80	66	51	84	55	75	51	103	69	71	63	70	112	50	1367	
Percent	11.6	4.9	5.7	4.7	5.8	4.8	3.7	6.2	4.0	5.5	3.7	7.5	5.1	5.2	4.6	5.1	8.2	3.7		

TABLE 20. Root Distribution Data for the Average of Coffee Trees $T\text{-}1_c$, $T\text{-}2_c$, $T\text{-}3_c$, & $T\text{-}4_c$. (La Hulera)(Root weights in Hundredths of a Gram)

DEPTH LAYER (cm)	Distance from trunk (cm) 20	40	60	80	100	120	140	160	180	200	220	240	260	280	300	320	340	360	Total	Pe ce
0-20	151	163	120	68	113	76	44	27	4	-	-	6	-	2	-	-	-	3	777	48
20-40	99	89	47	26	15	9	10	18	3	2	-	-	-	-	-	-	-	-	318	19
40-60	32	24	15	6	8	7	11	11	2	1	1	-	-	-	-	-	-	1	119	7
60-80	13	20	15	4	1	9	1	4	3	9	-	3	2	1	-	-	-	-	85	5
80-100	36	45	20	23	8	6	3	7	3	5	1	1	2	1	3	-	-	-	164	10
100-120	26	23	11	5	7	5	2	-	1	2	2	-	1	1	4	-	-	-	90	5
120-140	17	11	7	3	-	-	4	2	-	1	-	-	-	-	-	-	-	-	45	2
Total	374	375	235	135	152	112	75	69	16	20	4	10	5	5	7	-	-	4	1598	
Percent	23.4	23.5	14.7	8.5	9.5	7.0	4.8	4.3	1.0	1.3	0.3	0.6	0.3	0.3	0.5	-	-	0.3		

TABLE 21. Root Distribution Data for the Average of Rubber Trees $T\text{-}1_r$, $T\text{-}2_r$, $T\text{-}3_r$, & $T\text{-}4_r$. (La Hulera)(Root weights in Hundredth of a Gram)

DEPTH LAYER (cm)	Distance from trunk (cm) 20	40	60	80	100	120	140	160	180	200	220	240	260	280	300	320	340	360	Total	Pe ce
0-20	71	72	49	76	147	53	76	49	74	54	51	36	61	30	21	17	18	18	973	41
20-40	35	25	23	29	44	28	20	21	29	43	37	34	40	45	20	18	23	20	534	22
40-60	25	27	26	16	18	12	9	11	11	14	27	28	12	19	12	17	16	20	320	13
60-80	15	27	10	15	11	8	10	4	6	7	8	8	10	6	9	5	17	13	189	8
80-100	16	8	6	19	9	22	9	15	11	10	20	12	6	4	5	4	7	5	179	7
100-120	6	3	5	2	10	7	13	5	3	7	5	7	4	9	5	1	6	3	101	4
120-140	6	3	3	2	4	1	2	3	1	2	3	1	-	1	1	2	-	-	35	1
Total	174	165	122	150	243	131	139	108	135	137	151	126	133	114	73	64	87	79	2331	
Percent	7.5	7.1	5.2	6.4	10.4	5.6	6.0	4.6	5.8	5.9	6.5	5.4	5.7	4.9	3.1	2.8	3.7	3.4		

TABLE 22. Root Distribution Data for Rubber Tree $X-1_r$(Los Diamantes)
(Root weights in Hundredths of a Gram)

DEPTH LAYER (cm.)	Distance from trunk (cm)															Total	Per-cent
	20	40	60	80	100	120	140	160	180	200	220	240	260	280	300		
0-20	106	125	33	77	37	30	26	24	23	32	59	32	11	6	4	625	45.2
20-40	24	39	24	20	26	16	14	14	9	9	32	8	7	4	14	260	18.8
40-60	26	6	21	18	1	9	7	8	11	2	2	7	5	4	13	140	10.1
60-80	3	4	2	5	12	2	11	10	9	1	13	6	12	4	12	106	7.7
80-100	5	-	5	5	-	16	11	15	11	9	-	1	15	4	24	121	8.8
100-120	16	3	2	4	3	-	5	8	3	5	-	-	4	4	12	69	5.0
120-140	2	5	34	-	-	-	1	3	1	1	-	-	1	9	4	61	4.4
Total	182	182	121	129	79	73	75	82	67	59	106	54	55	35	83	1382	
Percent	13.2	13.2	8.8	9.3	5.7	5.3	5.4	5.9	4.8	4.3	7.7	3.9	4.0	2.5	6.0		

TABLE 23. Root Distribution Data for Rubber Tree X-2r(Los Diamantes)
(Root weights in Hundredths of a Gram)

DEPTH LAYER (cm)	Distance from trunk (cm)															Total	Per-cent
	20	40	60	80	100	120	140	160	180	200	220	240	260	280	300		
0-20	149	223	56	27	30	19	18	25	15	16	56	55	N.S.*	36	5	730	42.3
20-40	78	30	24	38	17	11	10	22	7	17	15	14	28	15	29	355	20.5
40-60	48	2	10	16	8	10	26	14	7	15	16	3	3	20	10	208	12.0
60-80	2	2	-	1	13	11	6	8	4	10	11	2	2	3	17	92	5.3
80-100	8	15	4	-	2	4	12	4	1	1	8	11	3	1	-	74	4.3
100-120	5	7	15	7	1	1	9	5	3	4	10	1	-	-	2	70	4.1
120-140	18	10	19	10	18	13	7	27	5	12	27	7	5	12	9	199	11.5
Total	308	289	128	99	89	69	88	105	42	75	143	93	41	87	72	1728	
Percent	17.8	16.7	7.4	5.7	5.2	4.0	5.1	6.1	2.4	4.3	8.3	5.4	2.4	5.3	4.2		

* No sample was taken at this point due to the soil line "dipping" to a depth of 20 cms. from the wire base-line.

TABLE 24. Root Distribution Data for Rubber Tree X-3_r (Los Diamantes)
(Root weights in Hundredths of a Gram)

DEPTH LAYER (cm)	Distance from trunk (cm) 20	40	60	80	100	120	140	160	180	200	220	240	260	280	300	Total	P c
0-20	71	116	106	67	73	46	63	46	35	32	32	55	86	16	19	863	4
20-40	26	62	25	17	17	15	47	27	18	8	13	49	26	58	34	442	2
40-60	4	15	9	7	6	11	2	11	7	1	5	5	12	3	22	120	
60-80	2	3	7	2	4	3	7	11	3	2	1	12	3	13	4	77	
80-100	1	2	-	2	-	-	1	6	6	2	2	1	3	15	11	52	
100-120	1	6	11	1	2	2	4	1	3	8	1	3	1	4	18	66	
120-140	34	18	39	5	12	29	2	4	4	13	8	3	8	7	11	197	1
Total	139	222	197	101	114	106	126	106	76	66	68	128	139	116	119	1817	
Percent	7.7	12.2	10.8	5.6	6.3	5.8	6.9	5.8	4.2	3.6	3.4	7.1	7.7	6.4	6.6		

TABLE 25 Root Distribution Data for the Average of Rubber Trees X-1_r, X-2_r, & X-3_r. (Los Diamantes)(Root weight in Hundredths of a gram)

DEPTH LAYER (cm.)	Distance from trunk (cm) 20	40	60	80	100	120	140	160	180	200	220	240	260	280	300	Total	P c
0-20	109	155	65	57	47	32	36	32	24	27	49	47	32	19	9	740	4
20-40	42	44	24	25	20	14	24	21	11	11	20	24	20	26	26	352	2
40-60	26	8	13	14	5	10	12	11	8	6	8	5	7	9	15	157	
60-80	2	3	3	3	10	5	8	10	5	4	8	7	6	7	11	92	
80-100	5	6	3	2	1	7	8	8	6	4	3	4	7	7	12	83	
100-120	7	5	9	4	2	1	6	5	3	6	4	1	2	3	11	69	
120-140	18	11	31	5	10	14	3	11	3	9	12	3	5	9	8	152	
Total	209	232	148	110	95	83	97	98	60	67	104	91	79	80	92	1645	
Percent	12.7	14.1	9.0	6.7	5.8	5.1	5.9	6.0	3.6	4.1	6.3	5.5	4.8	4.9	5.5		

NOTE:

On the observation of Figs. 31 through 39:

Each figure comprises two graphs: one on photocopy negative paper, one one on transparent paper. Each white spot on the negative paper represents a concentration of 0.03 gm of coffee absorbing roots per liter of soil. The brown spots on the transparent paper represent rubber absorbing root concentrations of 0.03 gm per liter of soil in the same profile.

Each square represents a cube of soil 20 x 20 x 20 cm from which each liter of soil was extracted with the core borer. The letter R on the left hand side of the graph indicates the position of the rubber tree, and C the position of the coffee tree. The irregular dotted line shows the soil-line in each profile.

Thus, rubber feeder-root distribution in each profile can be observed on the transparent paper, and the coffee on the negative paper. In order to observe the distribution of both root systems in the same profile, superimpose the transparent paper on the negative paper, taking care that the squares and the soil-lines coincide.

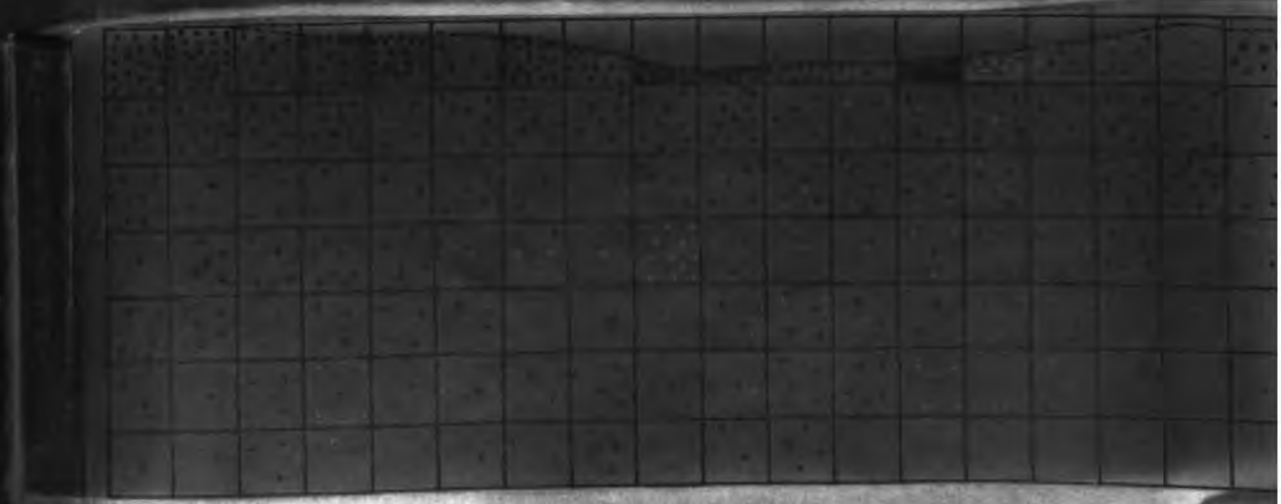

FIGURE 34 Absorbing root distribution of rubber tree 74r (transparent) and coffee tree 74c (negative) in profile 74 at La Hulera

FIGURE 35 Average absorbing root distribution of rubber trees 71r, 72r, 73r and 74r (transparent) and coffee trees 71c, 72c, 73c and 74c (negative) at La Hulera

FIGURE 36 Absorbing root distribution of rubber tree X1r (transparent) and coffee tree X1c (negative) in profile X1 at Los Diamantes

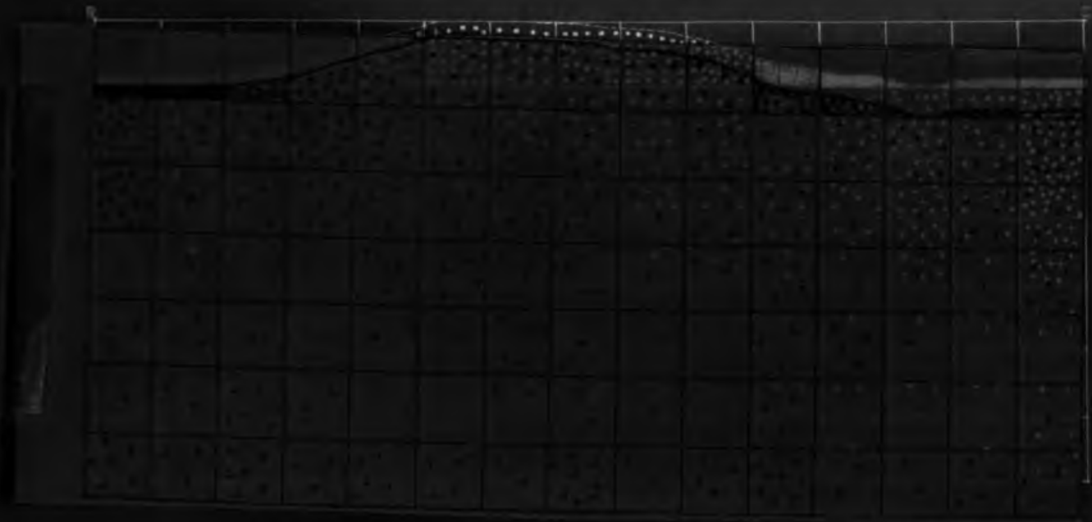

FIGURE 47 Absorbing root distribution of rubber tree [illegible]r (transparent) and coffee tree [illegible]c (negative) in profile [illegible] at Los Diamantes

FIGURE [illegible] Absorbing root distribution of rubber tree [illegible]r (transparent) and coffee tree [illegible]c (negative) in profile [illegible] at Los Diamantes

FIGURE [illegible] Average absorbing root distribution of rubber trees [illegible]r, [illegible]r, and [illegible]r (transparent) and coffee trees [illegible]c, [illegible]c and [illegible]c at Los Diamantes