SOME OBSERVATIONS ON PERMANENT MIXED CROPPING IN THE HUMID TROPICS

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REPRINT No. 149
Reprinted from *Turrialba*, volumen 11, No. 1, pgs. 26-33
Quarter January - March, 1961

INTERAMERICAN INSTITUTE OF AGRICULTURAL SCIENCES

Some observations on permanent mixed cropping in the humid tropics*

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COMPENDIO

Observaciones acerca de las diferencias en producción entre una plantación de caucho y otra de cultivo asociado de cacao y caucho sugieren que la razón de la superioridad del cultivo mixto (basada en los ingresos netos), puede deberse al hecho de que estimula una vegetación natural de climax de fisonomía de dos niveles, en la que los dos pisos se complementan. También hay evidencia de que este tipo de plantación asociada produce una cobertura del suelo que es muy similar a la del bosque climax. El autor.

Introduction

MIXED cropping, especially in tropical areas, has long been practiced in a very basic and primitive manner. The descriptions and drawings by Wagner (25) of the gardens of Nicoya, Costa Rica, indicate as many as fifteen to twenty different species of crop plants growing together. In certain areas of Latin America, beans are often seeded between the newly planted rows of sugar cane or coffee and are also sown in maize, just prior to the harvest of this crop. Maize itself is often planted between rows of young coffee and even on commercial coffee plantations one finds coffee shaded by various types of bananas, citrus, cacao and woodproducing shade trees. Only the latter example may be considered as a case of permanent mixed planting while the others are usually thought of as temporary.

Probably one of the most important reasons for mixed plantings is the "not all of the eggs in one basket" idea. Another theory, however, which has been advocated (14) is that it is ecologically sound to have more than one species growing in an area where, in nature, pure stands are almost never found. In tropical and sub-tropical forest areas, one to as many as five stories are encountered in the climax vegetation depending on climatic and edaphic conditions. When altering such sites from virgin conditions to permanent plantation-type plantings, should this same characteristic be copied? In this article, a review of the scant literature on this subject, together with some observations on a permanent planting of cacao *(Theobroma cacao)* and rubber *(Hevea brasiliensis)*, are presented in an attempt to throw more light on this matter.

Literature

In 1944, Hacquart (12) advocated the permanent mixed planting of *T. cacao* and Hevea rubber, the rubber to be planted in rows which would facilitate harvest and provide shade for the cacao plants which, in turn, would help to utilize the land more completely. In addition, it was suggested that, with this type of planting, there would be more rapid decomposition of the forest débris as well as a more complete ground cover.

Morales et al (18) recommended, in 1949, interplanting rubber with a number of different crops including corn *(Zea mays)* and yuca *(Manihot utilissima)* as a means of inducing farmers in Latin America to plant rubber on their farms. Results showed that, when rubber was interplanted with temporary cash crops, extra returns provided a source of income which assisted materially in the care of the rubber trees, and that these trees came into production sooner.

In 1952, Imle et al (11) indicated the advantage of planting perennial crops (tree crops) in high rainfall areas including "(a) their greater permanence and consequent stabilizing effect on the local population, (b) greater conservation of the soil resources and (c) less

* Received for publication on September 30, 1960.
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risk because tree crops normally can withstand extended periods of adverse weather that may be disastrous for annual crops". They suggested several planting systems for Hevea rubber and coffee *(Coffea canephora)* and rubber and cacao in which the rubber was to be planted in hedge lines. Further advantages claimed for this system were that the rubber would be easier to tap in hedge rows, and that there would be no more labor required for a mixed planting system of two hectares than for one hectare of rubber and one hectare of the other crop. In addition, they assumed a theoretical gain could be calculated by adding together the percentage above 50 of a full stand of each crop.

Allen (1,2) pointed out a number of advantages as well as disadvantages of cultivating other crops with rubber and indicated that the most promising intercrops on suitable soils are Liberian coffee *(C. liberica)*, cacao, Manila hemp *(Musa textilis)*, bananas *(Musa spp.)*, pineapples and gambier *(Uncaria gambier)*. He further stated that farming practices can be recommended only when they have been thoroughly tested by field experiments and when the results have been checked by cost trials, but at the time of the writing of his articles, the Department of Agriculture of Malaya did not have any definite information on this matter.

Murray (19, 20), reporting in 1955 on certain cacao shade experiments carried out in Trinidad, concluded that shade requirements for cacao tend to increase as conditions become less favorable, since shade acts as a buffer against these conditions. He further stated that, where soils are very fertile, shade is not only unnecessary but would tend to reduce yields.

In 1957, Poncin (22) wrote "it is clearly a logical idea to use crop-bearing trees for shading cocoa. Nevertheless, we are against it. In most cases it becomes necessary to sacrifice one crop or the other, to thin out and disfigure the taller trees at the very moment they begin to bear fruit, or else to be content with abnormally small cocoa harvests caused by over-shading. Nevertheless, we have some cocoa growing under Hevea rubber trees. This arrangment is, therefore, posible, but these stands, continually threatened by *Fomes*, yield only about half the general average, mainly because it is difficult to control the shade. However, we regard Hevea as a useful tree at Lukolela (Congo) because it is the only crop plant we know which will grow normally above poor stands of cocoa which we are reluctant to abandon".

Cramer (7) reported that it was a common practice in Indonesia to have mixed planting of rubber and coffee. Actually, the area of combined planting in coffee and rubber in Indonesia in 1935 was nearly a fourth of the total area planted with coffee. By 1939, this figure had dropped to about 16 percent. One of the reasons suggested for this drop was that mixed cropping with rubber was considered a good practice up to the time of tapping but that, as soon as the trees were brought into tap, it was recommended that all other vegetation be eliminated to provide better microclimatic conditions especially in the vicinity of the tapping panels, particularly from the standpoint of phytosanitation. (17)

Stadelman and Lescano (24) are altogether opposed to the idea of mixed plantings of rubber with cacao or coffee, although they do mention that the practice of mixed cultivation with annuals may be carried out during the establishment phase of the rubber providing that these crops are fertilized enough so as not to impede the growth of the rubber. According to these authors, coffee and cacao can produce nothing but trouble for the rubber and, if they are to be planted, should be planted in an area completely apart from the rubber.

Observations on a planned permanent mixed planting

One of the few planned permanent mixed cropping experiments with tree crops in the tropics was originally conceived by E. P. Imle while Director of the USDA Cooperative Rubber Research Program at the "La Hulera" Station in Turrialba, Costa Rica. Its establishment and subsequent development have been described in the Reports of the Cooperative Rubber Program (6), as well as by Imle et al (10) and Erickson (9).

Although this test was designed to compare rubber-cacao and rubber-coffee plantings with rubber-planted alone, observations will be limited primarily to the rubber-cacao and the rubber-alone sections, as these are the only ones with production data for both crops.

A brief resumé of the climatic and edaphic characteristics of the area indicates that the mean annual rainfall is 2639.3 mm. (103.9 inches) and the average annual temperature is 23.0° C (73.5° F). Elevation is 610 meters (200 feet) above sea level at 9°56' N and 83°38' W. The soil is alluvial, the area planted being an old river terrace that is quite level, and is classed as a silt loam with a scattering of small alluvial rocks and stones occurring throughout the profile.

The rubber-cacao planting has an area of 1.9 acres and was originally established in 1950 with 272 three component rubber trees and 441 cacao trees with the rubber planted at 6' x 10' x 90' in two row lanes, 145 trees per acre (358 trees per hectare) or 70 percent of the usual stand and the cacao planted 10' x 10' with a 15' alley each side of the rubber rows. There were 305 cacao plants per acre (753 per hectare) or 70 percent of the usual stand at this density. A diagram of this plan is given below as Figure 1.

The rubber-alone (control area) was planted in an area of 1.54 acres. The original planting had 320 rubber trees planted at 10' x 21' at a density of 207 trees per acre (511 trees per hectare). Only one half of this area, however, was planted to trees with the same *Hevea benthamiana* hybrid tops as those planted in the rubber-cacao section. For the purposes of this paper, yields from this section only are included and have been adjusted to the same area as the rubber-cacao planting.

The composition of the cacao plants was made up of a mixture of rooted cuttings of four different clones

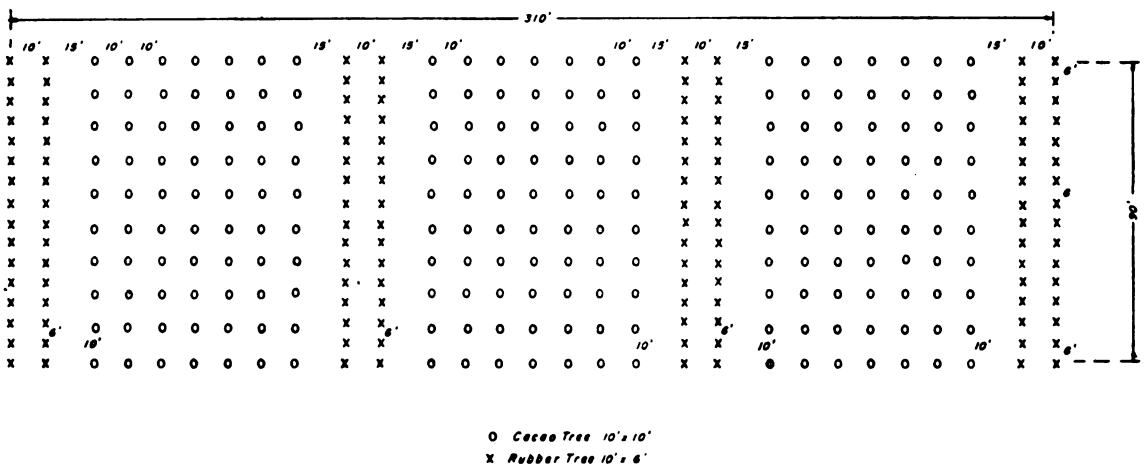

Fig. 1- Cacao-Rubber Planting - "La Hulera", Turrialba.

(UFC° 668, UFC° 613, UFC° 650 and UFC° 667); open pollinated seedlings of these same clones plus two other (UFC° 676 and UFC° 654) and check plants of unselected Matina seedlings. The seedling cacao plants were transplanted from the nursery to the field when they were 4 - 6 months old. Approximately 8 - 10 months had elapsed between the time of placing the cuttings in the propagator and establishing the rooted plants in the field.

In both the rubber-cacao as well as the rubber-alone section, the Hevea varieties were three-component trees formed by budding the following four high yielding eastern clones as panels on unselected rootstock (GV-31, GV-37, GA-1126, and GA-1581) and then following this with a bud at two meters of the following South American Leaf Blight (SALB) resistant *H. benthamiana* hybrids, as tops (FX-546, FX-561, FX-575, FX-590, FX-614, FX-636, FX-652, FX-662). These trees had all been a year and a half to two years in the nursery, undergoing the two budding operations, before planting in the test.

The cacao trees began to bear fruit in the third year and complete yield data per tree per month since that time is available at the InterAmerican Cacao Center at Turrialba, Costa Rica. Test tapping was begun on the rubber in 1955 but, owing to a number of administrative changes at the "La Hulera" Station, no complete yield records of rubber are available, due in part to interruptions in the tapping, until the rubber was again brought into tap in October of 1958. Since that time, individual tree records have been made each month.

Data for both cacao and rubber production is given in the Tables below. In Table 1, net returns from rubber trees in both the rubber-cacao as well as the rubber-alone plots have been tabulated. In Table 2, this same information is given with regard to cacao production. In Table 3, the two different plots are compared with respect to the net return from the rubber-cacao block and the rubber-alone block.

It should be mentioned in passing that, in the rubber—coffee section, the coffee production has been excellent since the first crop and that apparently there have been no detrimental effects from planting the two together. This work has been reported on by a number of authors. (6, 10, 16).

As described by Erickson (9) in 1956, there still seems to be no evident competition between the cacao and the rubber in the cacao-rubber planting. Although both crops are subject to attack by *Phytophthora palmivora* Butl., according to Orellana (21) different strains of this disease attack the different plants and thus neither crop is a source of infection for the other.

In addition to the differences in production, one of the outstanding contrasts between the rubber-alone plot and the rubber-cacao plot is the condition of the ground cover. The area between the rubber trees in the rubber-alone plot is filled with many light species of plants including a grass locally known as gamalote *(Paspalum fasciculatum)*, a number of different species of Araceae and some Heliconia species mainly *Heliconia acuminata*. This growth requires mowing or cutting about two or three times a year and more often close to the rubber trees themselves. Figures 2 and 3 show this ground cover which is not at all typical of the local climax forest vegetation.

Figure 2.—*Ground cover under the Hevea rubber planted at 10' x 21'. This had been completely mowed two months prior to the date of the picture.*

Figure 3.—*Another aspect of the ground cover under the rubber. Ferns,* Heliconia *species, grasses and other light-loving plants can be seen in abundance.*

Table 1.—Returns on rubber harvested - La Hulera

(Adjusted to 1.9 acres)

Date			Number of Trees Tapped	Dry Rubber Pounds	Price in US$ (New York)	Value	Cost of Production	Net Return
Nov.	58	A*	188	91.5	32.0c/	$ 29.28	$ 12.50	$ 16.78
		B*	303	170.5	32.0	54.57	20.20	34.37
Dec.	58	A	184	77.53	30.5	23.65	12.25	11.40
		B	308	148.4	30.5	45.26	20.55	24.71
Jan.	59	A	184	88.75	30.2	26.80	12.25	14.55
		B	306	166.0	30.2	50.14	20.40	29.74
Feb.	59	A	182	74.15	30.2	22.40	12.15	10.25
		B	298	140.1	30.2	42.32	19.90	22.42
Mar.	59	A	183	90.85	31.0	28.16	12.20	15.96
		B	311	180.8	31.0	56.06	20.75	35.31
Apr.	59	A	181	100.04	34.0	34.01	12.05	21.96
		B	311	196.7	34.0	66.86	20.75	46.11
May	59	A	181	91.95	36.5	33.56	12.05	21.51
		B	308	181.2	36.5	66.14	20.55	45.59
June	59	A	181	84.51	34.5	29.15	12.05	17.10
		B	306	158.2	34.5	54.58	20.40	34.18
July	59	A	181	84.84	34.8	29.52	12.05	17.47
		B	291	159.4	34.8	55.47	19.40	36.07
Aug.	59	A	180	91.06	39.0	35.51	12.00	23.51
		B	286	159.8	39.0	62.32	19.05	43.27
Sept.	59	A	179	76.24	40.5	30.88	11.95	18.93
		B	269	166.1	40.5	67.27	17.95	49.32
Oct.	59	A	172	86.74	41.0	35.56	11.40	24.16
		B	259	152.3	41.0	62.44	17.25	45.19
Nov.	59	A	170	72.47	45.2	32.76	11.30	21.46
		B	244	120.9	45.2	54.65	16.25	38.40
Dec.	59	A	174	78.93	41.5	32.76	11.60	21.16
		B	254	121.4	41.5	50.38	16.95	33.43

* A = Rubber in the rubber-cacao planting.
B = Rubber in the rubber-alone planting.

Table 2.—Returns on cacao harvested - La Hulera.

Month	Total Pods	Pounds	Price - N. Y. Spot Bahia	Value	Cost of Production	Net Return
Nov. 58	990	84.20	43.6c/	$ 36.71	$ 10.50	$ 26.21
Dec. 58	430	38.62	39.4	15.22	10.50	4.72
Jan. 59	923	88.52	35.5	31.42	10.50	20.92
Feb. 59	729	62.33	34.7	21.63	10.50	11.13
Mar. 59	387	36.25	38.1	13.81	10.50	3.31
Apr. 59	676	59.35	38.1	22.61	10.50	12.11
May 59	545	68.87	37.4	25.75	10.50	15.25
June 59	752	86.51	36.1	31.23	10.50	20.73
July 59	1310	150.61	34.6	52.11	10.50	41.61
Aug. 59	1873	255.11	36.0	91.84	10.50	81.34
Sept. 59	1566	199.01	34.9	69.45	10.50	58.95
Oct. 59	1640	187.20	34.2	64.02	10.50	53.52
Nov. 59	1395	157.03	33.9	53.23	10.50	42.73
Dec. 59	1247	136.90	30.9	42.30	10.50	31.80

Table 3.—Comparison of net returns of rubber alone block and rubber-cacao block.

Month	Net return of rubber from Rubber block (1.9 acres adjusted)	Net return of rubber & Cacao from mixed block (1.9 acres)	Net return of rubber & Cacao over Rubber alone
Nov. 58	$ 34.37	$ 42.99	8.62
Dec. 58	24.71	16.12	— 8.59
Jan. 59	29.74	35.47	5.73
Feb. 59	22.42	21.38	— 1.04
Mar. 59	35.31	19.27	— 16.04
Apr. 59	46.11	34.07	— 12.04
May 59	45.59	36.76	— 8.83
June 59	34.18	37.83	3.65
July 59	36.07	59.08	23.01
Aug. 59	43.27	104.85	61.58
Sept. 59	49.32	77.88	28.56
Oct. 59	45.19	77.68	32.49
Nov. 59	38.40	63.89	25.49
Dec. 59	33.43	52.96	19.53
TOTAL 14 Months	$ 518.11	$ 680.23	$ 162.12
TOTAL 1959	$ 459.03	$ 621.12	$ 162.09

The area in the rubber-cacao planting is practically free from undergrowth. A thin cover of *Pseudechinolaena polystachya* (H. B. K) Stapf. is to be found between the twin rows of rubber trees but, under the cacao trees, the cover consists almost exclusively of dead leaves and twigs with an occasional rubber seedling or a palm seedling, established by birds, growing here and there. This lack of undergrowth is due primarily to the dense shade of the cacao which limits the growth of grass and gives the appearance of the floor of the virgin forest of this particular ecological zone. Figures 4 and 5 taken of the rubber-cacao area, show this condition. The soil here is completely covered with decaying leaves, making an excellent duff. Young feeder roots of the cacao are found here in abundance.

Figure 4.—*This picture shows the rubber-cacao section of the planting. There is almost a complete absense of undergrowth and the soil surface is covered with leaves.*

Discussion

It was indeed unfortunate that cacao-alone and coffee-alone plantings were never established, and that the data for the coffee-rubber block is not complete. One of the reasons why there is so much disagreement between technicians as to mixed plantings is the fact that there are not sufficient experimental plots from which definite evidence may be obtained.

From the data presented it can be seen that the rubber-alone planting is only about 75 percent as efficient as the rubber-cacao planting in terms of net return. However, this figure becomes even more impressive when considering the fact that during the period when data was taken, the price for cacao dropped from a high of 43.6 cts. to a low of 30.9 cts. while rubber prices were rising from a low 30 cent level to a low 40 cent level. Still, we are unable to draw any conclusions in regard to the influence of the cacao in this mixed planting owing to the lack of a cacao-alone planting. It is also difficult to conjecture as to whether the reason for the superiority of the mixed planting is the fact that it is mixed. It is suggested that a mixed planting where there is no competition for light or space (both above as well as below ground) may be a perfectly satisfactory scheme while one in which the species are competitive, such as discussed by Budowski (5), may eventually only contain one species. Beard (4) and Richards (23), describing Beard's classification of Tropical American vegetation-types, set out many diagrams which indicate the storied effect of the climax forest. According to this system, Turrialba would be lower montane rain forest and would be composed of four strata or layers: 1) isolated emergents of 120 feet or more; 2) relatively continuous high layer of 90 - 120 feet (Rubber?); 3) low trees of 20 - 50 feet (cacao?) and 4) underbrush up to 10 feet. Ashton (3) concludes from his work in Brazil that the density of the low tree story is the predominant controller of light intensity. Does not the rubber-cacao planting meet these descriptions of this type of climax forest? Holdridge (15) has pointed out that this may be the case and that perhaps a plant such as "raicilla" (*Cephaelis ipecacuanha)* might well make up the underbrush story in a permanent mixed planting since it requires a high degree of shade for best production.

If the hypothesis is correct, how can it be rationalized with the observations of Murray (19, 20)

Figure 5.—*A closer view of the ground cover under the cacao. The two plants which are growing out of the cacao leaves are growing out of the cacao leaves are African Oil Palm seedlings, seeds of which were brought in by birds.*

and others (8) that for best production on good soils cacao does not need shade? The shade may not be so important for the cacao but rather for the soil, as Holdridge has indicated (14), and that, especially from the standpoint of the rubber, the cacao is aiding its growth in that the cacao is shading the soil and providing a good supply of leaf litter. This supply of organic matter to the soil surface is vital to continuous production and maximum deposition of this leaf litter depends upon maximum utilization of the aereal space.

Hardy (13) stresses the fact that there must be "root room" for all of the plants growing in any particular soil. A certain number of rubber trees or a certain

number of cacao trees could presumably fill up the available "root room" of any soil, but it might also be the case that, just as there is a storied effect above ground, there might also be a storied effect below ground, and that the roots of these plants could complement each other for utilization of the space available.

Although it could be assumed from the data presented that a planting of this mixed type is not only practical but also the best use of the land, a great many questions, hinted at above, must still be answered, for example, what is the root picture?, how many trees and how many species do best together?, and how should the spacing be established?, should management change as the planting matures?, and so on.

It is undoubtly difficult to make a general statement on mixed cropping that would cover a range of different soil and climatic situations but there are indications that this is good land use from an ecological standpoint and it is strongly recommended that more of this type of work be done on as complete and as exact a basis as possible so that this information may one day be available.

Summary

Observations on differences in production between a planting of rubber and a mixed planting of cacao and rubber suggest that the reason for the superiority of the mixed planting (based on net returns) might be due to the fact that it simulates the natural climax vegetation having a two story physiognomy with both of the stories complementing each other. Indications are also evident that this type of planting produces a ground cover that is quite similar to that of the climax forest.

It was recommended that more work in this particular field be carried out in order that more definite information be available.

Literature cited

1. ALLEN, E. F. Cultivating other crops with rubber. Planters' Bulletin of the Rubber Research Institute of Malaya. New Series No. 16. 1955. pp. 10-21.

2. ————Mixed farming and intercropping. Planters' Bulletin of the Rubber Research Institute of Malaya. New Series No. 17. 1955. pp. 38-41.

3. ASHTON, P. S. Light intensity measurements in rain forest near Santarem, Brazil. Journal of Ecology 46(1):65-70. 1958.

4. BEARD, J. S. The classification of tropical American vegetation types. Ecology 36(1):89-100. 1955.

5. BUDOWSKI, GERARDO. Sistemas de regeneración de los bosques de bajura en la América tropical. The Caribbean Forester 17(3-4). 1956. (English translation in same issue).

6. COOPERATIVE RUBBER PROGRAM OF THE U.S.D.A. Turrialba Reports, May through December 1952. Mimeographed Official Report.

7. CRAMER, P. J. S. A review of literature of coffee research in Indonesia. Turrialba, Costa Rica. Inter-American Institute of Agricultural Sciences. Miscellaneous Publication No. 15. 1957. 262 p.

8. DE VERTEUIL, L. L. Further observations on a trial of trees as shade for cacao. Tropical Agriculture (Trinidad) 32(3):241-243. 1955.

9. ERICKSON, ARNOLD L. Comparison of yields - cuttings versus seedlings from selected clones. *In* Conferencia Interamericana de Cacao. 6a. Salvador, Bahía, Brasil, 1956. Bahía, Brasil. Instituto de Cacau da Bahia. 1957. pp. 185-191.

10. IMLE, E. P., ERICKSON, A. L. & OECHSLI, L. P. Performance of clonal cuttings and clonal seedlings of cacao interplanted with rubber. *In* Conferencia Interamericana de Cacao. 5ª. Turrialba, Costa Rica. Trabajos presentados. Turrialba, Costa Rica. Instituto Interamericano de Ciencias Agrícolas. 1954. Vol. I. Doc. 25. 11 p. Abstract in Cacao (Turrialba, Costa Rica) 3(4). 1954.

11. ————MANIS, W. E., CAMACHO, EDILBERTO & HITTLE, C. N. Permanent mixed crops for the Atlantic Zone of Costa Rica. *In* Turrialba Reports of the USDA Cooperative Rubber Program, May through December 1952.

12. HACQUART, A. Project de culture mixte cacaoyers-hevea. *In:* Ringoet, A. Note sur la Culture du Cacaoyer et son avenir au Congo Belge. Institut National por L'Etude Agronomique du Congo Belge. Publications Serie Technique No. 28. 1944.

13. HARDY, FREDERICK (ed.) Cacao Manual. (English ed.). Turrialba, Costa Rica. Inter-American Institute of Agricultural Sciences. 1960. 395 p.

14. HOLDRIDGE, L. R. Arboles de sombra para el cacao. *En* Manual del Curso de Cacao, Edición Provisional. Turrialba, Costa Rica. Instituto Interamericano de Ciencias Agrícolas. 1957. pp. 113-117.

15. ————Ecological indications of the need for a new approach to tropical land use. Economic Botany 13(4):271-280. 1959.

16. LEON, JORGE & UMAÑA, RODRIGO. Rendimiento de café en setos comparado con siembra a distancia corriente. Turrialba (Costa Rica) 9(2):43-50. 1959.

17. MEIJER, W. H. Personal Communication, c/o Pirelli S/A Belém, Pará, Brasil.

18. MORALES, JULIO O., BANGHAM, WALTER N. & BARRUS, MORTIER F. Cultivos intercalados en plantaciones de Hevea. (Turrialba, Costa Rica) Instituto Interamericano de Ciencias Agrícolas. Boletín Técnico No. 1. 1949. 26 p.

19. MURRAY, D. B. Climatic requirements of cocoa with particular reference to shade. *In* Cocoa, Chocolate and Confectionery Alliance, Ltd. Report of the Cocoa Conference, 1955. London. 1955. pp. 66-70.

20. ————The use of shade for cacao. *In* Conferencia Interamericana de Cacao. 6a. Salvador, Bahia, Brasil, 1956. Bahia, Brasil. Instituto de Cacau da Bahia. 1957. pp. 111-116.

21. ORELLANA, R. G. Variation in *Phytophthora palmivora* Butl. Isolated from cacao and Hevea rubber. Phytopathology 44(9):481-512. 1954. (abst.).

22. PONCIN, L. The use of shade at Lukolela plantations. *In* Cocoa Chocolate and Confectionery Alliance, Ltd. Report of the Cocoa Conference, 1957. London. 1958. pp. 281-288.

23. RICHARDS, P. W. The tropical rain forest. Cambridge University Press. 1952. 450 p.

24. STADLEMAN, RAYMOND & LESCANO A., MANUEL. Manual del plantator de Jebe. Tingo María, Perú. Estación Experimental Agrícola. 1959. 139 p. (mimeogr.).

25. WAGNER, PHILIP L. Nicoya - A cultural geography. Berkeley, California. University of California Press. 1959. 250 p.

ERRATA: Figures # 3 and # 4 transposed.

Elevation on page 27 should read 610 meters (2,000 feet).