PLANT INTERACTIONS IN A MIXED CROP COMMUNITY OF ARECANUT (*Areca catechu* L.) AND CACAO (*Theobroma cacao* L.)

By

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Certificate

I hereby certify that this thesis entitled "Plant interactions in a mixed crop community of arecanut (*Areca catechu* L.) and cacao (*Theobroma cacao* L.)" embodies the results of bonafide research work done by Sri Khandige Shama Bhat, for the degree of Doctor of Philosophy of the University of Mysore, under my guidance and direct supervision. I, further, certify that this thesis or part thereof has not previously been formed the basis for the award of any degree, diploma, associateship, fellowship or other similar award.

Kodangallu)
Moodabidri)

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DECLARATION

I do hereby declare that the thesis entitled "Plant interactions in a mixed crop community of arecanut (*Areca catechu* L.) and cacao (*Theobroma cacao* L.)" is the result of the work carried out by me at the Central Plantation Crops Research Institute, Regional Station, Vittal, under the guidance of Dr. J.V. Bhat, D.Sc., F.A.Sc., F.N.I. Further, I declare that this work has not formed the basis of the award of any Degree or Fellowship previously.

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C O N T E N T S

I. GENERAL INTRODUCTION

GENERAL INTRODUCTION

Arecanut

The arecanut palm (*Areca catechu* Linn) is one of the graceful and elegant trees of the East. It is grown mostly for its seed commonly referred to as betelnut which is a popular masticatory of both great antiquity and among all Asiatic races and is best known as *guvaka*, *puga kramuka* (Sanskrit) and as *fufal* (Arab). Blatter (1926), quoting Watt (1889) stated that arecanut "is symbolical of festivity; it is accordingly a fit offering for the gods, and is an essential at the betrothal ceremony. From the most ancient times the presentation of pan has been a polite termination of ceremonial visits, hence the expression *biradana* — the dismissal. The well known vernacular names for the nut are: *supari*, *guagaya*, *kasaile*, *sari*, *tambul*, *gha*, *kamuka*, *adika*, *kunsi*, etc.".

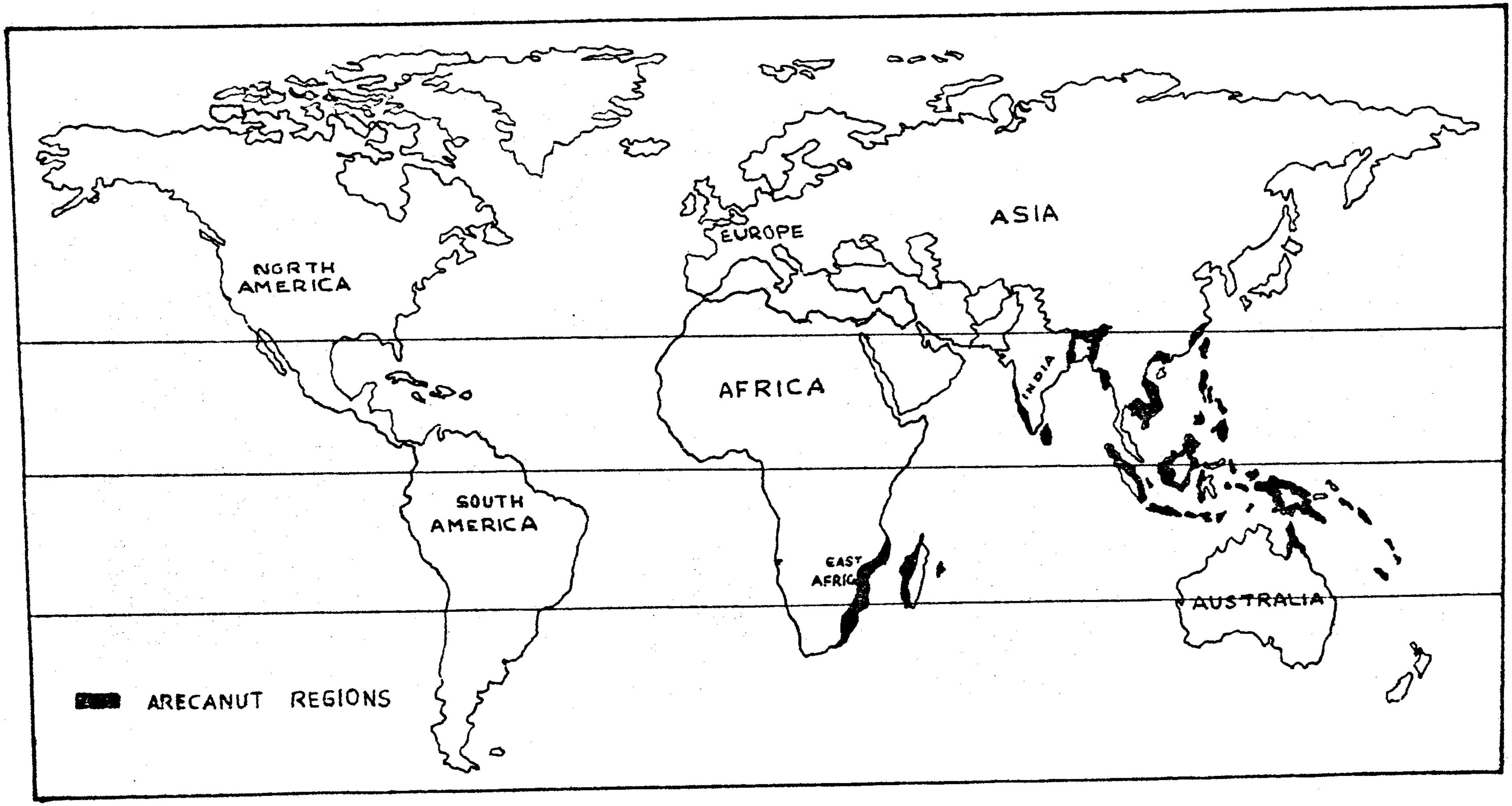
Kitaka and Johnson (1975) have stated that the arecanut palm is not well known in Europe or in America, though it ranks as one of the world's most important cultivated palm. This they attribute to the common use of chewing gum or tobacco in Europe and the Americans rather than to chewing betel which is the analogous practice in the Indo-Malaysian region.

Arecanut palm is essentially of the tropics and has a fairly wide geographical distribution from East Africa to the Pacific Islands (Kitzke and Johnson, 1975). However, it is found in significant numbers in only south and south-east Asia comprising of India, Bangla Desh, Sri Lanka, Malaysia, Indonesia and the Philippines (Fig. 1).

In India the use of arecanut and its cultivation constitute a distinct agricultural practice scarcely less important than that of other economic crops. Watt (1908) referring to the cultivation and marketing of arecanut in India, wrote "In Eastern and North Bengal and Assam, its cultivation has assumed still greater dimensions and that regular plantations of 5 to 20 or even 100 acres occur. Its cultivation has proved to be of the greatest value from the commercial and industrial stand point. The magnitude and importance of India's production of betelnuts may be judged not only by the extent of coastal trade but also by the annual consumption of betelnuts in India itself". He further stated "From the published reports of foreign imports and Indian production, it would seem safe to affirm that the annual consumption of betelnuts in India itself cannot be far short of a valuation of Rs.225 lakhs (22.5 millions) or £ 1,500,000."

The position of arecanut industry in the country is quite different than what it was in 1908. The partition of

FIG .1. ARECANUT REGIONS IN WORLD



the Indian subcontinent in 1947 into India and Pakistan had great impact on the arecanut industry. India lost nearly 50 per cent of the total area under arecanut to East Pakistan (now Bangla Desh) not to emphasise that even prior to the partition, India was importing arecanuts to meet its internal demand. Naturally the situation worsened after the separation and the country began regularly to import large quantities of arecanuts from other producing countries like Sri Lanka, Malaysia, etc. In fact, the annual import of arecanut was as high as 50,600 tonnes, valued at Rs.55.7 millions in 1951-52. Since then, India has taken up steps to encourage production of arecanuts in the country. The Government of India not only fixed quantitative and monetary ceilings on the volume of imports but also levied a duty on all arecanuts imported into India. Efforts were also made, simultaneously to increase production within the country. The above measures resulted in the increase of arecanut production progressively (Table 1) and as a result, the imports got gradually reduced. The imports in 1967-68 were a mere 136 tonnes and almost nil thereafter words (Table 2). Arecanut has not much importance in the export market. Only small quantities are being exported to Singapore, East Africa, Saudi Arabia, United Kingdom, Nepal, etc. There has been slight increase in the export since 1973-74 (Table 3).

Since the arecanut palm is not given the same importance as other plantation crops like rubber, tea, coffee, etc., in

Table 1. Area, production and productivity of arecanut in India

Year	Area ('000 ha.)	Production ('000 tonnes)	Average yield (kg/ha)
1961 – 62	116.83	95.17	815
1962 – 63	118.28	99.00	837
1963 – 64	123.13	98.46	800
1964 – 65	125.93	107.51	854
1965 – 66	138.10	119.90	866
1966 – 67	142.10	130.10	916
1967 – 68	147.40	135.40	918
1968 – 69	157.00	139.70	890
1969 – 70	160.70	137.70	857
1970 – 71	167.30	141.00	843
1971 – 72	173.80	147.10	846
1972 – 73	178.20	147.70	829
1973– 74	184.50	167.40	907
1974 – 75	189.20	164.70	871
1975 – 76	177.50	160.00	901
1976 – 77	170.70	165.10	967
1977 – 78	170.80	175.20	1026
1978 – 79	179.20	181.90	1015
1979 – 80	183.30	189.50	1034
1980 – 81	184.50	191.40	1037

(Source: Velappan and George, 1982)

Table 2. Import of arecanut

Year	Quantity imported in tonnes	Value in million rupees
1951 - 52	50600	55.73
1956 - 57	39903	54.46
1961 - 62	10041	4.53
1966 - 67	897	0.38
1967 - 68	136	0.11
1968 - 69	-	-
1969 - 70	-	-
1970 - 71	-	-
1971 - 72	90	0.007
1972 - 73	16	0.002

(Source: Velappan and Paulose, 1974)

Table 3. Export of arecanut

Year	Quantity exported in tonnes	Value in million rupees
1957 – 58	199	0.9
1959 – 60	200	1.2
1964 – 65	210	1.4
1966 – 67	210	1.5
1970 – 71	220	2.0
1975 – 76	560	6.6
1977 – 78	520	6.8
1978 – 79	580	7.9

(Source: Anon. 1980)

most other parts of the world, data on its cultivation, area and production are either not available or scanty. According to the available statistics, India is the largest arecanut producing country in the world (Table 4).

Watt (1889) had recorded that the arecanut palm "does not grow at any distance from the sea and will not succeed above 3000 feet (915 m) in altitude. It flourishes, however, in the dry plateau of Mysore, Kanara (both now in Karnataka state)". Blatter (1926) wrote that "the betel nut palm is cultivated exclusively within the moist tropical tracts that fringe the coast of India and practically within a belt of land that within a few exceptions, does not extend inland for more than 200 miles (320 km). It rarely ascends to altitudes of 3000 feet (915 m) and gradually disappears, even from the littoral area, as localities are entered where the duration of the dry hot months equals or exceeds the monsoons". It is interesting to note the present area of cultivation of the arecanut palm almost conforms to the above observations of Watt and Blatter, except that due to intensification of its cultivation, the crop has in recent years been extended to areas (mostly in peninsular India) where summers are hot, dry and rainless, and this has been made possible by frequent irrigations. Though experimental data are not available, it is known from experience that the arecanut palm thrives well within a temperature range of 14°C and 36°C though it is grown in areas where the

Table 4. World area and production of arecanut

Country	Area (ha)	Production (tonnes)
India	184500	191400
Bangladesh	79521	57056*
Sri Lanka	19650	56670*
Malaysia	4132	12000 (estimate)

(*Source: Krishnappa, 1973)

temperature ranges from a minimum of 4°C to a maximum of about 40°C (Bhat and Khader, 1982). Because of its susceptibility to lower temperatures, the palm also does not come up well at altitudes above 1000 meters of sea level. Smith (1958), while describing the cold tolerance of the cultivated palms, reported that in Florida due to a light frost on December 2, 1957, followed by hard freezes on December 12 and 13, when minimum of 20°F (-6.5°C) and 27°F (-2.8°C) were recorded, the foliage of arecanut palm were destroyed and even death occurred to one palm.

Notwithstanding the above limitations arecanut palm is cultivated in India in a wide range of weather conditions (Table 5), covering the states of Kerala, Karnataka, Assam, Meghalaya, Tamil Nadu, West Bengal, Maharashtra, Goa, Andhra Pradesh and Tripura (Fig. 3).

The arecanut palm comes up well in a variety of soils provided water and nutrients are available in adequate quantities and drainage is good. They grow well in laterite loamy and alluvial soils with pH ranging from 3.5 to 8.0.

Cacao ✓

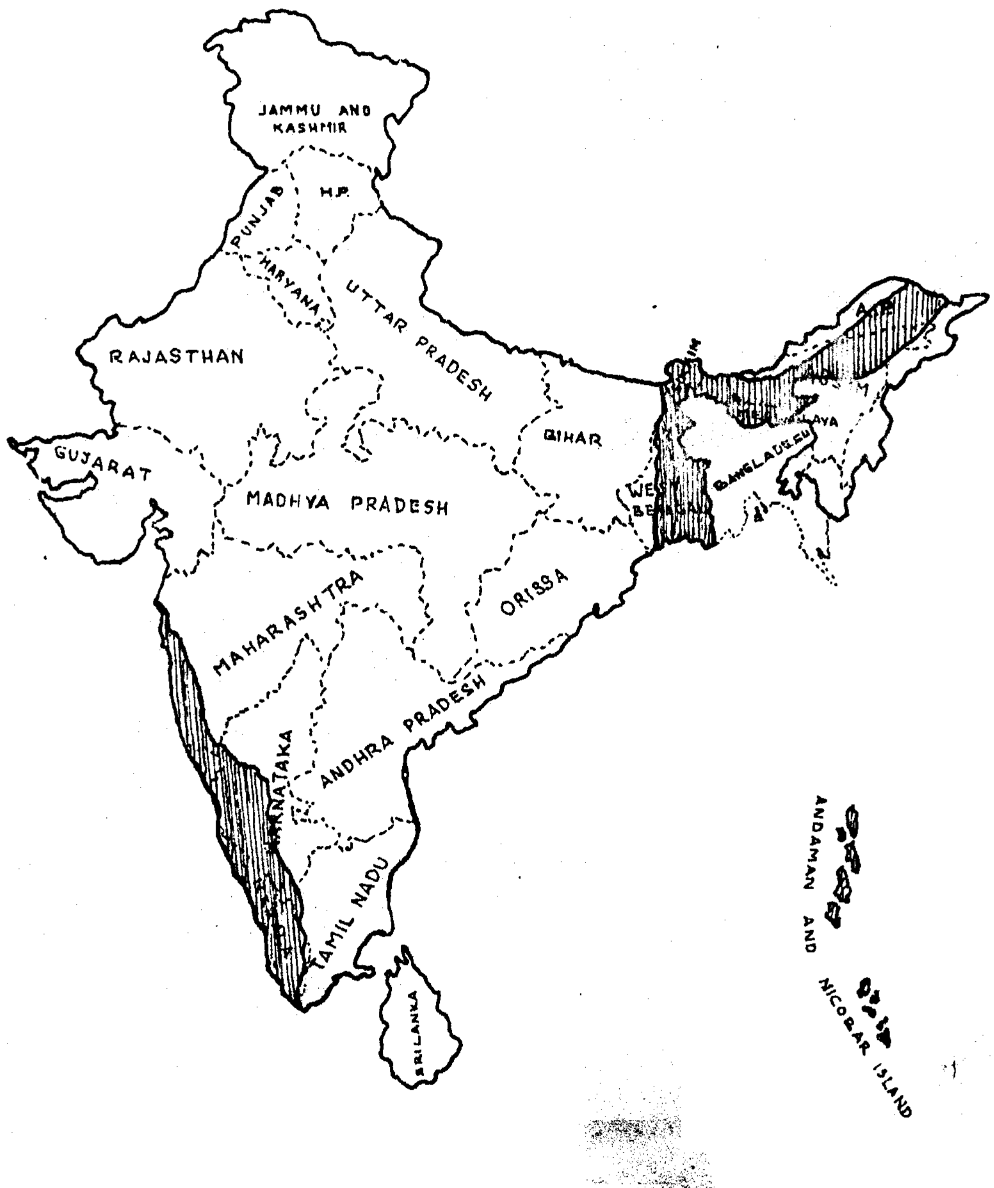
The name, *Theobroma cacao* (L.) of the tree known in Mexico as *[illegible]* or *[illegible]* was coined by Linnaeus in 1720/ quoted by Chatt (1953). Chatt (1953) wrote that "the choice of *Theobroma*

Table 5. Climatic data of important arecanut producing centres

Location	Altitude m (above MSL)	Lati-tude	Longi-tude	Rainfall: Monthly average mm	Rainfall: No. of rainy days	Sunshine hr/day (average)	Temperature (°C) (1981 - absolute): Maximum Highest	Maximum Lowest	Minimum Highest	Minimum Lowest
Vittal (Karnataka)	200	12° 75'N	75° 25'E	3180.9	129.4	7.2	39.0	25.5	28.0	18.5
Hirehalli (Karnataka)	845	13° 50'N	77° 70'E	976.5	74.6	7.4	36.0	19.5	25.0	10.5
Peechi (Kerala)	50	10° 30'N	76° 10'E	2548.4	126.2	8.0	37.8	25.5	27.0	16.2
Palode (Kerala)	225	8° 42'N	77° 20'E	4299.2	146.0	*	37.0	24.0	26.5	15.0
Mohitnagar (West Bengal)	5	26° 31'N	88° 43'E	2924.6	98.6	*	39.9	22.0	26.7	6.7
Kahikuchi (Assam)	48	26° 11'N	91° 47'E	1307.1	77.2	*	36.4	23.3	29.8	4.5

*Not available

FIG.2. ARECANUT REGIONS IN INDIA



(Greek for food of gods) was a graceful compliment to the mythology of the Aztecs, who firmly believed in the divine origin of the seed. According to their tradition, it was a gift from the gods in Paradise, transported to them by Quetzalcoatl, the God of Air". The history of cacao begins in Central America with the Maya Indians, who were the first known people to have realised the valuable qualities of the bean. Cacao was not only appreciated by the natives as a highly nourishing drink, but the beans were also used as a substitute for money for the purchase of slaves and other luxuries. "By all accounts, cacao cultivation by the Indians, notably the Aztecs of Mexico and the Mayas in Central America, was well established long before the New World was discovered" (Chatt, 1953).

Before further proceeding with the subject it is necessary to make a distinction between cacao and cocoa. Chatt (1953) observed that "although no precise convention is followed in the literature in English, there is a tendency to use the adjective cacao when writing about the crop and raw materials prepared from it and to restrict the word cocoa for the description of the finished product". Later Arc and Gwynne-Jones (1974) preferred to limit the use of the word cacao to name the plant and cocoa for the crop or fruit and the manufactured product. Some other writers, Urquhart (1961), Thorold (1975) and Wood (1975) used the word cocoa for both the plant and the product. In this thesis, the words cacao and cocoa are adopted following the convention suggested by Chatt (1953).

The Spaniards were the first to import cacao into Europe and were also the pioneers who introduced it as a plantation crop to many countries of the America. From the sixteenth century onwards cacao was planted in most of the tropical regions of Central and South America as well as on many of the Caribbean Islands. This plantation industry was further developed by the Portuguese, Dutch, British and French and later on by the liberated slaves. In the seventeenth century it was spread over to the islands Gulf of Guinea, America, South East Asia, and in nineteenth century it was introduced to the South Pacific Islands of Samoa and New Guinea (Urquhart, 1961). Laryea (1974), in his foreword to the book entitled "Cacao in West Africa" authored by Are and Gwynne-Jones (1974) stated that cacao is often described as the 'Golden Tree' and is more than gold to many countries, especially those in West Africa, because of its contributions to their economic development.

Into India cacao is believed to have been introduced more than 200 years ago. According to Watt (1893), cacao was being grown to a limited extent in the 19th century by the Roman Catholic missionaries in Malabar. Ratnam (1961), a horticulturist working in the Madras (now Tamil Nadu) Agriculture Department, studied the old correspondence of the East India Company. He found that eight cacao (criollo) seedlings were first introduced in 1798 from the Amboyna Islands of East Indies by the East India Company into the valleys of Courtallam in Madras Presidency (now mostly comprised of Tamil Nadu) during the time of James Mouro, then collector of Tirunelvelli district. These were grown along with similar other introduced plants in specially maintained gardens. By 1819, 67 young plants had been raised from the seeds produced on these plants. Later in 1842, the Board of Revenue introduced cacao seedlings to Kolli hills of Salem and later into Nilgiris. In 1873 the Government of India obtained 50 seedlings of Pentagonas (possibly Theobroma pentagona) from Guatemala, but there was no further mention about the fate of these seedlings (Ratnam, 1961). According to various other accounts also, small introductions of cacao appear to have been made periodically from Ceylon (now Sri Lanka) and Malaya (now Malaysia) and grown mainly in botanic gardens and government farms.

America grew most of the cacao the world required till the beginning of the present century and thus chanced to be the top producer of the commodity. The lead was however gradually taken over by West Africa which has since then attained its predominant position and maintained it for the past four decades. In recent years, the growth of world cacao bean production has been rather small when seen in the light of the rapid expansion which took place in the late 1950's and early 1960's when the production jumped (rose) by almost 50 per cent. In Africa, the output expanded sharply as a result of new planting and intensive cultivation practices. The rate of increase of world production of cacao from the period 1957-59 to 1962-64 was 6.4 per cent per annum, during the period from 1962-64 to 1969-71 the rate of increase was only 2.1 per cent (Anon. 1972). The output has once again expanded considerably in recent years in Oceania (Papua and New Guinea) and in Asia (Malaysia). Cacao production in different regions of the world is given in Table 6.

Cacao has a multitude of uses, the main one being as powdered cacao a flavour component for beverages and confections and an essential ingredient in the various forms of chocolate, besides in the preparation of candies, cakes, and similar sweets. Cacao now ranks as the third most popular of the major non-alcoholic beverages on a world wide scale and next only to tea and coffee, but is at the same time, even better known for its other uses. Cocoa butter another product of the fruit, is used in the manufacture of cosmetics and pharmaceutical preparations.

Table 6. Production of cacao beans (World) - (1980-81)
(in '000 tonnes)

Region and country	1980-81	Region and country	1980-81
North America		Africa	
Costa Rica	7.8	Angola	0.2
Cuba	2.[illegible]	Cameroon	118.0
Dominican Republic	33.0	Comoro Islands	0.1
Grenada	2.0	Congo	2.5
Guatemala	3.5	Equatorial Guinea	8.0
Haiti	2.5	Gabon	3.5
Honduras	0.3	Ghana	258.0
Jamaica	1.5	Ivory Coast	412.0
Mexico	32.0	Liberia	5.0
Nicaragua	0.4	Madagascar	1.8
Panama	1.0	Nigeria	159.0
Trinidad and Tobago	3.0	Sao Tome and Principe	7.0
Other	0.4	Sierra Leone	9.0
Total	89.4	Tanzania	0.7
		Togo	15.0
		Uganda	0.1
		Zaire	4.0
South America		Total	1005.2
Bolivia	3.0		
Brazil	357.0	Asia and Oceania	
Colombia	36.0	Fiji Islands	0.2
Ecuador	84.0	India	2.0
Peru	9.0	Indonesia	7.0
Surinam	0.1	Malaysia	47.0
Venezuela	13.5	Papua New Guinea	28.0
Total	502.6	Philippines	5.0
		Solomon Islands	0.2
		Sri Lanka	1.9
		Vanuatu	0.8
		Western Samoa	1.5
		Total	91.1

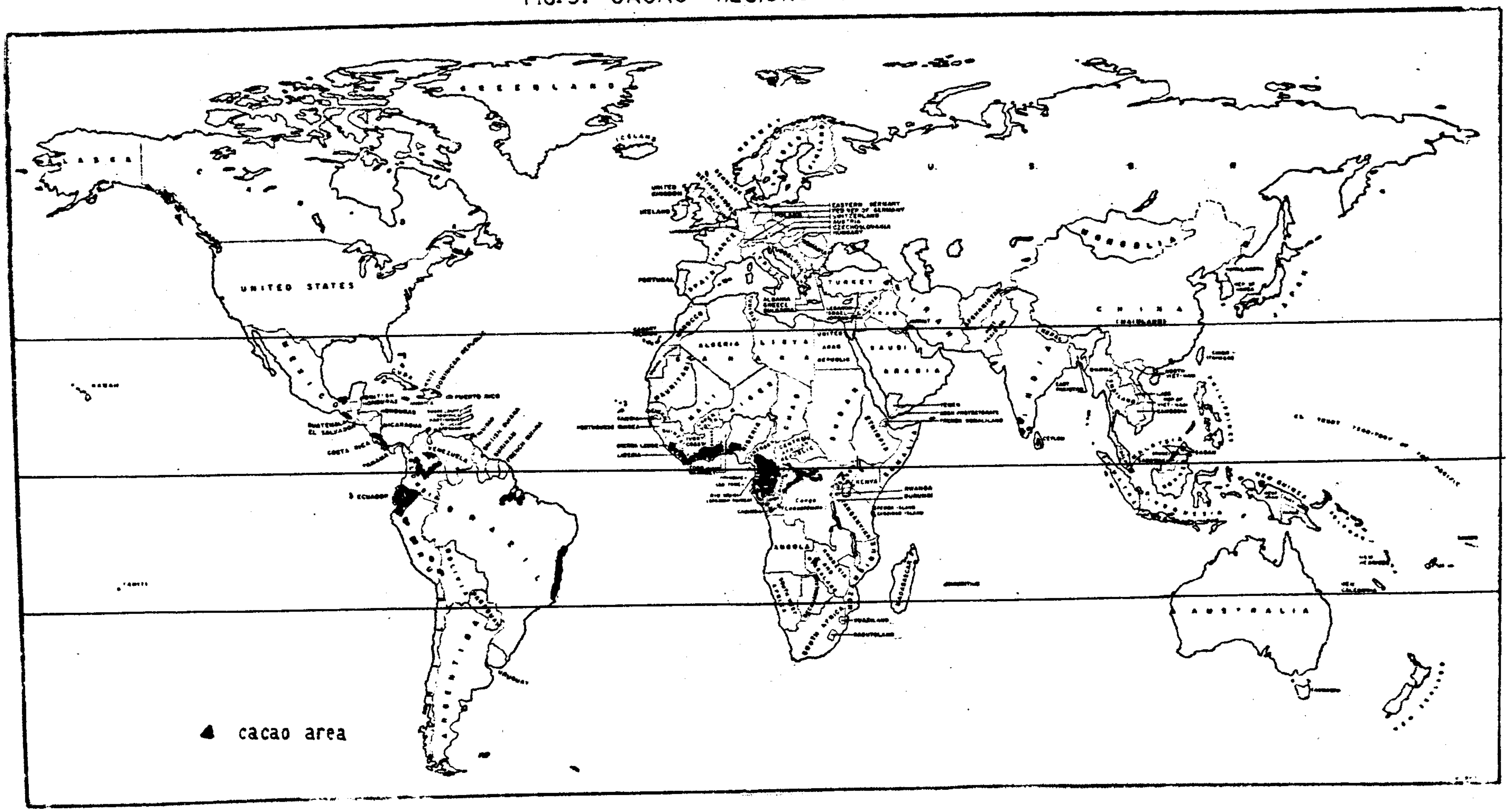
Grand Total: 1689.1

Source: Foreign Agriculture Circular, FCB 1-82, USDA, 1982.

Cacao is cultivated in the tropical lowlands (Fig. 3). Though the crop flourishes between the latitudes 20°N and 20°S, the main production areas are situated within a belt extending 10° north and south of equator. Cacao is grown from sea level up to an elevation of around 500 m. It thrives best in the lower altitudes below 200 m to 300 m, though it is grown successfully in sheltered valleys at altitudes up to 1000 m, an altitude where it is reported that the lower temperature may be the chief limiting factor (Urquhart, 1961). Urquhart (1961) stated that the minimum rainfall required by cacao in the absence of irrigation is dependent on the distribution of rainfall and the type of soil and its capacity to hold moisture. A mean minimum of 90 to 100 mm per month with an annual precipitation of at least 1500 to 2000 mm is deemed necessary unless supplementary irrigation can be provided during dry periods. The microclimate around the cacao plants is considered of considerable significance in its growth and yield of fruits.

Cacao has an optimum growth temperature of 25.5°C within a range of 15.0° to 30.5°C (Wrigley, 1971). Erneholm (1948), as cited by Urquhart, in his study of limitations imposed on cacao growing in South America concluded that cultivation of cacao on commercial scale is limited to those areas where the minimum daily temperature does not fall below 10°C (50°F) and the annual mean

FIG. 3. CACAO REGIONS IN WORLD



temperature is not less than 21°C (70°F). According to Adams and McKelvie, quoted by Wrigley (1971), cacao in Ghana grows under conditions where the diurnal variation range, 35°C (95°F)—13°C (55°F), is wide but when the weekly mean of maximum temperature falls below 28.3°C (83°F), flushing gets suppressed. When the mean daily temperature falls below 29.4°C (85°F), it appears to be followed two months later, by a reduced number of flowers.

Chatt (1953) stated that cacao soils should be relatively high in their colloid content. Their nutrient status, accordingly depends on the depth of organic layer and the chemical composition of soil organic matter is influenced by the composition of the parent rock on account of the transfer of nutrients through the soil by the growing plant. Acidity is said to be indicative of nutrient deficiency. Also, in soils having an acid layer below the humus, root distribution is restricted. Solid rock should not be less than 150 cm (five feet) below the surface of the soil so as to allow ample space for root development. Urquhart (1961) stated that cacao requires a soil which can be easily penetrated by its roots, is retentive of moisture during the dry season and permits the circulation of air and moisture. A great proportion of the cacao of the world is grown on structured clay-loams, loams and sandy loams.

The cacao soils in West Africa have a reaction of pH 5.5 and upwards, the most fertile of them being of the range of 6.5 to 7.0. Acid soils of pH 4.5 or below, are usually low in nutrients and hence unsuitable. Cacao can be grown on soils up to pH 8.5, but such alkaline soils are sometimes associated with an excess of calcium components, which may give rise to chlorosis in the leaf of cacao tree. Are and Gwynne-Jones (1974) have stressed the importance of soil depth up to three meters for the proper development of cacao roots. According to them an 'ideal' cacao soil is one which has a pore space of 60-70 per cent of total volume.

Cacao, whose natural environment is the lower storeys of the forest, usually welcomes shade at planting out and not infrequently the mature crop is grown under shade. Wrigley (1971) stated that investigations started at the Imperial College in Trinidad in 1950 on the effect of shade and fertiliser showed that young cacao grow best with 50 per cent direct sunlight. As the trees came into bearing there was no further response to fertiliser in the shade plots whereas with increasing light intensity the yield increased logarithmically up to 75 per cent of full sunlight provided no other factors remained limiting.

The argument, as to whether the crop should be grown with or without shade, is really of a fundamental importance in tropical agriculture as on it depends the balance between carbohydrate nutrition and mineral nutrition. The effect of the shade is to reduce the production of carbohydrates by photosynthesis. If one wishes to keep a cacao tree alive under favourable soil conditions, lower the photosynthesis rate, longer it will remain alive. Conversely, in areas of high light intensity with no shade, the tree will have to take up minerals at increased levels to balance the accumulating products of photosynthesis which otherwise are toxic. This implies, both an adequate supply of mineral nutrients and a permeable soil which does not become waterlogged in the wet season and allows the roots to forage. For instance, in the volcanic islands of the Pacific and Grenada, provided adequate minerals are available, cacao produces its maximum yield in full sunlight. In Trinidad, on the other hand, the cacao tree cannot cope with more than 75 per cent sunlight (Urquhart, 1961).

Cacao - Prospects, development and research in India :

Though cacao was introduced into India some 200 years ago, no serious attempt had been made to establish it as an agricultural plantation crop in the country unlike coffee or tea. After India attained independence in 1947, the Union Government began to feel that this potentiality should be explored and if possible exploited at least to make India self-sufficient in its requirements of cacao.

Accordingly, it requested Mr. D.H. Urquhart, an authority on cacao, to visit India and submit a report on the prospects for growing cacao in India. In his report, Urquhart (1959), reported that India offered considerable scope for cacao cultivation in several parts of South and East India. He felt that the best growth of cacao in India would be obtained in the irrigated alluvial soils, particularly the Tamil Nadu, Kerala, Andhra Pradesh and Tripura. He opined that suitable conditions would be found between the coastal zone and the foot hills up to 1000-1300 m elevations above MSL on the east and west coasts of Peninsular India. He recommended the growing of basic types, particularly Amelonado and Upper Amazon. He found that the growth and stand of most of early plantings were good and concluded that cacao could come up well in several parts of India.

Slowly, the cultivation of cacao began to pick up. In 1960, the area under cacao in India was estimated to be about 80 ha (Rao, 1962). The variety recommended at that time was almost wholly Criollo, but the general demand by the manufacturers within India was for the 'basic' or Forastero types. The import of raw cacao beans, which was limited at around 4000 tonnes annually from an earlier 2000 tonnes, was not adequate to meet even the internal demand.

In 1962, Narasinga Rao, a scientist-administrator of the Indian Council of Agricultural Research, New Delhi made another review of the prospects of cacao cultivation in India. Since almost the entire area of cacao was under Criollo, he made the plea to grow Criollo cacao only, and exclusively for export. He had reasons to believe that India then was the only "repository" of pure Criollo in the world and contended that "it needs particular emphasis that from all the evidences on hand, and with the unbiased views elicited by enquiries, it may be safely asserted that its performance in India compares very well with the basic Forastero types grown elsewhere and from purely the growers' point of view, it may be taken with confidence that it is an excellent type to grow, all other factors being equal". He then went on to discuss about the superior performance and wider performance for Forastero elsewhere in the world and proposed that until a firm decision was taken about the choice of a suitable variety for India based on field trials, no further expansion of area under cacao might be taken up.

Sri Ram (1964, 1965) an Indian Council of Agricultural Research scientist made a further review of the situation in India. He opined that selected areas in Kerala, Tamil Nadu, Karnataka, Andhra Pradesh, Goa and Andaman and Nicobar Islands, Maharashtra, Orissa and Madhya Pradesh would be suitable regions for cacao cultivation (approximately up to the 20th parallel north). He recommended the cultivation of the basic types, particularly the Amazons and their hybrids.

In the meanwhile, during the III Plan (1962-1967) of the Government of India, a scheme to develop cacao cultivation in the three southern states of Kerala, Tamil Nadu, and Karnataka was approved for execution. Under this programme, it was also proposed to introduce exotic planting material of the Forastero or 'basic' type into the country (Rao, 1962). However, to obviate the risk of a mix up between the bulk (Forastero) and fine (Criollo) varieties, it was proposed that Criollo would be grown in the southern States of Tamil Nadu, Kerala, Karnataka and Maharashtra, where it was already established, and Forastero in the eastern States of Orissa, Assam and Tripura.

By the end of the sixties, the superior attribution of Forastero became apparent in the southern states also. It was at this time a decision was taken to replant the entire area with this variety. As a result, during 1967-1973, India imported through the courtesy of M/s. Cadbury Fry India Ltd., about 7300 kg seeds from Malaysia. These seeds were distributed to various State agencies for raising seedlings and distributing them to the planters.

From 1974, the import of seeds for large scale distribution came to a halt. Subsequent distribution of seedlings has been carried out by using seeds collected from within the country only. The States of Kerala and Karnataka have maintained nurseries for this variety since 1964 and over 2.5 million seedlings had been estimated to have been distributed up to 1979 by the State Departments of Agriculture and Horticulture (of Kerala and Karnataka). Approximately, a like number of seedlings was likely to have been distributed by private agencies and nursery men as well.

In 1975, the Indian Council of Agricultural Research, has constituted a technical group consisting of scientists, development workers, processors and selected farmers' representatives to discuss in detail the research and developmental programmes on cacao in the country. The group met in May 1975 and earmarked an area of about 6800 ha of land as suitable for planting cacao in the states of Kerala, Karnataka, Tamil Nadu and Maharashtra. The group also suggested the establishment of two seed gardens. It identified research problems like (1) standardisation of manuring, cultural, spacing and pruning techniques, (2) breeding for high yield and drought tolerance, (3) identification and control measures for pests and diseases, (4) development of the technique for fermentation of small batches of cacao beans, and (5) standardisation of quality parameters, substitution of cacao fat (instead of other edible fats hitherto being used) in bakery products.

In 1979, the Government of India convened another group meeting of the representatives of cacao processors, growers, development agencies and representatives of State Governments and National Institutions engaged in cacao research and development to consider various issues relating to research, development, marketing and processing of cacao in the country. The following salient decisions were taken in the meeting: (1) the area under cacao in India was estimated at around 13,200 ha and the production of cacao beans by 1990 was estimated to reach around 20,000 tonnes; (2) the likely requirement of the existing industrial units being around 4,000 tonnes, steps should be taken for exporting the surplus, and (3) agricultural research should be intensified for standardising the agro-techniques and control of pests and diseases.

However, research on cacao can be stated to have commenced in India much earlier, in fact in 1956. The first work related to the development of vegetative propagation techniques developed during 1956-1961 at the Fruit Research Station, Kallar, Tamil Nadu (Kailasam et al., 1964).

The Central Plantation Crops Research Institute (CPCRI) Kasaragod was identified by the Indian Council of Agricultural Research (ICAR) in 1970 as the main centre in India for research on cacao (with the bulk of the load to be carried out in its Regional Station at Vittal, South Kanara district, Karnataka). The first planting of cacao was made in 1964 at Vittal as a mixed crop with arecanut (<u>Areca catechu</u> L.) palm which was the principal crop at this Research Station and for which reason for long the Station was known for. Earlier, Urquhart (1959), while discussing the potentialities for planting cacao in India, supported the suggestion of Fazlulah Khan an ICAR Scientist-administrator, that cacao could perhaps be with advantage interplanted in arecanut gardens. Urquhart had proposed intercropping cacao in coconut gardens also. Two more agronomic field experiments to study the cultural requirements of the crop have been initiated at different centres under the CPCRI (Bhat, 1979(b)). Besides the agronomic experiments, research on the genetics and breeding, and pests and diseases of cacao crop have been initiated at CPCRI. Other universities and institutes have also in recent years taken up research on the improvement of the crop (Bhat and Nagar, 1979 unpublished).

Multiple cropping

Multiple cropping, relay cropping, overlap cropping, intercropping, multistoreyed cropping, mixed cropping, etc., are some of the terms that are being frequently used by the agricultural and horticultural scientists in recent years. All these terms, though convey different meanings, in reality they all mean an intensive land use whereby two, three or even more crops are either simultaneously or successively raised over an area of land in a year. These systems are aimed at increasing production per unit area and per unit time and incidentally provide additional work to the agricultural labour. Aiyer (1949) defined the term mixed cropping as the system of growing two or more crops (or varieties) in the same field, garden or plantation, not in separate blocks each carrying a single crop but all of them mixed together and occupying jointly the same ground and sharing in common the cultural operations of the field as though the latter were intended for one single crop, and sown or planted either promiscuously in the midst of each other or systematically in alternating rows or otherwise.

According to Andrews and Kassam (1976), multiple cropping is intensification of cropping in time and space dimensions, growing two or more crops on the same field in a year. They recognised eight major multiple cropping patterns which are based on two underlying principles, viz., intercropping, meaning growing crops simultaneously in mixtures and sequential cropping, i.e., growing individual crops in sequence. They grouped mixed, row strip and relay intercropping on the principle of intercropping and double (and triple, etc.) and ratoon cropping on the latter principle of sequential cropping. Several other forms of multiple cropping patterns are derived through the synthesis of the simultaneous and sequential cropping systems. Trenbath (1976) preferred to use the term, mixed crop community for the system of intercropping where the components of the mixtures are usually different crop species (or varieties) and are sometimes of different age-classes of the same genotype. According to Nelliat and Iyer (1977) the term intercropping as applied to plantation crops refers to growing annuals or biennials in the interspaces of the main crop. The term mixed cropping as related to plantation crops is confined to growing perennial crops in the interspaces of other perennial crops. Willey (1981) preferred to cover under the term intercropping any system where there is a significant amount of intercrop competition. As is the convention with the workers of Central Plantation Crops Research Institute, Kasaragod (India), the term mixed cropping is retained in this treatise since the components involved in the study are two perennial crops. The general term multiple cropping is used when a distinction is not desired between intercropping (with annuals or biennials) and mixed cropping.

Scope and importance of multiple cropping

As Dr. Rehm, Director, Institute of Tropical and Sub-tropical Crop Science, University of Gottingen has remarked in his foreword to Dr. Nair's (1979) book (Intensive Multiple Cropping with Coconuts in India), "Multiple cropping with trees as the dominant component is one of the safest and the most variable and adaptive systems of land use allowing permanent and remunerative cultivation in humid tropical regions. It has a long tradition in South-East Asia, though only in recent years scientific investigations have been initiated on its ecological principles and ways of improving management and economic returns. The research on multiple cropping carried out at the Central Plantation Crops Research Institute at Kasaragod, Kerala, is an outstanding example of these endeavours". "No time should, therefore, be lost in developing highly productive systems of agricultural and silvicultural land use fully adapted to precarious ecology of the humid tropics". Whereas Dr. Nair's book deals on the Principles, Programmes and Prospects with reference to multiple cropping of coconuts in relation to several other plants studied at CPCRI at Kasaragod, the work embodied in this thesis is the outcome of investigations carried out by the author, on another invaluable palm in fact a monopoly crop of the subcontinent the betel palm or the arecanut palm when it is cultured alone or in combination (as mixed crop) with another perennial in this instance an imported exotic tree, viz., the cacao tree, at the Vittal Regional Station of the same Institute.

Whereas during the centuries past, man continued to grow several types of grains, trees, and herbs, the restrictions imposed by the land on the one hand on the increase that has occurred among the animals - mostly the humans - on the other, man has been compelled to eliminate many plant species and restrict his choice to a few hundred of selected species of plants for his food and for other purposes, whilst so doing, man has however been careful enough to choose the right genetic types (though in the process he has lost for ever many others) as his sole objective has been to enhance crop production, adequate enough to feed himself and such of the animal species which he has chosen to be conducive to his welfare as he perceives at any time on the time scale of his life on this sphere he calls mother earth for it is the earth he realises that always feeds him.

Traditionally agricultural research since man embarked on a scientific approach to look into the principles involved and conducted his expeditions in its technology, has all along been, to say it in the most accepted sense, in two dimensions (1) increasing the cultivated area and (2) attempting to increase the yield per unit area. he has, during recent years barged on newer concepts, or increased the dimensions of his scope by adopting time and scale (as shall be explained at length later) in his outlook. It is this that has provided him with a new hope of continuing to live on this globe not withstanding the doubling of the population that occurred within a decade and the threat the population explosion poses during even the early years of the oncoming millienium. This hope lies in the promises the multiple cropping holds in the future agriculture still to explain in this direction.

Though nature marvels herself in multiple crops and the history of multiple cropping as an art is as old as farming of crops by mankind the science of multiple cropping gained popularity and its principles understood only during recent years. The widespread practice of it as of today, however, is mostly prevalent in areas of high rainfall in the tropics where both the moisture, light and temperatures are favourable for year round crop production and where otherwise labour has to idle for want of harvest throughout the seasons. The future of mankind perhaps lies on the principle of multiple cropping as the area for cultivation can never be commensurate with the increase occurring as apparent in population and this has indeed brought into clear focus the advantages this cropping system offers over the single (mono) cropping method practiced for centuries by man throughout the history.

One of the assured advantages of intercropping in contradiction to single cropping is the dependability of return to the cultivator not to mention the maximal utilization of the land resource of the small farmers, with all kinds of limitations in his resources. The actual manner in which such farming is resorted to and benefits it will confer upon the cultivator depends, undoubtedly on the location of the land, rainfall, the kind of soil, the demand for the produce, labour available, and a variety of other resources essential for achieving maximum profit within the limitations of his total environment and investment. Suffice it to say that where farming has become capital intensive the production is at high level even in the developing countries, leave alone the developed countries, wherein such farming have brought in heavy returns. No doubt this type of cropping has yet to yield profitable results in dry land areas with low production and limitation of other parameters essential for the increased output. In a country like India wherein 80 per cent live in the rural areas and have to depend upon the land for their survival and wherein the cropping practices have to produce not only more food but such of the small "luxuries as chewing" and provide occupation for the rural population, multiple cropping appears to be the answer and has to be perforce adopted for all practical purposes. Fortuitously also, the nature is by and large bounteous to the country in both the moisture and sunlight for such cropping, and hunger which often posed a threat to the teeming population, no longer keep the wolf at the door.

Multiple cropping with arecanut

The practice of multiple cropping in arecanut gardens has been in vogue even in early years (Watt, 1889, Blatter, 1926; Aiyer 1949; Nambiar, 1949). Watt (1893) reported that several fruit trees are interplanted with arecanut in Karnataka and coconut with arecanut in Kolaba. Aiyer(1949) reported the practice of planting several fruit trees like mango, jack, guava, orange and other citrus trees besides coconuts with arecanut trees in which "the gardens are fully shaded, the crowns of many trees mingle, others carry their canopies higher, resulting in two or more tiers at irregular heights". The system of planting many crops like cardamom, pepper, betelvine and banana in arecanut gardens of the malnads of Western Karnataka and the Konkan are "unique" and "perhaps the oldest and most clearly defined form of mixed cropping in respect of permanent crops" (Aiyer, 1949). Nambiar (1949) stated that the custom of growing other crops in arecanut gardens is fairly universal. Sevappa (1951) reported that several tuber and other fruit crops are raised in the arecanut gardens of Malabar (Kerala). Abraham (1956) mentioned the advantage of growing pepper using arecanut trees as standards.

But the objective of growing the secondary crops in arecanut gardens was not intensive cropping. The long pre-bearing (juvenile) age of 5 to 8 years, the low income in the early years of bearing, the fluctuation in the yield of the main crop due to pests and diseases (which had no proper control measures in those days) and seasonal conditions forced the planters to take up multiple cropping. They had no markets near about or were sometimes cut off from the marketting centres due to lack of communication or transport (as in the interior _malnad_ of Karnataka state). The farmers were therefore compelled to grow their day to day requirements, vegetables and fruits in the arecanut gardens. The crops chosen as inter or mixed crop also changed from tract to tract, though a crop like banana was observed to be more commonly employed. If growers at Sirsi (Karnataka) prefer cardamom and pepper as intercrops, the planters in some other parts select pepper and yam as best suited to that locality (Bhat, 1978).

Scientific investigations on the different aspects of multiple cropping in arecanut gardens were, however, commenced after the establishment of Central and Regional Arecanut Research Stations in India by the erstwhile Indian Central Arecanut Committee (Bhat, 1982) and later continued at the CPCRI at its Regional and Research Centres, and several publications have emanated from these sources (Abraham, 1974; Bhandary, 1974; Bhat, 1974, 1978b; Brahma, 1979; Khader and Antony, 1968; Muralidharan and Nayar, 1979; Nagaraj, 1974; Naidu, 1959; Nayar, 1982; Roy, 1974;

Sadanandan, 1974; Sannamarappa and Muralidharan, 1982).

Multiple cropping with cacao

In the traditional system cacao is grown in association with forest tree communities and these latter species serve as shade tree (Chatt, 1953; Murray and Nichols, 1966; Urquhart, 1961). An account on the suitability of a variety of shade plants has been given by Benstead (1951, 1953), De Verteuil (1955), Murray (1957) and Wood (1975). The use of economically important trees (other than forest trees) like coconut, oil palm and rubber for shading in Malaysia is reported by several workers (Chalmers, 1968; Blencowe, 1969; Blencowe and Hubbard, 1972; McCulloch, 1968; Tan Tai Kin, 1968). Urquhart (1961) reported that in Ceylon cacao has been planted among rubber and in Papua and New Guinea with coconut. Rodrigo and Mangobat (1964) reported the performance of cacao under coconuts in the Philippines. Cacao is also being tried under the mixed cropping system in India (Bhat and Bavappa, 1972; Nelliat et al. 1974; 1979; Nair, 1979; Nelliat, 1979) and the present area under the crop, largely as a mixed crop, is estimated at about 29,000 ha (Table 7).

Mixed cropping of arecanut and cacao

Mixed cropping of arecanut and cacao has been initiated in India at the Central Plantation Crops Research Institute,

Table 7. *Area under cacao in India

State	Area (ha)
Kerala	24,118
Karnataka	4,252
Tamil Nadu	600
Others	30
Total	29,000

*Estimated

(Bhat and Leela, 1968; Bhat and Bavappa, 1972; Bhat, 1978(a), 1978(b), 1979).

Cacao as a mixed crop in arecanut gardens has been thought of under certain special circumstances, apart from the usual advantageous of mixed cropping as pointed above. Firstly, the arecanut crop is susceptible to the disease 'Koleroga' or fruit-rot caused by Phytophthora arecae. In certain years (as happened in the late thirties and again in 1973 and 1978) when the conditions are favourable, the fungus indeed takes a heavy toll of the crop. Even the existing method of preventive spraying of Bordeaux mixture becomes almost impossible due to continuous and heavy rainfall during the monsoon. Secondly, the yellow leaf disease of arecanut, which remains today the most serious problem facing the arecanut growers, (whose etiology is not still clear) is prevalent in different intensities in several areas of Kerala and two or three pockets of Karnataka, the two important arecanut growing States of the Union. Besides declining yield, year after year, this is the principal cause of the slow death of palms in the infected areas. A third major factor is the likely over production of arecanuts in the country. The country has almost reached to self-sufficiency in arecanut, as stated earlier by end of 1969-70, and there was indication of fall in the prices of arecanut during the early seventies. There is also no great hope of improving the arecanut prices by way of export to the advanced countries in view of the difficulty in popularising its use as a chewing material. Burkill (1935) wrote that "Readers should remember that betel is the most complex of luxuries of its nature, requiring several ingredients, although sometimes, as in North China, the arecanut is chewed without its usual accompaniments; therefore the custom of chewing betel cannot easily be transplanted into a new country unless several materials can be assembled there. The result is that the habit has spread more slowly than, say, the habit of smoking tobacco, or drinking coffee". The above considerations together with the limited scope for planting cacao as a monocrop in the country has resulted in linking of cacao with arecanut palms as mixed crop in arecanut gardens.

Unlike the traditional inter or mixed cropping systems in arecanut gardens which have been evolved through trial and error and long experience by the farmers supported by recent research findings, the problem of mixed cropping arecanut with cacao requires greater care, caution and courage, in the absence of adequate knowledge. First of all, cacao is new to the country as an agricultural plantation crop and secondly in the mixed cropping systems of arecanut and cacao both the crops involved, it may be remembered, are of perennial nature. Mixed cropping systems, besides, are more complex than monocultures. "The display of phytoelements will vary both in space and time depending upon interspecific competition as well as interspecific competition" (Allen et al., 1976). Based on the net effect of interactions between species populations, Hart (1974) modified Odum's (1971) original concepts of interaction between two species population as follows: intra

<u>Commensalistic Polyculture</u>: The interaction between crop species has a positive net effect on one species and no observable effect on the other species.

<u>Amensalistic Polyculture</u>: The interaction between crops species has a negative net effect on one species and no observable effect on the other species.

<u>Monopolistic Polyculture</u>: The interaction between crop species has a positive net effect on one species and a negative effect on the other species.

<u>Inhibitory Polyculture</u>: The interaction between crop species has a net negative effect on all species.

Plant interactions have been referred to as 'interference effects' (Harper, 1961) or 'neighbour effects' (Trenbath and Harper, 1973).

Risser (1969), while discussing the relationships among herbaceous grassland plants, pointed out that adaptations which help plants to cope with the environmental complex in a competitive relationship are to be examined. Quoting

Daubenmire (1968) has enumerated a number of adaptations which under specific circumstances may prove to be significant in competition; (a) times of root penetration, (b) ability to obtain nutrients in short supply, (c) endurance in drought or soil of poor aeration, (d) longevity, (e) abundant seed production and efficient seed dissemination, (f) life-form (g) compensation point, (h) food reserves available to young plants, (i) time of initial growth, (j) rate of growth, (k) nutrient uptake ability, (l) vegetative reproduction, (m) genetic variability, (n) plasticity, (o) vigour and size of plant, and (p) reproductive potential.

Though all of the above characteristics may not operate in crops like arecanut and cacao, a few of them are certain to have influence in bringing about the interaction in the mixed cropping system involved in the two species. The present studies were therefore taken up to ascertain some of the factors involved in the competition and determine if possible their exact influence in the crop production.

II. MATERIALS AND METHODS

MATERIALS AND METHODS

All the investigations reported in this thesis were carried out at the experimental gardens attached to the Central Plantation Crops Research Institute (CPCRI), Regional Station, Vittal, Karnataka State, India. Vittal is 45 km south-east of Mangalore city on the west-coast of the country and is about 200 m above mean sea level. It lies on 12°15' north latitude and 75°25' east longitude. The Station has a farm covering an area of 69.0 ha. It receives on an average 3169 mm rainfall spread over a period of 129 rainy days (Table 5). Otherwise the area comes under the tropical sun, bright for the most part of the day. The average sunshine per day is 7.2 hours. The maximum temperature ranges from 25.5°C to 39.0°C and the minimum temperature from 18.5°C to 28.0°C. Greater part of the soil is typical laterite which has been classified as sandy clay loam with an average pH of 5.4 (Mohapatra, 1977). It is fairly deep and well drained.

For the purpose of field observations an experimental garden with a mixed crop of arecanut palms and cacao trees (Plate 1 planted in 1970 in a 6 x 2 x 4 confounded asymmetrical factorial design was utilised. The design of the experiment was originally finalised in consultation with the Deputy Statistical Adviser and Senior Professor of Statistics, Institute of Agricultural Research Statistics (ICAR), New

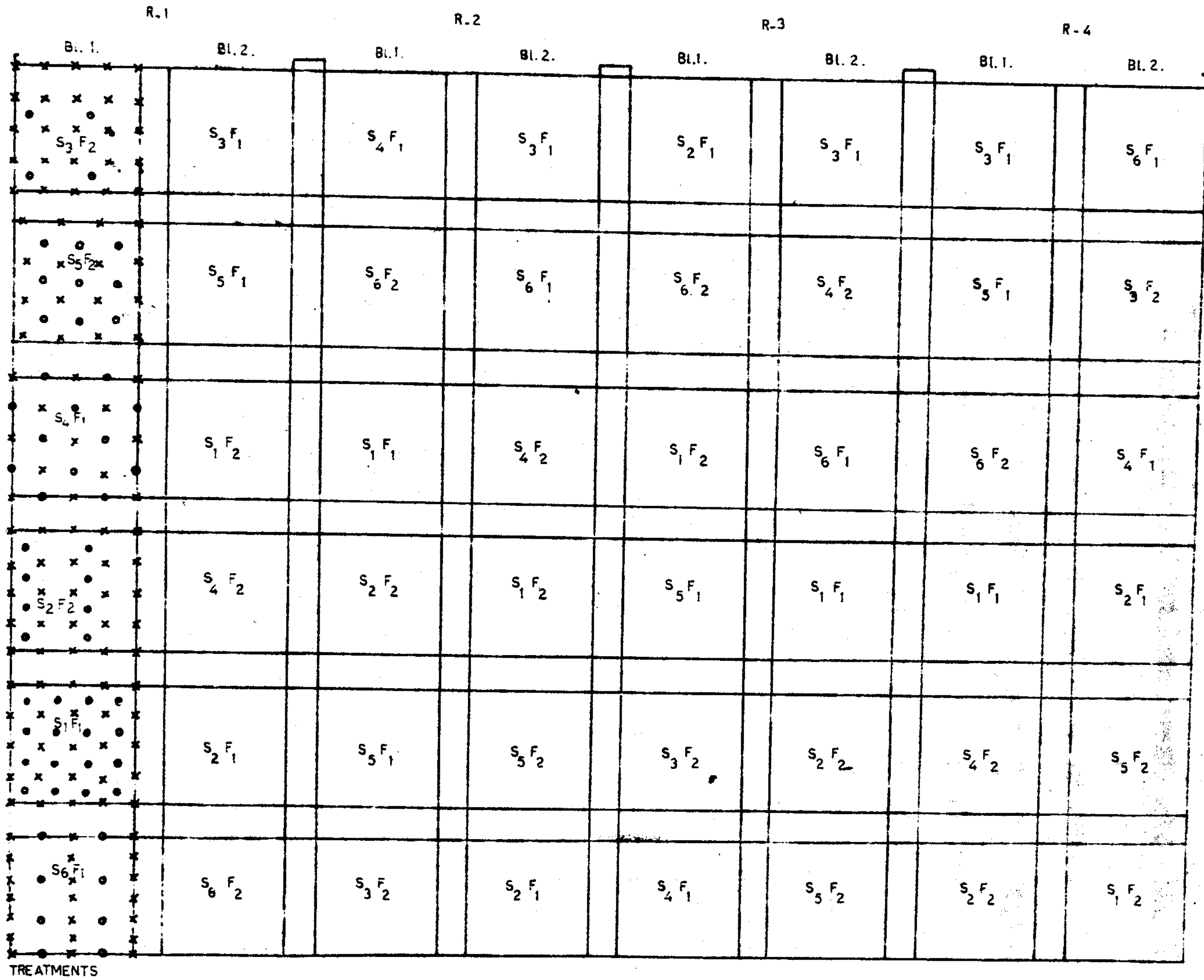
Plate 1. Experimental garden with mixed cropping of arecanut and cocoa

Plate 1

Delhi. The cacao consisted of Forastero variety introduced from Malaysia and arecanut of a well known local (South Kanara) variety. At the time of planting in the field in 1970, cacao seedlings were 12 months old and arecanut seedlings 18 months old. The experimental lay out had six different spacings (S) and two fertiliser (F) levels (Fig.4). The different spacings consisted of: (1) arecanut at 2.7m x 2.7m and cacao at 2.7m x 2.7m (2) arecanut at 2.7m x 2.7m and cacao at 2.7m x 5.4m (3) arecanut at 2.7m x 2.7m and cacao at 5.4m x 5.4m (4) both arecanut and cacao at 3.9m x 3.9m (5) both arecanut and cacao at 3.3m x 3.3m and (6) arecanut at 1.8m x 5.4m and cacao at 3.6m x 5.4m. The fertiliser levels were: (1) both arecanut and cacao fertilised at 100 g N, 40 g P_2O_5 and 140 g K_2O per tree per year and (2) arecanut at 100 g N, 40 g P_2O_5 and 140 g K_2O and cacao at 200 g N, 80 g P_2O_5 and 280 g K_2O per tree per year. During the first and second years only 1/3 and 2/3 of the above doses of fertilisers were applied and the full dose was commenced from the third year. The fertilisers used were urea, super phosphate and muriate of potash. In addition to the fertilisers, the arecanut palms were applied with green leaf manure and cattle manure each at 10 kg per palm per year. The fertilisers were applied in two split doses, once in September and for a second time in March each year.

Both cacao and arecanut seedlings after planting were provided with artificial shade with palm leaves during the

FIG. 4. MIXED CROPPING OF ARECANUT AND CACAO
LAYOUT OF THE DESIGN (6×2×4) CONFOUNDED ASYMMETRICAL FACTORIAL



TREATMENTS	SPACING (m) FOR × ARECANUT	○ CACAO
S_1	2·7 × 2·7	2·7 × 2·7
S_2	2·7 × 2·7	2·7 × 5·4
S_3	2·7 × 2·7	5·4 × 5·4
S_4	3·9 × 3·9	3·9 × 3·9
S_5	3·3 × 3·3	3·3 × 3·3
S_6	1·8 × 5·4	3·6 × 5·4

FERTILIZER

F_1 100 g N, 40 g P_2O_5 and 140 g K_2O for both the crops / tree / yr.

F_2 100 g N, 40 g P_2O_5 and 140 g K_2O for arecanut and
200 g N, 80 g P_2O_5 and 280 g K_2O for cacao / tree / yr.

first two years in the field. Care was taken to see that they were also irrigated uniformly during the dry weather period from last week of November to April or the onset of rains each year. Other cultural operations normally called for in similar plantations were also attended to.

Since the experiment originally designed had no treatment, sole crop (of arecanut or cacao), two separate blocks planted with sole crops of each under identical conditions contiguous with the experimental garden were utilised for obtaining additional information.

Details of the observations made and methods adopted to cover the programmes envisaged in this study are presented under each chapter in the body of the thesis.

III. GROWTH, FLOWERING AND FRUIT SET IN ARECANUT AND CACAO MIXED CROPPING

GROWTH, FLOWERING AND FRUIT SET IN ARECANUT AND CACAO MIXED CROPPING

Introduction

Growing plants require light, water, nutrients, oxygen and carbon dioxide from germination till death. The demand for these factors by young plants which have restricted canopy size and root ramification, is low. As the growth of plants proceeds, the demand for the growth factors increases rapidly and competition for these factors sets in if any one is in short supply. The result is that the rate of growth of the individual plant retards to the extent of interference. Also, plants growing in an eco-system or in a community behave in a different way than those isolated plants in terms of growth morphogenesis and physiology display. Donald (1963) states that plants show extreme plasticity and respond remarkably in size and form to environmental condition and he considers the presence of competing neighbours as the most potent of the external forces. Competition from neighbouring trees may reduce a plant to diminutive size. Plastic responses of this type have been the subject of study of agronomists and horti-culturists for many years since the interaction of such responses with density is ultimately reflected in crop yield. Agronomist's anxiety is to study how much of change is brought about in the plants behaviour due to various stresses with a view to arrive at that optimum response where he can get maximum yield per unit area. High density planting may not only affect the overall architecture of the plant and its flowering behaviour but also can bring in a reduced yield of crop.

According to Halle (1978), though it has been well established that vegetative architecture is a constant and stable characteristic of the plant, yet ecologically imposed variations can often bring in changes in the form. Quoting Kahn (1975), he reports examples of several trees, Euphorbia mellifera Ait., Arbutus unedo L., Mangifera indica L., etc., wherein the vegetative architecture is variable which is attributed to environment and most closely with the amount of incident light. The degree of shading and the amount of incident light are important environmental conditions in determining the vegetative and reproductive behaviours of components in mixed crop communities, especially when perennial crops are involved in the system. Even the degree of shading and the quantum of light intercepted varies with the age of the trees as in the case of coconut pointed by Nelliat et al. (1974). In the initial juvenile preflowering stage, the canopy of coconut is not fully developed and intercepts only a small fraction of the solar energy. At this stage minimal competition can be expected both for solar energy and for soil nutrients. In the reproductive or middle age of the palm, the canopy reaches its full size and only very little light is transmitted. After about 30 years of age, shading slowly decreases and quantum of light passed down also increases. In such a condition as prevailing under coconut or arecanut palms, the component crop chosen must be able to adapt to the ever changing environment.

Mixed cropping with certain crop combinations helps to increase the net yield or compensate the loss of yield by exploiting the environment in a more efficient way. This is possible where the mixed crop components exploit the environmental supplies of growth factors in differing ways. Such complementary use of resources is "annidation" (Ludwig, 1950). Among the various forms of annidation recognised, space is one. The better or complementary use of above ground space is possible when the leaf canopies of mixed crop component occupy different vertical layers. The taller component should be tolerant of strong light and high evaporative demand and the shorter component forming the lower storey must be tolerant of shade besides relatively high humidity. Similarly complementary use of below sub-ground is possible if the components in the mixed cropping system exploit different layers of the soil by virtue of their different root systems. This latter aspect of root systems in respect of arecanut and cacao mixed cropping has been studied and the results presented in the following chapter. In this chapter an attempt has been made to present the results of study on the growth patterns of the above ground portions of the two species involved, at various stages of growth, beginning from the early planting stage till the trees are about ten-year old. These studies also aim at understanding how much of above ground space is effectively utilised by the two components under study. Another aspect covered relates to the flowering and fruits set of the two crops in this instance arecanut and cacao.

Materials and Methods

1. Growth characters

The studies relating to the growth habits of arecanut and cacao trees were made in the mixed cropping experimental garden whose details are given earlier. On the arecanut palms the following measurements were made annually from the year of planting in 1970 to 1980.

Height of trees, girth of stem, internodal distance, number of nodes and number of leaves.

On the cacao trees the following measurements were recorded.

Height of tree, girth of stem at 30 cm above ground level, spread of canopy in two directions (east-west and north-south).

2. Flowering and fruit set

The number of trees flowered each year was recorded and the percentage of trees flowered under each treatment (density of planting) was calculated. Regular observations on the spadices produced, female flowers produced and fruits set in four randomly selected arecanut palms in each treatment plot were made during two years (1978-79 and 1979-80). In cacao trees also the number of trees flowered each year was recorded. For determining the fruit set, 100 flowers (produced during different months) in each tree were labelled before anthesis and counts of the fruit set were taken after it was ensured that they have set and fruit commenced developing.

Results

1. Growth characters

Arecanut palms: The data on growth (height, girth and number of leaves) parameters of the arecanut palms beginning from the year of field planting (1970) and for subsequent two years (1971 and 1972) are given in Table 8 for the six spacing combinations of arecanut and cacao. It is seen that in the year of planting the mean height, girth of stem and number of leaves are 162.0 cm, 10.4 cm and 4.6 cm respectively. There is no significant difference in the

Table 8. Growth of arecanut palms during initial 3 years

Table of means

Treatments*	1970 No. of leaves	1970 Girth (cm)	1970 Height (cm)	1971 No. of leaves	1971 Girth (cm)	1971 Height (cm)	1972 No. of leaves	1972 Girth (cm)	1972 Height (cm)	1972 No. of nodes
S1	4.7	10.5	164.9	4.5	12.4	151.3	6.2	26.6	266.6	0.6
S2	4.6	10.3	155.5	4.5	12.3	147.5	6.3	25.2	258.6	0.6
S3	4.5	10.4	158.0	4.4	12.2	151.3	6.2	25.6	262.3	0.6
S4	4.8	10.4	160.0	4.6	12.9	156.4	6.4	26.4	272.5	0.6
S5	4.6	10.5	167.6	4.5	12.4	150.8	6.2	25.2	261.3	0.6
S6	4.6	10.6	165.8	4.5	12.9	153.4	6.3	26.0	271.5	0.6
Mean	4.6	10.4	162.0	4.5	12.5	151.8	6.3	25.5	265.5	0.59
SE/plot	0.13	0.70	13.4	0.3	0.8	5.3	0.3	1.6	11.6	0.2
CV (%)	2.80	6.2	8.3	6.4	6.2	3.5	4.3	6.4	4.4	31.5

*Treatments

Spacing	Arecanut	Cacao
S1	2.7m x 2.7m	2.7m x 2.7m
S2	2.7m x 2.7m	2.7m x 5.4m
S3	2.7m x 2.7m	5.4m x 5.4m
S4	3.9m x 3.9m	3.9m x 3.9m
S5	3.3m x 3.3m	3.3m x 3.3m
S6	1.8m x 5.4m	3.6m x 5.4m

ANOVA in Appendix, Table 8(1)

growth parameters among the plants planted under different treatments. One year after planting the plants have shown a slight reduction in the height which is due to the shorter petiole length of leaves produced during the period under field condition. There is increase in the girth though not in number of leaves. At the end of second year the plants have attained a mean height of 265.5 cm and 25.5 cm girth with a mean of 6.3 leaves. At the end of two years also none of above three characters of plants under different treatments differed significantly. From third year onwards the palms began to expose distinct nodes and by end of fourth year all the palms had exposed nodes and internodes.

From sixth year onwards, besides height of stem and number of leaves, additional characters like girth and internodal distance at last exposed node, and girth and internodal distances at 60 cm height (where a permanent mark was painted) were also recorded. The growth data recorded at the end of sixth (1976) to tenth (1980) year are summarised in Tables 9, 10, and 11. In all these years or ages the palms do not show any significant difference due to treatments in respect of all the characters except internodal distances in the sixth year. At the tenth year also the internodal distance at 60 cm height and number of leaves showed significant difference due to spacings. The mean height of stem which is 228.2 cm at the end of sixth year, reaches to 623.2 cm at the tenth year. At the same period the girth increment is from 45.3 cm to 45.8 cm only. The mean number of leaves increases from 8.4 to 9.1.

Table 9.   Growth parameters of arecanut palms, 1976

Table of means

Treatments	Height (cm)			Girth at [illegible] (cm)			Girth at [illegible] (cm)		
	F_1	F_2	Mean	F_1	F_2	Mean	F_1	F_2	Mean
S_1	214.0	248.0	231.0	43.7	44.2	44.0	34.8	36.7	35.8
S_2	214.5	256.0	235.3	43.8	46.5	45.1	35.8	38.1	37.0
S_3	235.5	200.8	218.1	46.5	45.5	46.0	38.7	35.3	37.5
S_4	236.3	238.5	237.4	46.5	46.8	46.7	37.1	39.3	38.2
S_5	228.0	200.3	214.1	45.1	45.1	45.1	37.2	36.5	36.8
S_6	240.8	225.5	233.1	45.7	44.0	44.8	37.3	36.8	37.0
Mean	228.2	228.2	228.2	45.2	45.3	45.3	36.8	37.3	37.0
SE/plot		32.5			2.0			2.1	
CV (%)		14.2			4.4			5.6	

Table 9. (concd.)

Treatments	IND at PM (cm) F_1	IND at PM (cm) F_2	IND at PM (cm) Mean	IND at LEN (cm) F_1	IND at LEN (cm) F_2	IND at LEN (cm) Mean	No. of leaves F_1	No. of leaves F_2	No. of leaves Mean	No. of nodes F_1	No. of nodes F_2	No. of nodes Mean
S_1	15.1	16.8	15.9	13.8	14.2	14.0	8.0	8.4	8.2	15.4	16.3	15.8
S_2	14.6	14.9	14.7	13.1	13.3	13.2	8.4	8.5	8.5	15.4	18.6	17.0
S_3	14.7	13.9	14.3	13.7	12.0	12.8	8.5	8.4	8.4	17.1	16.4	16.7
S_4	14.8	14.4	14.6	12.6	12.8	12.7	8.7	8.5	8.6	18.6	18.0	18.3
S_5	15.0	13.7	14.4	13.0	12.0	12.5	8.3	8.3	8.3	17.1	16.6	16.9
S_6	14.7	14.6	14.6	12.6	12.7	12.6	8.5	8.6	8.6	18.4	17.0	17.7
Mean	14.8	14.7	14.8	13.1	12.8	13.0	8.4	8.5	8.4	17.0	17.1	17.1
SE/plot		0.8			0.8			0.3			2.0	
CV (%)		5.3			6.0			3.9			11.9	
CD (P=0.05)												
for spacings		0.79			0.79			-			-	
for interaction		0.12			-			-			-	

S_1-S_6 — for legend see Table 8

PM - Permanent mark (60 cm above ground level)
IND - Internodal distance
LEN - Last exposed node

ANOVA in Appendix, Table 9(1)

Table 18. Growth parameters of arecanut palms, 1978

Table of means

Treat-ments	Height (cm)			Girth at PH (cm)			Girth at LKH (cm)		
	F_1	F_2	Mean	F_1	F_2	Mean	F_1	F_2	Mean
S_1	461.8	497.3	479.8	44.0	44.4	44.2	36.6	39.2	37.9
S_2	442.8	492.5	467.6	43.1	45.4	44.2	37.1	40.2	38.7
S_3	485.3	420.3	452.8	48.8	44.7	45.3	40.9	38.5	39.7
S_4	467.5	475.0	471.3	45.6	46.8	46.2	39.0	40.3	39.7
S_5	482.3	415.0	439.0	43.8	44.6	44.1	38.1	38.4	38.3
S_6	479.5	466.0	473.1	45.1	43.4	44.2	40.1	39.1	39.6
Mean	466.5	461.3	463.9	44.3	44.9	44.7	38.6	39.3	39.0
SE/plot		45.0			1.8			2.3	
CV (%)		9.7			4.0			6.9	

	IND at PH (cm)			IND at LKH (cm)			No. of leaves		
	F_1	F_2	Mean	F_1	F_2	Mean	F_1	F_2	Mean
S_1	13.9	16.6	15.2	11.3	12.4	11.9	8.6	8.9	8.7
S_2	14.0	13.2	13.6	11.2	11.0	11.1	8.8	9.0	8.9
S_3	14.0	13.2	13.6	11.6	10.5	11.0	9.3	9.1	9.2
S_4	14.2	13.5	13.8	10.3	10.7	10.5	9.3	9.0	9.2
S_5	13.9	13.3	13.6	10.2	10.8	10.5	8.9	9.1	9.0
S_6	13.3	13.2	13.3	11.8	11.8	11.4	9.1	9.1	9.1
Mean	13.9	13.8	13.8	10.9	11.2	11.1	8.9	9.0	9.0
SE/plot		1.4			1.1			0.4	
CV (%)		9.9			10.3			6.0	

Table 10 (contd.)

	No. of nodes		
	P_1	P_2	Mean
S_1	33.1	33.9	33.5
S_2	33.1	38.2	35.6
S_3	37.0	34.2	35.6
S_4	36.6	38.3	37.4
S_5	35.4	33.9	34.6
S_6	38.0	35.0	36.5
Mean	35.5	35.6	35.5
SE/plot		3.0	
CV (%)		8.4	

S_1–S_6 — for legend see Table 8

PM – Permanent mark (60 cm above ground level)

IND – Internodal distance

LEN – Last exposed node,

ANOVA in Appendix, Table 10(i)

Table 11. Growth parameters of arecanut palms, 1980

Table of means

Treatments	Height (cm)			Girth at PM (cm)			Girth at LEN (cm)			IND at PM (cm)		
	F_1	F_2	Mean	F_1	F_2	Mean	F_1	F_2	Mean	F_1	F_2	Mean
S_1	590.8	662.0	626.4	44.7	46.0	45.3	36.3	37.6	36.9	15.7	17.1	16.4
S_2	610.8	661.0	635.9	44.5	46.6	45.5	35.4	39.4	37.4	15.8	15.2	15.5
S_3	666.0	574.3	620.1	47.5	45.9	46.7	38.9	36.1	37.5	15.4	14.5	15.0
S_4	619.8	616.0	617.9	46.7	46.6	46.7	38.9	38.5	38.7	15.0	15.1	15.1
S_5	633.0	573.0	602.8	46.2	44.9	45.6	37.3	37.8	37.6	15.3	14.1	14.7
S_6	647.3	624.8	636.0	45.6	44.6	45.1	38.7	36.4	37.6	15.2	15.1	15.2
Mean	627.8	618.5	623.2	45.8	45.8	45.8	37.6	37.6	37.6	15.4	15.2	15.3
SE/plot		38.6			1.7			1.7			0.8	
CV (%)		6.2			3.7			4.5			5.2	
CD (P=0.05)												
for spacings		-			-			-			0.84	
for interaction		55.78			-			2.50			1.19	

(contd.)

Table 11. (contd.)

Treatments	IND at LEN (cm)			No. of leaves			No. of nodes		
	F_1	F_2	Mean	F_1	F_2	Mean	F_1	F_2	Mean
S_1	9.0	8.1	8.5	8.8	9.1	9.0	47.9	48.5	48.2
S_2	9.4	7.8	8.6	8.9	9.3	9.1	49.4	55.2	52.3
S_3	8.5	8.1	8.3	9.4	9.0	9.2	51.3	48.1	49.7
S_4	7.6	7.3	7.5	9.1	9.7	9.4	50.2	51.3	50.7
S_5	7.2	8.2	7.7	9.1	9.1	9.1	52.1	52.2	52.1
S_6	7.7	9.4	8.6	9.1	9.1	9.1	54.1	48.4	51.2
Mean	8.2	8.2	8.2	9.1	9.2	9.1	50.8	50.6	50.7
SE/plot		1.3			0.3			3.3	
CV (%)		15.9			3.3			6.5	
CD (P=0.05)									
for spacings		-			0.26			-	
for interaction		-			0.36			4.78	

S_1–S_6 — for legend, see Table 8

PM = Permanent mark (60 cm above ground level)
IND = Internodal distance
LEN = Last exposed node

ANOVA in Appendix, Table 11(i)

Since there is no significant difference in the height of the palms due to various treatments, the average height of palms at the end of each year was worked out and is depicted in Figure 5. It is evident from the figure that the arecanut palm grows almost linearly till the end of tenth year.

The data on spread of arecanut palm crowns recorded at 2 yearly intervals from second year after planting are given in Table 12. It may be observed that the rate of increase in the spread is very rapid till fourth year and it gets reduced in later years. The rate of increase is only 2.2 per cent between eighth and tenth year.

Cacao trees: The data on growth (height, girth, spread of tree east-west and north-south) characters during different stages of growth beginning from the year of field planting till tenth year are given in Tables 13 to 16. It is evident that till the end of two years none of the characters studied, excepting the east-west spread, differ significantly due to treatments (different spacings). In 1971 i.e., second year from planting the east-west spread of trees under widest spacing (5.4m x 5.4m) is the largest. From 1976 or sixth year onwards the trees commence to show significant difference in height due to spacings. The trees under the closest spacing of 2.7m x 2.7m continue to be tallest and those with the widest spacing 5.4m x 5.4m

FIG. 5. ARECANUT PALM HEIGHT IN RELATION TO AGE

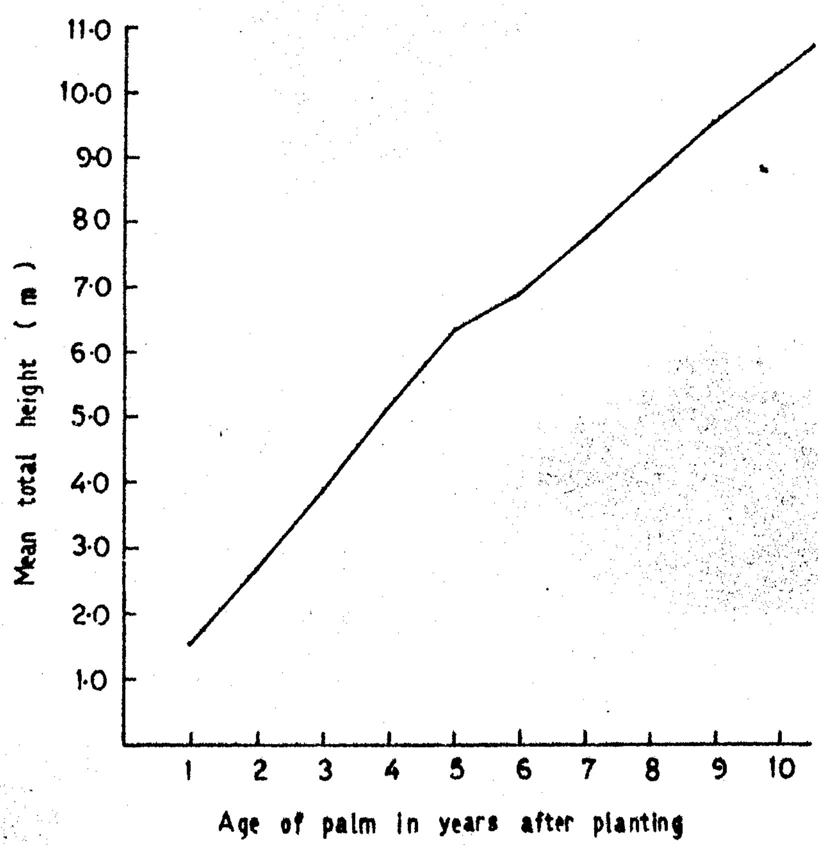


Table 12. Spread of arecanut crown during initial 10-year growth period

Age of palms (yr)	Diameter of crown spread (cm)	% increase	Area covered (m²)
2	145	—	1.65
4	263	81.4	5.43
6	317	20.5	7.89
8	367	15.8	10.58
10	375	2.2	11.04

Table 13. Growth of cacao trees during initial 3 years

Table of means

Treatments	1970		1971				1972			
	Girth (cm)	Height (cm)	Girth (cm)	Height (cm)	Spread SN (cm)	Spread EW (cm)	Girth (cm)	Height (cm)	Spread SN (cm)	Spread EW (cm)
S_1	5.0	86.7	10.4	201.9	123.2	117.0	17.5	225.8	226.2	212.6
S_2	4.6	83.1	10.2	191.0	113.6	105.5	16.7	214.0	203.9	200.5
S_3	5.2	84.3	10.8	200.4	126.9	122.8	16.5	220.4	203.1	205.0
S_4	4.7	83.2	10.0	204.6	119.9	110.4	16.8	220.8	209.0	189.9
S_5	4.9	84.7	9.9	195.5	114.5	110.7	17.0	217.1	211.8	198.9
S_6	4.8	87.3	10.5	211.0	127.2	116.2	17.7	222.4	218.5	204.5
Mean	4.8	84.9	10.3	200.7	120.9	113.8	17.0	220.1	212.1	201.9
SE/plot	0.5	4.9	0.7	13.1	9.6	6.8	1.5	10.1	13.7	13.9
CV (%)	10.4	5.8	6.8	6.5	7.9	6.0	8.8	4.6	6.5	6.9
CD (P=0.05)						10.28				

S_1–S_6 — for legend, see Table 8

SN - South North
EW - East West

ANOVA in Appendix, Table 13(i)

Table 14. Growth parameters of [redacted] trees, 1976

Table of means

Treat-ments	Girth (cm)			Height (cm)			Spread (SN) (cm)			Spread (EW) (cm)		
	F_1	F_2	Mean	F_1	F_2	Mean	F_1	F_2	Mean	F_1	F_2	Mean
S_1	32.1	32.7	32.4	431.5	453.5	443.5	407.5	418.5	413.0	418.3	434.5	426.4
S_2	33.2	32.8	33.0	376.3	405.8	391.0	422.0	445.8	433.9	439.5	474.5	457.0
S_3	33.2	32.8	33.0	369.3	348.3	358.8	406.8	406.8	406.8	408.3	416.5	412.4
S_4	33.8	33.0	33.4	393.8	374.5	384.1	415.5	422.5	419.0	420.8	415.0	417.9
S_5	34.7	33.0	33.9	389.0	363.5	376.3	436.5	394.3	415.4	414.0	422.3	418.1
S_6	34.7	34.5	34.6	377.5	352.3	364.9	418.8	433.0	425.9	440.3	436.0	438.1
Mean	33.6	33.1	33.3	389.9	383.0	386.5	417.8	420.8	419.3	423.50	433.1	428.3
SE/plot		1.7			41.6			44.5			52.6	
CV (%)		5.1			10.8			10.6			12.3	
CD (P=0.05) for spacings		-			42.53			-			-	

S_1-S_6 — for legend, see Table 8

SN - South North
EW - East West

ANOVA in Appendix, Table 14(1)

Table 15. Growth parameters of cacao trees, 1978

Table of means

Treatments	Girth(cm)			Height(cm)			Spread (SN) (cm)			Spread (EW) (cm)		
	F_1	F_2	Mean	F_1	F_2	Mean	F_1	F_2	Mean	F_1	F_2	Mean
S_1	38.5	38.8	38.7	463.0	524.0	493.5	516.0	528.0	522.0	510.0	518.0	514.0
S_2	40.2	38.7	39.5	443.0	430.0	436.5	515.0	522.0	518.5	530.0	598.0	564.0
S_3	41.2	40.9	41.1	446.0	409.0	427.5	493.0	560.0	526.5	529.0	557.0	543.0
S_4	42.1	39.2	40.7	421.0	416.0	418.5	499.0	502.0	500.5	522.0	517.0	519.5
S_5	40.5	40.7	40.6	463.0	436.0	449.5	529.0	524.0	526.5	528.0	550.0	539.0
S_6	40.7	41.5	41.1	453.0	430.0	441.5	525.0	517.0	521.0	520.0	525.0	522.5
Mean	40.5	40.0	40.3	448.0	441.0	444.5	512.0	526.0	519.0	523.0	544.0	533.5
SE/plot		2.8			34.6			26.5			40.0	
CV (%)		6.9			7.8			5.1			7.5	
CD (p=0.05) for spacings		-			35.42			-			-	

S_1-S_6 — for legend, see Table 8

SN — South North
EW — East West

ANOVA in Appendix, Table 15(1)

Table 16. Growth parameters of cacao trees, 1980

Table of means

Treatments	Girth (cm)			Height (cm)			Spread (SN) (cm)			Spread (EW) (cm)		
	F_1	F_2	Mean	F_1	F_2	Mean	F_1	F_2	Mean	F_1	F_2	Mean
S_1	43.2	43.7	43.4	503.0	526.0	514.5	534.0	536.0	535.0	528.0	534.0	531.0
S_2	46.5	44.9	45.7	496.0	473.0	484.5	556.0	537.0	546.5	650.0	644.0	647.0
S_3	48.9	46.9	47.9	496.0	427.0	461.5	580.0	613.0	596.5	591.0	613.0	602.0
S_4	48.3	45.1	46.7	491.0	463.0	477.0	552.0	578.0	565.0	582.0	597.0	589.5
S_5	46.5	45.4	45.9	500.0	445.0	472.5	573.0	585.0	579.0	572.0	580.0	576.0
S_6	47.7	46.6	47.2	495.0	462.0	478.5	590.0	549.0	569.5	639.0	611.0	625.0
Mean	46.8	45.4	46.1	497.0	466.0	481.5	564.0	566.0	565.0	594.0	596.0	595.0
SE/plot	3.2			33.2			44.7			43.6		
CV (%)	6.9			6.9			7.9			7.3		
CD ($P=0.05$)												
for spacings	-			-			-			44.57		
for fertilisers	-			19.58			-			-		

S_1–S_6 — for legend, see Table 8

SN - South North
EW - East West

ANOVA in Appendix, Table 16(i)

shortest in all the years except in 1978 (eighth year). In the tenth year the east-west spread is significantly lowest in 2.7m x 2.7m spacing. The cacao plants which record a mean height of 85 cm at the time of planting attain a mean height of 482 cm i.e., about 5.7 times the original height in ten years. The rate of increase of height up to the sixth year is rapid and thereafter it is slow and slower still as the age advances. The spread of trees also increases year after year and the rate of spread is faster till eighth year, which later declines. The mean girth of cacao trees at 30 cm above ground level, which is 4.8 cm when the plants are planted in the field has reached to 46.1 cm when they are ten year old i.e., the increase is about 9.6 times the original size.

The difference in the girth of plants planted under different treatments do not show any significant difference.

The ratio between the total height of arecanut and cacao trees (from ground level up to top of canopy in both the cases) during different ages after planting are given in Table 17. It can be seen that the height of arecanut palm is slighly less than the cacao trees or almost on par in the first two years. Thereafter the arecanut palms take a lead. The ratios in the height remain almost same (1.0 : 0.6) till the end of seventh year after planting and thereafter it widens with the arecanut trees growing faster than

Table 17. Relative heights of arecanut and cacao at different ages

Age of tree (year)	Height of tree (cm)*		Ratio
	Arecanut	Cacao	
1	152	200	1 : 1.32
2	265	250	1 : 0.94
3	388	286	1 : 0.74
4	511	323	1 : 0.63
5	635	364	1 : 0.57
6	686	416	1 : 0.61
7	778	446	1 : 0.57
8	870	475	1 : 0.55
9	954	496	1 : 0.52
10	1039	517	1 : 0.50

* From ground level to top of canopy

*From ground level to top of canopy

the cacao trees. It is also seen that though the total height of arecanut palms is more than that of cacao trees, even from the early years, it is only after seventh year that the entire crown of arecanut palms get lifted up above the level of cacao canopy (Fig. 6).

The area available per plant and the progressive coverage of the canopy of cacao trees (horizontal spread) under different spacings are given in Table 10. It is clear that the rate of spread and the area covered by the trees are fairly uniform at different ages irrespective of the treatments (spacing given to the trees) up to eighth year from planting. At the end of the tenth year the trees under the closest spacing of 2.7m x 2.7m have comparatively lesser horizontal spread than trees with wider spacing. It is also seen that the rate of spread is rapid till eighth year and thereafter there is a tendency to slow down (Fig. 7). In so far as the space available per tree is concerned it may be observed that the percentage of area covered increases with the density of planting. Under the closest spacing of 2.7m x 2.7m, 51.9 per cent of the available space is covered within two years and within ten years the space covered is 306.0 per cent of available space i.e., only about one-third of the canopy is within its zone and two-thirds of branches extend far beyond the tree in the row (Fig.8(i). The situation in the widest spacing (5.4m x 5.4m) is that about 50.0 per cent of

FIG. 6. COMPARATIVE HEIGHTS OF ARECANUT AND CACAO IN RELATION TO AGE

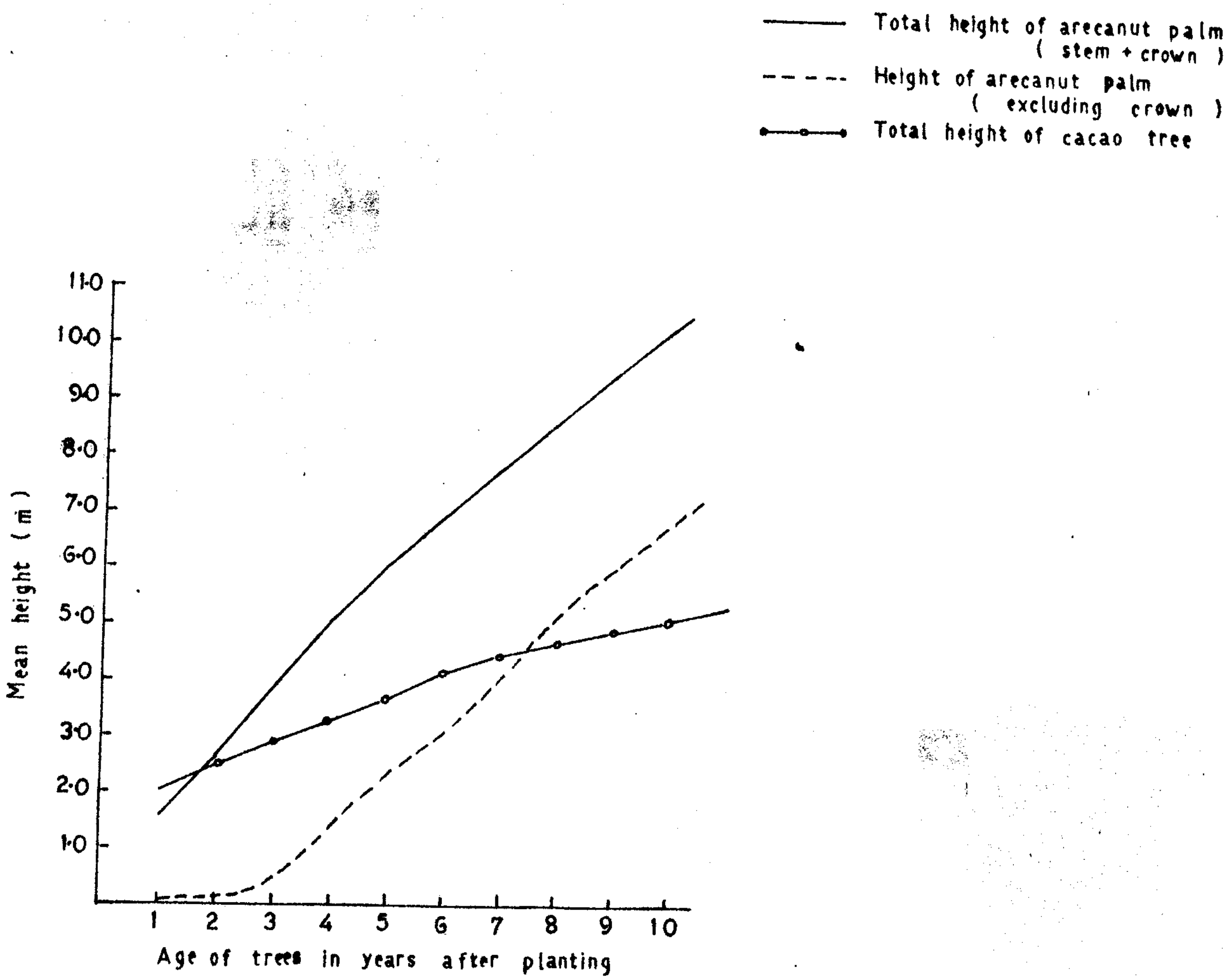
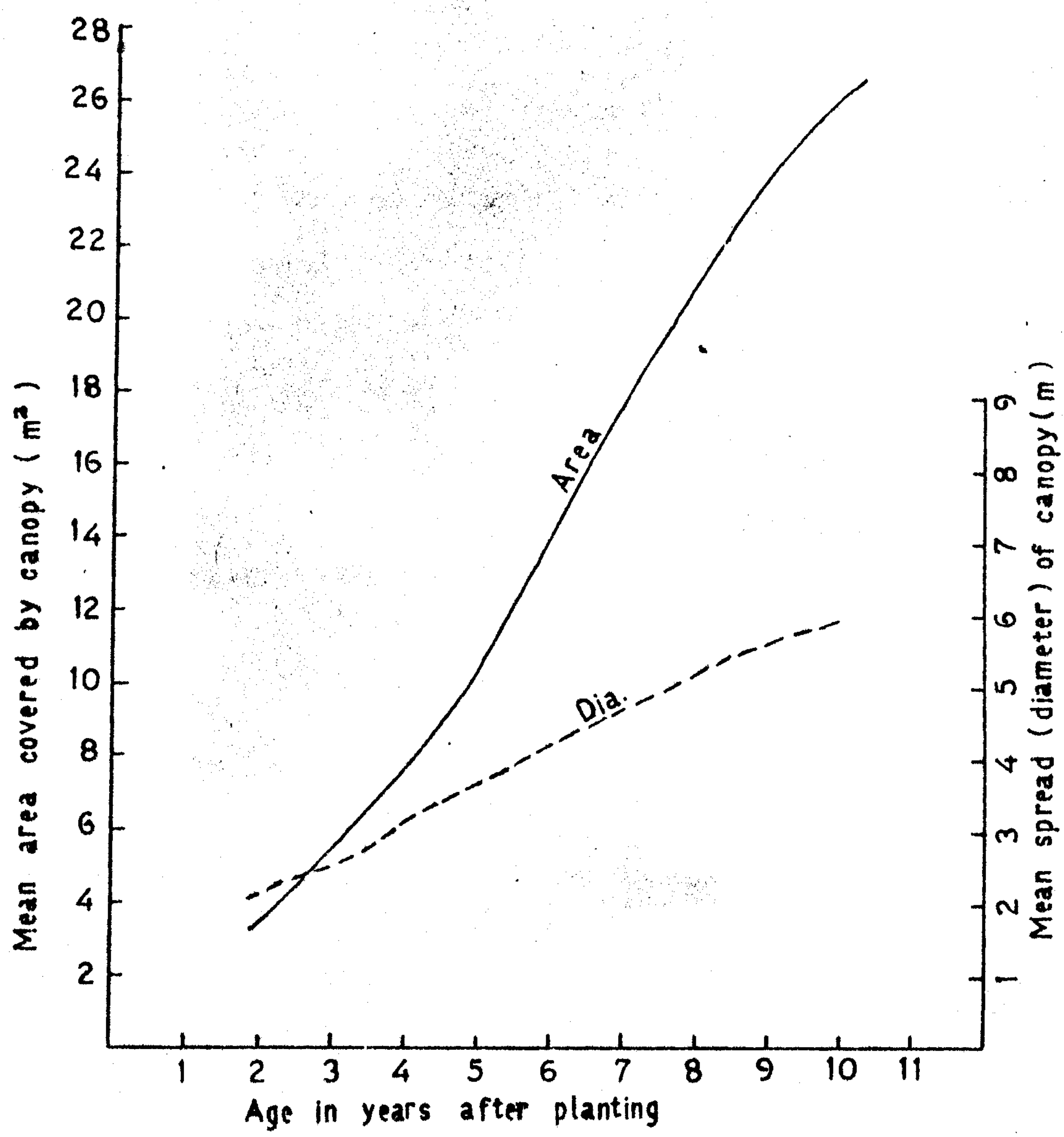


Table 18. Area covered by the canopy of cacao

Spacing (m)	Area available / plant (m^2)	Area covered (m^2)				
		2nd year	4th year	6th year	8th year	10th year
2.7 x 2.7	7.29	3.78 (51.9)	8.29 (113.7)	13.82 (189.6)	21.03 (288.5)	22.31 (306.0)
2.7 x 5.4	14.58	3.20 (21.9)	8.27 (56.7)	15.58 (106.9)	22.95 (157.4)	27.75 (190.3)
5.4 x 5.4	29.16	3.27 (11.2)	6.66 (22.8)	13.17 (45.2)	22.48 (77.1)	28.18 (96.6)
3.9 x 3.9	15.21	3.12 (20.5)	6.95 (45.7)	13.78 (90.5)	20.38 (134.0)	26.14 (171.9)
3.3 x 3.3	10.89	3.31 (30.4)	7.31 (67.1)	13.62 (125.1)	22.26 (204.4)	26.19 (240.5)
3.6 x 5.4	19.44	3.53 (18.2)	8.12 (41.8)	14.65 (75.4)	21.40 (110.1)	27.93 (143.7)
Mean		3.36	7.60	14.1	21.8	25.4

Figures in parentheses give the percentage of available space covered.

FIG. 7. HORIZONTAL SPREAD OF CACAO CANOPY



the available space is covered only after six years and even then not fully covered at the end of as many as ten years. The areas covered by the canopies of arecanut and cacao at the tenth year are shown in Fig. 8(ii).

A comparison of the arecanut trees grown under sole cropping (open without shade or mixed crop) and under mixed crop condition made at the tenth year is given in Table 19. It is seen that the two sets of palms do not appreciably differ in overall vigour or growth.

A comparison of the cacao trees grown under open condition (without shade) and under the mixed cropping system made at the tenth year is given in Table 20. It is seen that there is no appreciable difference in the vigour and overall growth of the trees grown under the two conditions, though the height and spread are slightly more under the mixed crop shaded condition.

2. Flowering and fruitset

Arecanut palm: The percentages of palms flowered at different ages after planting are given in Table 21. The first flowering was noticed on the fourth year of planting. The percentage of mean number of palms flowered at 5th, 6th 7th 8th and 9th year were 28.8, 51.9, 61.1, 75.6 and 96.6 respectively. Various densities of arecanut and cacao or levels of fertilizers have no significant influence on the percentage of palms flowered at different ages. The analysed data on the average number of spadices and female

FIG. 8(i). HORIZONTAL SPREAD OF ARECANUT AND CACAO CANOPIES IN RELATION TO AGE SPACING 2·7 m × 2·7 m

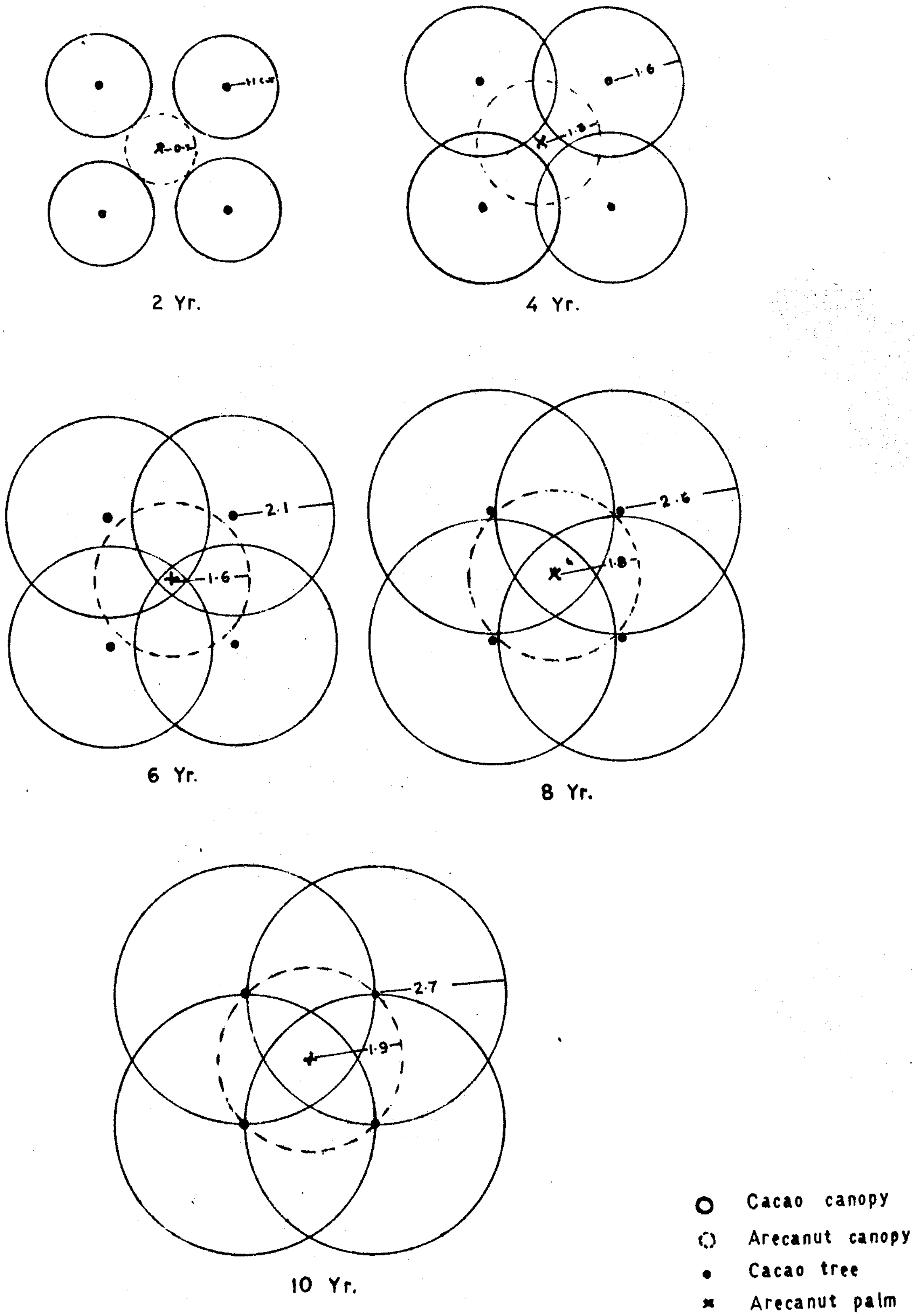
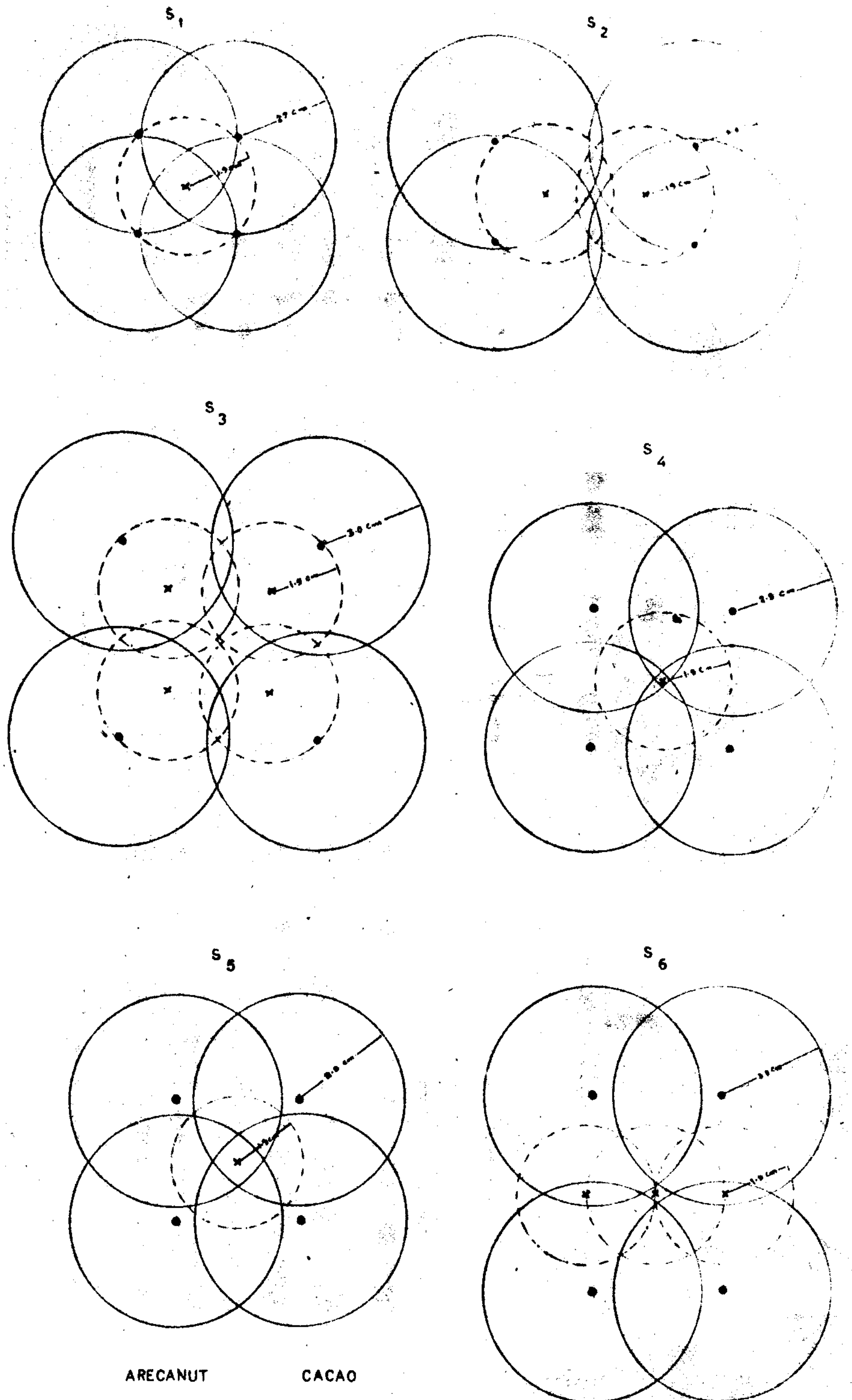


FIG. 8 (ii). HORIZONTAL SPREAD OF ARECANUT AND CACAO IN RELATION TO SPACING (at 10th yr.)



	ARECANUT	CACAO
S_1	2·7× 2·7 m	2·7 × 2·7 m
S_2	2·7× 2·7 m	2·7 × 5·4 m
S_3	2·7 × 2·7 m	5·4 × 5·4 m
S_4	3·9 × 3·9 m	3·9 × 3·9 m
S_5	3·3 × 3·3 m	3·3 × 3·3 m
S_6	1·8 × 5·4 m	3·6 × 5·4 m

● Cacao tree
× Arecanut palm
O Cacao canopy
◌ Arecanut canopy

9(ii)

Table 19. Growth parameters of arecanut under sole and mixed cropping with cacao

Characters	Mean values		Difference
	Sole crop	Mixed with cacao	
Height (m)	7.82	8.16	- 0.32
Girth at PM (cm)	49.24	51.48	- 2.24
Girth at LEN(cm)	42.84	43.80	- 0.96
IND at PM (cm)	16.40	17.92	- 1.52*
IND at LEN(cm)	8.20	7.56	0.64
No. of nodes	61.64	65.40	- 3.76
No. of leaves	9.60	9.80	- 0.20

* Significant at P = 0.05

PM - Permanent mark (at 60 cm above ground level)
LEN- Last exposed node
IND- Internodal distance

Table 20. Comparative growth of cacao : open *vs* shade

Character	Mean value		Difference
	Open	Shade	
Girth (cm)	0.51	0.49	0.02
Height (m)	5.39	5.59	-0.20
Spread (m) (East West)	5.46	6.99	-1.53*
Spread (m) (North South)	5.56	6.61	-1.05*

*Significant at P=0.05

Table 21. Effect of density on flowering in arecanut (percentage of palms flowered)

Table of means

Treatments	1973-74			1974-75			1975-76		
	F_1	F_2	Mean	F_1	F_2	Mean	F_1	F_2	Mean
S_1	1.0	0.0	0.5	22.0	14.0	18.0	42.0	48.0	45.0
S_2	0.0	2.0	1.0	17.0	34.0	25.5	59.0	47.0	53.0
S_3	3.0	2.0	2.5	35.0	32.0	33.5	54.0	54.0	54.0
S_4	3.1	4.7	3.9	18.8	40.6	29.7	43.8	64.1	53.9
S_5	0.0	0.0	0.0	38.5	30.8	34.6	53.8	48.1	51.0
S_6	2.4	4.8	3.6	39.3	23.8	31.6	62.0	47.6	54.8
Mean	1.6	2.2	1.9	28.4	29.2	28.8	52.4	51.4	51.9
SE/plot		0.8			3.4			4.4	
CV (%)		40.7			11.9			8.5	

(contd.)

(Table 21 (contd.)

Treatments	1976-77			1977-78			1970-79		
	F_1	F_2	Mean	F_1	F_2	Mean	F_1	F_2	Mean
S_1	57.0	59.0	58.0	70.0	66.0	68.0	96.0	97.0	96.5
S_2	70.0	58.0	64.0	81.0	73.0	77.0	98.0	95.0	96.5
S_3	64.0	67.0	65.5	79.0	84.0	81.5	99.0	96.0	97.5
S_4	54.7	76.6	65.6	75.0	81.2	78.1	98.4	93.8	96.1
S_5	40.6	51.9	46.3	69.2	73.1	71.2	90.4	100.0	95.2
S_6	75.0	59.5	67.3	81.0	73.8	77.4	96.4	98.8	97.6
Mean	60.2	62.0	61.1	75.9	75.2	75.6	96.4	96.8	96.6
SE/plot		4.3			3.4			0.9	
CV (%)		7.0			4.5			0.9	
CD(P=0.05) for interaction		-			-			1.29	

S_1-S_6 — for legend, see Table 8

ANOVA in Appendix, Table 21(i)

flowers produced and fruits set per palm per year are presented in Table 22. Here also none of the characters observed differ significantly due to various combinations of planting or levels of fertilisers. The mean number of spadices produced, number of female flowers produced, number of flowers set and percentage of fruits set per palm per year are 4.52, 720.3, 269.0 and 34.6 respectively.

Cacao trees: The percentages of trees flowered at different ages after planting are given in Table 23. The first flowering was seen during second year of planting. The percentages of mean number of trees flowered during 3rd and 4th year are 56.8 and 90.1 respectively. During 5th year there has been cent per cent flowering. The data on fruits set are given in Table 24. There is no significant difference in fruit set between different treatments. The mean percentage of fruit set is only 2.5.

Discussion

Exploitation of the environmental resources or factors by the component crops in a complementary rather than purely on competitive way is stressed very much in the success of mixed cropping. In achieving this, several manipulations in the selection of crops and managing the crops in the field have been arrived at with regard to annual crops in several

Table 32. Production of spadices, female flowers and fruit set in arecanut

Table of means

Treatments	No. of spadices			No. of ♀ flower			No. set			% set (retransformed)		
	F_1	F_2	Mean	F_1	F_2	Mean	F_1	F_2	Mean	F_1	F_2	Mean
S_1	3.9	4.5	4.2	563.9	588.0	575.9	185.8	208.5	197.1	26.0	34.5	30.2
S_2	4.8	4.3	4.5	631.1	632.4	631.7	232.6	263.1	247.9	35.1	40.3	37.7
S_3	4.8	4.3	4.5	828.1	774.6	801.4	358.5	327.3	342.9	43.7	37.3	40.5
S_4	5.3	5.3	5.3	856.7	875.4	866.1	296.2	330.4	313.3	35.0	34.5	34.7
S_5	4.6	3.9	4.2	795.4	642.2	718.8	294.6	263.1	278.8	35.9	31.2	33.5
S_6	4.2	4.6	4.4	642.2	814.0	728.1	165.9	301.5	233.7	25.0	38.0	31.3
Mean	4.6	4.5	4.5	719.6	721.1	720.3	255.6	282.3	269.0	33.3	35.9	34.6
SE/plot		1.1			226.7			130.7			7.6	
CV(%)		23.4			31.5			48.6			21.8	

S_1–S_6 — for legend, see Table 8.

ANOVA in Appendix, Table 22(i)

Table 23. Effect of density on flowering in cacao (percentage of trees flowered)

Treat-ments	1972-73 F_1	1972-73 F_2	1972-73 Mean	1973-74 F_1	1973-74 F_2	1973-74 Mean
S_1	62.5	53.1	57.8	100.0	87.5	93.8
S_2	40.7	65.6	53.1	84.4	96.9	90.6
S_3	56.2	68.8	62.5	87.5	87.5	87.5
S_4	58.3	55.6	56.9	91.7	91.7	91.7
S_5	52.1	50.0	51.0	93.8	79.2	86.4
S_6	68.8	50.0	59.4	100.0	81.2	90.6
Mean	56.4	57.2	56.8	92.9	87.3	90.1
SE/plot		5.1			3.3	
CV (%)		8.9			3.7	

S_1-S_6 — for legend, see Table 8

ANOVA in Appendix, Table 23(i)

Table 24. Effect of density on fruit set in cacao

Treatments	% Fruit set		
	F_1	F_2	Mean
S1	1.6	3.5	2.6
S2	3.8	2.5	3.1
S3	3.0	1.8	2.4
S4	2.0	2.5	2.3
S5	2.8	2.0	2.4
S6	1.8	2.3	2.0
Mean	2.5	2.4	2.5
SE/plot		1.4	
CV (%)		55.6	

S_1–S_6 — for legend, see Table 8

ANOVA in Appendix, Table 24(1)

countries by various workers (as is evidenced in a number of publications and proceedings of several workshops and symposia on multiple/inter cropping), (Papendick et al. 1976; Willey, 1981; Gomes and Gomes, 1983). Similar efforts with regard to crops involving perennial trees are limited. One of the important aspects studied by workers in the annual crops is the growth patterns of the component crops. Differences in plant heights and combinations of leaf canopy have been considered as one of the major factors essential in better exploitation of the environmental resources, viz., space. Swaminathan (1980) stated that in designing multilevel cropping of plantation crops an effective use of both horizontal and vertical space should be taken into account.

The two perennial crops involved in the present study have contrasting above ground morphological characters, one (arecanut palm) is having a tall single stem with a raised crown and the other (cacao tree) with a comparatively short stem but with a much wider branching canopy. The studies made have revealed the much differing architectural and progressive growth pattern of the species involved. Information on the progressive utilisation and coverage of the space above ground has also become available.

By looking at the various growth characters of the arecanut palms at different periods and stages of growth, It is indicated that within different population of arecanut as well as cacao the growth and vigour of the former is uniform when both the crops are planted simultaneously. In other words growing cacao as a mixed crop with arecanut at the densities tested has no adverse effect on the vigour of the latter. But similar observations on cacao reveal that differences in the vigour or overall growth of the trees occur under the different densities after the trees attain the age of four years. Trees under the densiest spacing of 2.7 x 2.7m with an equal density of arecanut palms grow taller and have a lesser spread than trees under the widest spacing or least density with 5.4 x 5.4m for cacao and 2.7m x 2.7m for arecanut. This may probably be due to the mutual shading of the cacao trees (which was maximum) under this spacing at the horizontal space and thus force the trees to exploit the vertical space to collect more light. It is also evident that both the crops are not having the mutual shading effect at least during the first two years of growth though thereafter they have the mutual shading effect from the sides. It is only after the seventh year the arecanut stem attains significant height and the crown gets lifted up above the canopy of cacao trees. So it can be expected that the shade of arecanut palms on the top of canopy of cacao can be expected to fall only after seventh year. In other words the interception of vertical light by the canopy of arecanut may have greater influencing effect on cacao canopy after seventh year and till then it is mostly the interception of slanting rays that may influence both arecanut and cacao mutually.

It is also indicated in the present studies that the horizontal coverage of the space is very efficient when cacao is mixed cropped with arecanut. It is most efficient at the closest spacing of 2.7m x 2.7m adopted for cacao. In the widest spacing of 5.4m x 5.4m even after ten years the ground is not fully covered by the canopy of cacao trees. Similarly the space that become available immediately above the ground level after the crown of arecanut gets lifted up after about seven years is advantageously utilised by the spreading cacao canopy. The crown of areca-nut palm and the canopy of cacao trees occupy different varied levels which is probably a good example of annidation.

The comparison made of on the growth of the cacao trees under the mixed cropping condition and under the sole cropping reveals that in the former case the trees are slightly taller and have significantly larger canopy spread than the latter. The girth of stems under the two conditions do not differ significantly. The environmental conditions under the mixed cropping system is probably responsible for the better growth of cacao trees.

The advantage of having a tall tree canopy of arecanut over the comparatively shorter tree canopy of cacao is that the competition factors which are absorbed through leaves (light and CO_2) can be expected to be minimum. Another factor which favours arecanut as a mixed crop with cacao is the possible penetration of more and more slant rays of sun as the age of the arecanut trees advances in view the crowns of the arecanut palms getting lifted gradually higher up. At this stage it may not be out of place to mention that arecanut palms attain a height of about 18 to 20 meters when they are about 20-25 years of age (personal observation) whereas cacao trees reach only about 8 to 10 meters at that age. It may be possible to restrict the growth of cacao trees by pruning adjustments. Thus the likely greater demand of light by the cacao trees as they grow older is met without much interruption by the single stem (12 to 20 cm diameter) arecanut palm. On its part cacao can and does serve as an effective protector for the tender, delicate stem of arecanut from direct and harmful exposure to sun in the early years as the latter are highly susceptible to sunscorch. Another benefit of growing cacao is that under the mixed crop conditions, weed growth is almost completely suppressed, probably because of the combined effect of shade as well as of leaf litter which gets deposited on the surface (Plate 2). The sole cropping with arecanut provides congenial condition for

Plate 2. Leaf litter of cacao deposited on the floor of the garden

Plate 2

rampant growth of weeds (Plate 3). One possible disadvantage of cacao as a mixed crop is at the time of underplanting (replanting) to replace ageing and uneconomical arecanut palms. The arecanut seedlings planted under the dense canopy of cacao have to struggle to emerge out of the etiolated condition. They develop thin and weak stem (Plate 4).

The mixed cropping condition did not bring in any significant difference either in the percentage of trees flowered at different ages or in the percentage fruits set in both the crops, thereby indicating that the combinations adopted had no adverse effect on flowering and fruit set in either of the crops.

Plate 3. Weed growth under the sole cropping of arecanut

Plate 3

Plate 4. Underplanted arecanut palm (weak and thin) struggling to emerge out of the cacao canopy

Plate 4

IV. ROOT DISTRIBUTION OF ARECANUT AND CACAO AS INFLUENCED BY MIXED CROPPING SYSTEM

ROOT DISTRIBUTION OF ARECANUT AND CACAO AS INFLUENCED BY MIXED CROPPING SYSTEM

Introduction

"Of the two environments in which plants grow, the soil is much the more complex. This is true whether air and soil are each considered from the physical, chemical or biological viewpoint. The soil not only affects the development and activities of roots directly, but also by modifying the function of roots, it affects the growth and yield of the above ground parts to a large degree, soil is a product of climate and vegetation" (Weaver, 1926).

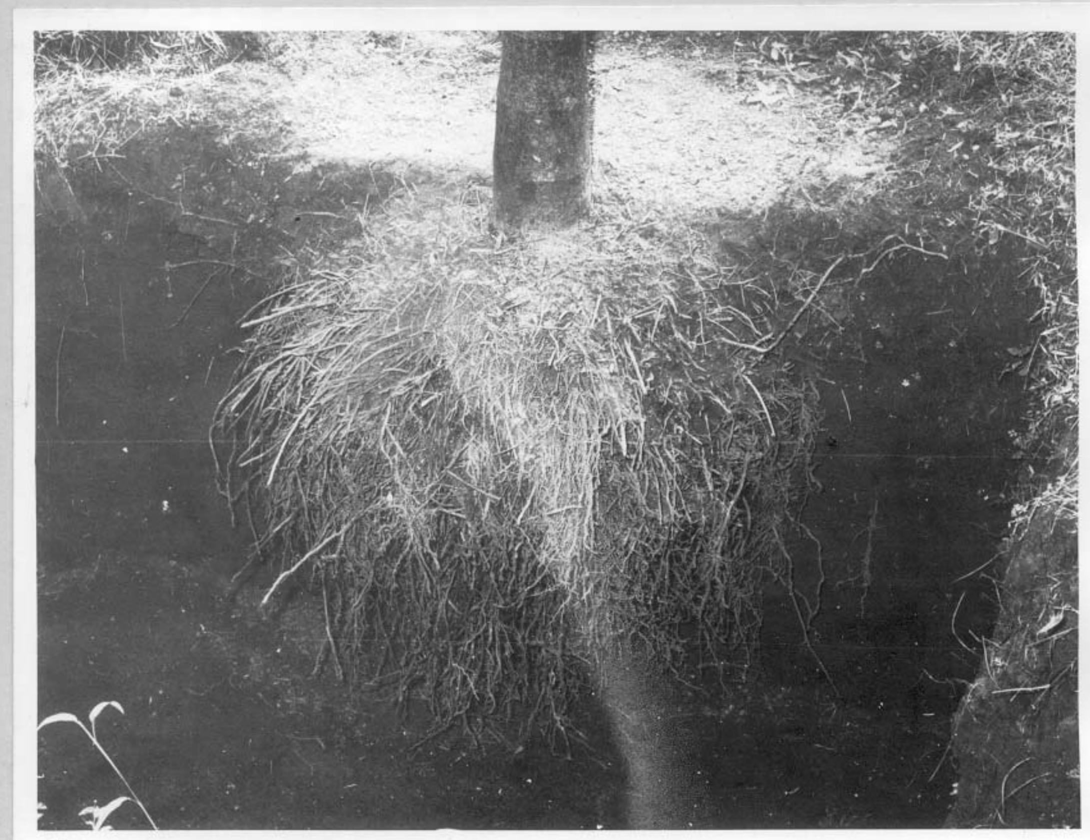
In the preface to his classic Root Development of Field Crops, Weaver described his subject as 'greatly neglected'. Russel (1977) stated that "the same claim could have been made more recently, plant and soil scientists have usually found little common interest in the study of the growth and function of root systems in the soil". He further added that the situation is now changing.

Knowledge of the plant root systems is the key to fundamental ecological understanding of many aspects of botany and their applied sciences such as agriculture, horticulture and forestry. For cultivated crops, it is important to obtain detailed information on the factors which impede root growth in the subsoil, and thus to decrease the risk of lower yields. The importance of the information on the root systems of plants involved in multiple cropping has a special significance since for the system to be advantageous, competition between species for available water and nutrients must be lower than competition between plants of the same species in single stands (Aiyer, 1949; Trenbath, 1976). Sanchez (1976) in his appraisal of the present knowledge and future needs of multiple cropping, stated that "the largest knowledge gap, by far, is what happens below the ground. Basic studies are needed on crop root competition, and how two or more different root systems can better utilise limited supplies of water and nutrients".

The root systems of the two species, *Areca catechu* and *Theobroma cacao*, involved in the present studies have been investigated by many workers where these crops are in pure stands. The arecanut palm, being a monocotyledon, has a fibrous type of root system without a tap root, and numerous roots radiate in all directions from the base of the stem or bole (Plate 5). Davis (1961) described the roots of the palm in relation to their origin, size, shape, function, structure, etc., and classified them into (i) the

Plate 5. Root system of arecanut palm

Plate 5



main adventitious roots emanating from the bole; (ii) the rootlets that branch from the main roots or their branches; (iii) the pneumatophores or breathing organs and (iv) the aerial roots which arise from the lower parts of stem. Bhat and Leela (1969) studied the distribution of arecanut roots in relation to density of planting under well drained deep laterite soil condition. They reported that 61 to 67 per cent of all roots (on dry weight basis) and 51 to [illegible] per cent of fine roots are concentrated within 50 cm radius of the palm and more than 80 per cent of all roots are within 1 to 1.25 m from the trunk, though some roots extend laterally beyond 1.75 m. The maximum concentration of from 66 to 79 per cent of all roots and from 72 to 76 per cent of fine roots are within the first 50 cm layer of the soil surface. The second layer, 51 to 100 cm deep, contains 18 to 23 per cent of all roots and 14 to 20 per cent of fine roots. The maximum depth of penetration of the roots is 2.6 m. Close planted palms appear to have a greater tendency to explore the lower strata than those planted wider apart. The quantity of roots (dry weight) per unit volume of soil within the feeding zone increases with increasing plant density, whereas the calculated gross quantity of roots produced per palm decreases with increased density of planting. As against the above, the root system of arecanut in a low lying garden with high water table, the lateral spread of roots is up to 2.75 m distance from the bole. The depth of spread is only up to 1.4 m (Bhat, 1978(b).

The root system of cacao has been investigated in different parts of the world by various investigators under varied ecological and edaphic conditions (McCreary et al. 1943; Hardy, 1944, 1971; van Himme, 1959; Dasilva, 1960; Zevallos and Alvim, 1966, 1967; Cadima, 1970; Oyanat-Nejad, 1971; Zevallos and Coral, 1972; and Falade, 1977). The general description of the root system do not vary very much. During germination the cacao bean produces a tap-root that grows rapidly downwards into the soil and gives rise to many laterals just below the soil surface. The tap-root continues to grow and reaches its maximum length in about the fourth year. The lateral roots develop rapidly and by about the fifth or sixth year occupy most of the upper layers of the soil. The dimensions and form of the tap-root of a tree are apparently and mainly decided by the penetrability, porosity and aeration of the soil. In the mature tree the length of the tap-root is about a meter. The length of tap-root will be less if there is a layer of impenetrable soil or a high water table or more if there is an exceptionally deep well-drained and porous soil. In any case the tap-root seldom exceeds about 150 cm in length. A typical tap-root is thick and tapering and devides into two or three short branches at its apex (Plate 6). Lateral woody roots emerge in whorls from the upper part of the tap-root. The number of distinct whorls, the number of laterals in each whorl, the thickness and length of the laterals and the extent of branching appear to be decided mainly by the features of the soil. In compact clay soils having shallow humus layer, the laterals are relatively few in number, they are thin and long, sparsely branched and often contorted. In open-structured porous soils having deep humic layer the laterals tend to be numerous though thick, short and straight with many branches. From the laterals numerous find fibrous rootlets emerge, which tend to associate with decomposing leaf litter and other organic matter. 'Sinker' roots are also produced occasionally from the main laterals, which descend more or less vertically to a depth of about a meter. Work of DaSilva (1960) in Sao Tome on the root systems of cacao trees grown in clay soils derived from basalts on steep slopes (30 to 50 per cent) shows that under those conditions the distribution of the root system is very different. The tap-root remains dominant. The laterals with restricted growth and ramification traverse diagonally downwards towards the parent rock at depth of 90 or 120 cm and there is no root mat on the surface.

Plate 6.   Tap and lateral roots of cacao

Plate 6

Swarbrick (1964) studied the growth and root distribution of some temporary shade plants for cacao in West Nigeria. Zevallos and Alvim (1967) while studying the influence of the shade tree, Erythrina glauca, on some soil factors relating to cacao yields state that the lateral roots of the cacao trees situated near the Erythrina grow to a depth of 60 cm whereas with cacao trees located further away from the shade trees similar penetration of lateral roots are not found. Bhat and Bavappa (1972) studied the pattern of root spread of a set of young arecanut and cacao trees (each 7-year old) planted mixed. They found that the maximum concentrations in both is confined to a core of 60 cm radius and 50 cm depth from the base of each tree. Falade (1977) reported that the distribution of cacao roots is influenced by nitrogen fertiliser application. The application of fertiliser either decreased, increased or did not affect the quantity of roots depending on the fraction, soil depth and dose of nitrogen considered.

From the foregoing it is seen that most of the information available on the root system of cacao (except that reported by DaSilva, 1960) is based on the studies made on cacao trees growing under humid tropical forest soils with rich deposits of humus or litter mulch. The information provided by Bhat and Bavappa (1972) is for a young garden. Cacao as an agricultural plantation crop mixed with arecanut is of recent evocation in India and information on the behaviour of the root systems of the two trees under these conditions is lacking. Hence the present study.

Materials and Methods

The study was undertaken in the experimental garden of the CPCRI, Regional Station, Vittal during January to May, 1980. The garden has a deep, fairly uniform, well drained laterite soil and is irrigated during dry weather from middle of November to middle of May each year. The trees (both arecanut and cacao) selected for the study were uniformly 10-year old.

The procedure adopted for studying the root system was the soil-block or the quantitative method, with slight modifications, used or described by Franco and Inforzato (1951), Leon and Umana (1961) and Gehrke Velez (1962) who undertook similar studies in coffee and rubber and later found suitable and applicable for arecanut (Bhat and Leela, 1969). The method consisted of digging a trench, 50 cm wide between two adjacent trees commencing at a distance of 25 cm from the centre of each tree. The soil from the trench was removed in rectangular blocks 50 cm wide, 25 cm long and 10 cm deep, layer by layer. Excavation was continued until no traces of roots were seen. The roots from each block of soil were washed, dried and weighed. Among the various parameters described by Bohm (1979), only root dry weight was recorded after separating the roots as thick (> 2 mm in diameter) and fine (< 2 mm in diameter). The studies were made for three sets of trees viz., (1) arecanut palms planted as sole crop; (2) cacao planted as sole crop; and (3) arecanut and cacao planted as mixed crop.

Results

1. Arecanut palms planted as sole crop

The data on distribution of total, thick and fine roots at different distances from the centre of the palm are given in Table 25. It may be observed that 61.1 per cent of all roots, 69.9 per cent of thick roots and 51.3 per cent of fine roots (less than 2 mm in diameter) are concentrated within 50 cm radius from the centre of the palm. In the next sector lying between 51 and 100 cm from the stem the concentration of total, thick and fine roots are 27.9, 23.2 and 33.1 per cent respectively. In the area beyond 101 cm contains 11.0 per cent of all roots, 6.9 per cent of thick roots and 15.6 per cent of fine roots.

The data on distribution of total, thick and fine roots at different depths are given in Table 26. It can be

Table 25. Distribution of arecanut roots at different distances from the tree (sole crop)

Distance from the stem	Total wt. of all roots (g)	% all roots	Thick roots (g)	% thick roots	Fine roots (g)	% fine roots
0-25	216.00	20.35	130.00	23.22	85.70	17.10
26-50	432.50	40.76	261.30	46.66	171.50	34.21
51-75	205.70	19.38	89.20	15.93	116.50	23.24
76-100	90.05	8.49	40.55	7.24	49.50	9.88
101-125	61.90	5.83	19.90	3.55	42.00	8.38
126-150	55.05	5.19	19.00	3.40	36.05	7.19
Total	1061.20	100.00	559.95	100.00	501.25	100.00

(Data pertain to the profile excavated)

Table 26. Distribution of arecanut roots at different depths (sole crop)

Depth (cm)	Total wt. of all roots (g)	% all roots	Thick roots (g)	% thick roots	Fine roots (g)	% fine roots
0–10	220.60	20.79	72.20	12.89	148.40	29.61
11–20	164.00	15.45	86.60	15.46	77.40	15.44
21–30	161.80	15.25	94.70	16.91	67.10	13.39
31–40	96.20	9.07	49.60	8.86	46.60	9.30
41–50	61.90	5.83	37.10	6.63	24.80	4.95
51–60	63.00	5.94	41.50	7.41	21.50	4.29
61–70	51.70	4.87	35.00	6.25	16.70	3.33
71–80	47.40	4.47	32.90	5.88	14.50	2.89
81–90	37.45	3.53	29.65	5.29	7.80	1.55
91–100	22.65	2.13	16.75	2.99	5.90	1.17
101–110	17.00	1.60	11.90	2.13	5.10	1.01
111–120	16.00	1.51	8.30	1.48	7.70	1.53
121–130	15.85	1.49	10.15	1.81	5.70	1.14
131–140	11.20	1.05	5.90	1.05	5.30	1.06
141–150	9.80	0.92	4.60	0.82	5.20	1.04
151–160	11.95	1.13	6.05	1.08	5.90	1.18
161–170	8.20	0.77	3.30	0.59	4.90	0.98
171–180	8.35	0.79	4.55	0.82	4.80	0.96
181–190	9.95	0.94	3.55	0.63	6.40	1.28
191–200	9.40	0.89	2.90	0.52	6.50	1.30
201–210	9.05	0.86	2.25	0.41	6.80	1.36
211–220	2.90	0.27	—	—	2.90	0.58
221–230	1.20	0.11	0.50	0.09	0.70	0.14
231–240	1.75	0.16	—	—	1.75	0.34
241–250	0.50	0.05	—	—	0.50	0.10
251–260	0.40	0.04	—	—	0.40	0.08
Total	1061.20	100.00	559.95	100.00	501.25	100.00

(Data pertain to the profile excavated)

noted that the roots extend up to a depth of 2.6 m below ground level. The maximum quantity of all roots (66.4 per cent), thick roots (60.7 per cent) and fine roots (72.7 per cent) are within the first 50 cm depth. The lower strata, 51 to 100 cm below ground level contains 21.0 per cent of all roots, 27.8 per cent thick roots and 13.2 per cent of fine roots. The strata below 101 cm contains only 12.6 per cent of all roots, 11.5 per cent of thick roots and 14.1 per cent of fine roots.

2. Cacao trees planted as sole crop

Table 27 shows the dry weight of roots in the profile excavated at different distances from the centres of the tree. It is seen that maximum concentration is within 25 cm radius from the tree. The percentages of all roots, thick and fine roots within 50 cm radius are 80.7, 86.3 and 68.7 respectively. There is a sharp decrease in the dry weight of all categories of roots beyond 50 cm radius. More than 99.0 per cent of all roots, 99.0 per cent of thick roots and 98.0 per cent of fine roots have their lateral spread within 180 cm radius from the tree.

Table 28 shows the dry weight of roots at different depths. It is clear that they have traversed to a maximum depth of about 350 cm, though the maximum ramification of all roots (67.8 per cent), thick roots (71.6 per

Table 27. Distribution of cacao roots at different distances from the tree (sole crop)

Distance from centre of stem (cm)	Total wt. of all roots (g)	% all roots	Thick roots (g)	% thick roots	Fine roots (g)	% fine roots
0–25	605.10	63.26	465.38	71.62	139.72	45.56
26–50	166.72	17.43	95.62	14.71	71.10	23.19
51–75	79.77	8.34	43.88	6.75	35.89	11.70
76–100	41.67	4.38	17.59	2.71	24.28	7.92
101–125	34.79	3.64	16.84	2.59	17.95	5.85
126–150	21.10	2.20	8.64	1.33	12.46	4.06
151–175	7.15	0.75	1.88	0.29	5.27	1.72
Total	956.50	100.00	649.83	100.00	306.67	100.00

(Data pertain to the profile excavated)

Table 28. Distribution of cacao roots at different depths (sole crop)

Depth (cm)	Total wt. of all roots(g)	% all roots	Thick roots (g)	% thick roots	Fine roots (g)	% fine roots
0-10	99.26	10.38	36.24	5.58	63.02	20.35
11-20	123.43	12.90	75.24	11.58	48.19	15.72
21-30	163.16	17.06	129.30	19.90	33.86	11.04
31-40	157.54	16.47	132.99	20.46	24.55	8.00
41-50	104.76	10.95	91.29	14.06	13.47	4.35
51-60	72.45	7.57	61.49	9.46	10.96	3.57
61-70	43.21	4.52	32.75	5.04	10.46	3.41
71-80	40.32	4.22	28.26	4.35	12.06	3.93
81-90	13.14	1.37	7.34	1.13	5.80	1.89
91-100	13.97	1.46	8.69	1.34	5.28	1.72
101-110	11.21	1.17	6.66	1.03	4.55	1.48
111-120	8.80	0.92	4.13	0.63	4.67	1.52
121-130	8.86	0.93	4.92	0.76	3.94	1.28
131-140	7.67	0.80	3.48	0.53	4.19	1.37
141-150	6.12	0.64	3.05	0.47	3.07	1.00
151-160	7.23	0.76	3.38	0.53	3.85	1.26
161-170	7.94	0.83	3.72	0.57	4.22	1.38
171-180	8.32	0.87	2.78	0.43	5.54	1.81
181-190	8.59	0.90	2.20	0.34	6.39	2.08
191-200	10.05	1.06	3.47	0.53	6.58	2.15
201-210	8.77	0.92	3.11	0.48	5.66	1.85
211-220	4.25	0.44	0.68	0.10	3.57	1.16
221-230	5.20	0.54	1.15	0.18	4.05	1.32
231-240	5.28	0.55	1.15	0.18	4.13	1.35
241-250	4.19	0.44	0.40	0.06	3.79	1.24

Table 28 (contd.)

Depth (cm)	Total wt. of all roots (g)	% all roots	Thick roots (g)	% thick roots	Fine roots (g)	% fine roots
251–260	3.85	0.40	0.41	0.06	3.44	1.12
261–270	2.22	0.23	0.38	0.05	1.92	0.63
271–280	1.78	0.19	0.48	0.07	1.30	0.42
281–290	0.83	0.09	0.20	0.03	0.63	0.21
291–300	0.85	0.09	0.30	0.05	0.55	0.18
301–310	0.59	0.06	0.06	0.01	0.53	0.17
311–320	1.52	0.16	0.04	0.01	1.48	0.48
321–330	0.58	0.06	0.07	0.01	0.51	0.17
331–340	0.52	0.05	0.00	0.00	0.52	0.17
341–350	0.06	0.01	0.00	0.00	0.06	0.02
Total	956.50	100.00	649.83	100.00	306.67	100.00

(Data pertain to the profile excavated)

cent) and fine roots (59.7 per cent) is within 50 cm from ground level. There is a sharp decrease in all categories of roots below 51 cm depth. The horizon within 100 cm has 86.9 per cent of all roots, 92.9 per cent of thick roots and 74.2 per cent of fine roots. The strata beyond 100 cm contains only 13.1 per cent of all roots, 7.1 per cent of thick roots and 25.8 per cent of fine roots.

3. Arecanut and cacao trees planted as mixed crop

The dry weight of arecanut roots at different distances from the tree is given in Table 29. It is seen that 64.9 per cent of all roots, 72.6 per cent of thick roots and 51.0 per cent of fine roots are within 50 cm radius from the centre of the stem. The sector between 51 and 75 cm radius contains 26.1 per cent of all roots, 21.1 per cent of thick roots and 35.1 per cent of fine roots. The third sector between 76 and 100 cm is occupied by only 7.5 per cent of all roots, 5.4 per cent of thick roots and 11.1 per cent of fine roots. There is rapid decrease in the quantity of all categories of roots after 100 cm radius. Thus within a radius of 100 cm, 98.4 per cent of all roots, 99.1 per cent of thick roots and 97.2 per cent of fine roots have their lateral spread.

The dry weight of arecanut roots at different depths is presented in Table 30. The maximum concentration with 55.2 per cent of total roots, 54.0 per cent of thick roots

Table 29. Distribution of arecanut roots at different distances from the tree (mixed garden)

Distance from centre of stem (cm)	Total wt. of all roots (g)	% all roots	Thick roots (g)	% thick roots	Fine roots (g)	% fine roots
0-25	878.00	21.60	631.43	24.20	247.05	16.90
26-50	1757.43	43.25	1262.86	48.41	494.09	33.97
51-75	1060.20	26.09	549.10	21.05	511.10	35.13
76-100	302.88	7.45	141.04	5.41	161.84	11.12
101-125	33.22	0.82	13.46	0.52	19.76	1.36
126-150	8.09	0.20	1.89	0.07	6.20	0.43
151-175	11.59	0.29	5.04	0.19	6.55	0.45
176-200	4.93	0.12	2.33	0.09	2.60	0.18
201-225	7.26	0.18	1.71	0.06	5.55	0.38
Total	4063.60	100.00	2608.86	100.00	1454.74	100.00

(Data pertain to the profile excavated)

Table 30. Distribution of arecanut roots at different depths (mixed garden)

Depth (cm)	Total wt. of all roots(g)	% all roots	Thick roots (g)	% thick roots	Fine roots (g)	% fine roots
0-10	43.17	1.062	9.04	0.346	34.13	2.346
11-20	222.85	5.484	86.39	3.311	136.46	9.380
21-30	456.91	11.243	224.08	8.589	232.83	16.004
31-40	881.82	21.700	639.94	24.529	241.88	16.627
41-50	637.88	15.697	448.27	17.182	189.61	13.033
51-60	517.00	12.722	358.25	13.732	158.75	10.912
61-70	427.08	10.509	293.22	11.239	133.86	9.201
71-80	362.36	8.917	243.29	9.325	119.07	8.184
81-90	244.25	6.010	158.82	6.087	85.43	5.872
91-100	126.24	3.106	90.28	3.460	35.96	2.471
101-110	67.09	1.650	34.02	1.304	33.07	2.273
111-120	34.04	0.837	9.28	0.355	24.76	1.702
121-130	17.96	0.441	7.12	0.272	10.84	0.745
131-140	10.10	0.248	2.40	0.091	7.70	0.529
141-150	5.78	0.142	1.95	0.074	3.83	0.263
151-160	3.56	0.087	0.90	0.034	2.66	0.182
161-170	1.63	0.040	0.36	0.013	1.27	0.087
171-180	1.07	0.026	0.27	0.010	0.80	0.054
181-190	0.42	0.010	0.15	0.005	0.27	0.018
191-200	0.33	0.008	0.21	0.008	0.12	0.008
201-210	0.23	0.005	0.18	0.006	0.05	0.003
211-220	0.56	0.013	0.20	0.007	0.36	0.024
221-230	0.63	0.015	0.11	0.004	0.52	0.035
231-240	0.00	0.000	0.00	0.000	0.00	0.000
241-250	0.18	0.004	0.13	0.004	0.05	0.003
251-260	0.33	0.008	0.00	0.000	0.33	0.022
261-270	0.00	0.000	0.00	0.000	0.00	0.000
271-280	0.00	0.000	0.00	0.000	0.00	0.000
281-290	0.13	0.003	0.00	0.000	0.13	0.008
Total	4063.60	99.997	2608.86	99.997	1454.74	99.999

(Data pertain to the profile excavated)

and 57.4 per cent of fine roots is within 50 cm depth and whereas 41.3 per cent of all roots, 43.8 per cent of thick roots, and 36.6 per cent of fine roots are within the layer between 51 to 100 cm. The magnitude of roots traversing deeper than 100 cm is comparatively low though the roots tend to reach to a maximum depth of about 300 cm.

The dry weight of cacao roots at different distances from the stem is given in Table 31. It is obvious that 41.9 per cent of all roots, 51.9 per cent of thick roots and 24.0 per cent of fine roots are within 25 cm radius. The sector between 26 and 50 cm radius contains 14.1 per cent of all roots, 13.2 per cent of thick roots and 15.7 per cent of fine roots. The third sector comprising of the space between 51 and 75 cm has 11.4 per cent of all roots, 9.4 per cent of thick roots and 15.1 per cent of fine roots. There is generally a decrease in the quantity of total and thick roots beyond 75 cm radius, from 7.1 to 3.5 per cent in the case of total roots and 6.3 to 1.7 per cent in the case of thick roots except between 101 to 125 cm.

The dry weight of cacao roots at different depths from surface is seen in Table 32. The first horizon up to 50 cm is occupied by 39.7 per cent of all roots, 45.4 per cent of thick roots and 2?.8 per cent of fine roots.

Table 31. Distribution of cacao roots at different distances from the tree (mixed garden)

Distance from centre of stem (cm)	Total wt. of all roots (g)	% all roots	Thick roots (g)	% thick roots	Fine roots (g)	% fine roots
0-25	344.31	41.87	272.05	51.89	72.26	23.98
26-50	115.80	14.08	69.26	13.21	46.54	15.66
51-75	94.02	11.43	49.14	9.37	44.88	15.11
76-100	58.44	7.11	33.03	6.30	25.41	8.55
101-125	89.98	10.94	56.73	10.82	33.25	11.19
126-150	48.14	5.85	21.26	4.06	26.88	9.05
151-175	42.77	5.20	14.04	2.68	28.73	9.67
176-200	28.93	3.52	8.76	1.67	20.17	6.79
Total	822.39	100.00	524.27	100.00	298.12	100.00

(Data pertain to the profile excavated)

Table 32. Distribution of cacao roots at different depths (mixed garden)

Depth(cm)	Total wt. of all roots (g)	% all roots	Thick roots (g)	% thick roots	Fine roots(g)	% fine roots
0-10	124.51	15.140	76.53	14.597	47.98	16.148
11-20	98.71	12.003	77.53	14.788	21.18	7.128
21-30	77.54	9.429	68.50	13.065	9.04	3.042
31-40	17.32	2.106	13.23	2.523	4.09	1.376
41-50	8.25	1.003	2.00	0.381	6.25	2.103
51-60	28.74	3.495	22.54	4.299	6.20	2.086
61-70	55.94	6.802	47.22	9.006	8.72	2.934
71-80	91.82	11.165	83.00	15.831	8.82	2.968
81-90	65.91	8.014	56.78	10.830	9.13	3.072
91-100	16.28	1.979	10.47	1.997	5.81	1.955
101-110	14.59	1.774	7.21	1.375	7.38	2.483
111-120	12.78	1.554	4.00	0.762	8.78	2.955
121-130	9.24	1.123	3.90	0.743	5.34	1.797
131-140	23.99	2.917	14.14	2.697	9.85	3.315
141-150	13.85	1.684	5.12	0.976	8.73	2.938
151-160	11.68	1.420	4.09	0.780	7.59	2.554
161-170	12.06	1.466	2.65	0.505	9.41	3.167
171-180	10.30	1.252	3.70	0.705	6.60	2.221
181-190	8.97	1.091	2.45	0.467	6.52	2.194
191-200	8.55	1.040	2.37	0.452	6.18	2.079
201-210	6.18	0.751	1.56	0.297	4.62	1.554
211-220	8.05	0.979	2.08	0.396	5.97	2.009
221-230	11.32	1.376	5.49	1.047	5.83	1.962
231-240	4.14	0.503	0.93	0.177	3.21	1.080
241-250	5.24	0.637	0.20	0.038	5.04	1.696

Table 32 (contd.)

Depth(mm)	Total wt. of all roots(g)	% all roots	Thick roots (g)	% thick roots	Fine roots(g)	% fine roots
251–260	4.96	0.603	0.71	0.135	4.25	1.430
261–270	3.82	0.464	0.00	0.000	3.82	1.285
271–280	3.94	0.479	0.43	0.082	3.51	1.181
281–290	4.37	0.531	0.83	0.158	3.54	1.191
291–300	3.83	0.466	0.56	0.106	3.27	1.100
301–310	3.99	0.485	0.78	0.148	3.21	1.080
311–320	4.32	0.525	0.00	0.000	4.32	1.453
321–330	5.19	0.631	0.14	0.026	5.05	1.699
331–340	5.57	0.677	1.24	0.236	4.33	1.457
341–350	4.24	0.515	0.52	0.099	3.72	1.252
351–360	5.16	0.627	0.77	0.146	4.39	1.140
361–370	3.76	0.457	0.24	0.045	3.52	1.184
371–380	4.55	0.553	0.00	0.000	4.55	1.531
381–390	4.48	0.545	0.00	0.000	4.48	1.507
391–400	2.87	0.349	0.00	0.000	2.87	0.965
401–410	2.49	0.303	0.36	0.068	2.13	0.716
411–420	3.21	0.390	0.00	0.000	3.21	1.080
421–430	2.79	0.339	0.00	0.000	2.79	0.939
431–440	1.20	0.146	0.00	0.000	1.20	0.403
441–450	0.80	0.097	0.00	0.000	0.80	0.269
451–460	0.51	0.062	0.00	0.000	0.51	0.171
461–470	0.14	0.017	0.00	0.000	0.14	0.047
471–480	0.24	0.029	0.00	0.000	0.24	0.080
Total	822.39	100.004	524.27	99.983	298.12	99.978

(Data pertain to the profile excavated)

The second horizon from 51 to 100 cm has 31.5 per cent of all roots, 42.0 per cent of thick roots and 13.0 per cent of fine roots. The third zone covering 101 to 200 cm has 15.3 per cent of all roots, 9.5 per cent of thick roots and 28.7 per cent of fine roots. The fourth layer between 201 to 300 cm is occupied by 6.8 per cent of all roots, 2.4 per cent of thick roots and 14.5 per cent of fine roots. The region below 301 cm to 400 cm has 6.7 per cent of all roots, 0.8 per cent of thick roots and 17.0 per cent of fine roots. The distribution of all groups of roots progressively decrease in the deeper layers beyond 100 cm, though the roots ramify to a depth of up to about 400 cm.

Discussion

The present studies clearly bring out the general pattern of the root system in the arecanut palm and in the cacao tree when they are planted as either sole crops or in mixed conditions under irrigated conditions in well drained laterite soil. Arecanut when planted as sole crop has more than 85 per cent of the total root system within a cylindrical mass of soil 100 to 125 cm in radius from the stem and extending about 100 cm in depth below ground level, though comparatively a small percentage (11) extend about 150 cm distance laterally and 300 cm downwards from the bole. The maximum concentration and ramification of thick and fine roots is within the top 50 cm layer of the soil. This is in general agreement with earlier studies (Bhat and Leela, 1969).

Cocoa when planted as sole crop has more than 85 per cent of the total root system within a soil mass of 100 to 125 cm in radius from the stem and extending up to 200 cm depth below ground level, though the remaining 15 per cent of the roots traverse as deep as 330 cm. The general pattern of root system of cacao it would appear to show a marked variation in its distribution habit from those described by McCreary et al. (1943) and Hardy (1944,1971) in the humid tropical soils of West Africa and by DaSilva (1960) in clay soils of Sao Tome. In the forest soils the root system is reported to be superficial with roots reaching to not more than 100 to 150 cm depth. The fibrous rootlets are found to associate with decomposing leaf litter and organic matter (Hardy, 1944). In Sao Tome in clay soils derived from basalts there is no root matting on the surface soil (Da Silva, 1960). The present studies, it is interesting to note, have revealed a more aggressive form of root system in irrigated, well-drained laterite soils of Vittal (West Coast of India).

Under mixed crop conditions the root system of arecanut palm though has more or less a similar sphere of activity (both laterally and vertically) as sole crop (Figs. 9 and 10), there appears to be some difference in percentage distribution of different types of roots under the two systems (Tables 26 and 30). Under mixed crop condition, interestingly more than 96 per cent of thick roots are within 100 cm depth, whereas under pure crop system only about 88 per cent are within the same depth. The quantity of fine roots in the top 50 cm layer is only 57 per cent under mixed crop condition as against 73 per cent when planted pure. There is a greater exploitation by the fine roots in the second layer between 50 to 100 cm under mixed crop condition than under pure crop system, the percentages of fine roots in the second layer under the two systems being 36.6 and 13.2 respectively.

Under mixed crop conditions the orientation of cacao roots also appear to get modified. The roots of cacao spread up to about 200 cm laterally and penetrate as deep as 480 cm when planted mixed with arecanut as against up to about 175 cm laterally and to a depth of 350 cm when the tree is a sole crop (Figs. 11 and 12). The percentage distribution of different categories of roots also seem to vary under the two systems of planting. The percentage of all roots is only 39.7 in the first 50 cm layer when the crop is planted mixed, whereas it is 67.8 per cent under sole crop condition. The percentage of fine roots is only 29.8 in the first 50 cm layer under mixed crop condition, but under sole crop system it is 59.7 per cent under the same depth. In fact, the

FIG.9. LATERAL DISTRIBUTION OF ARECANUT ROOTS

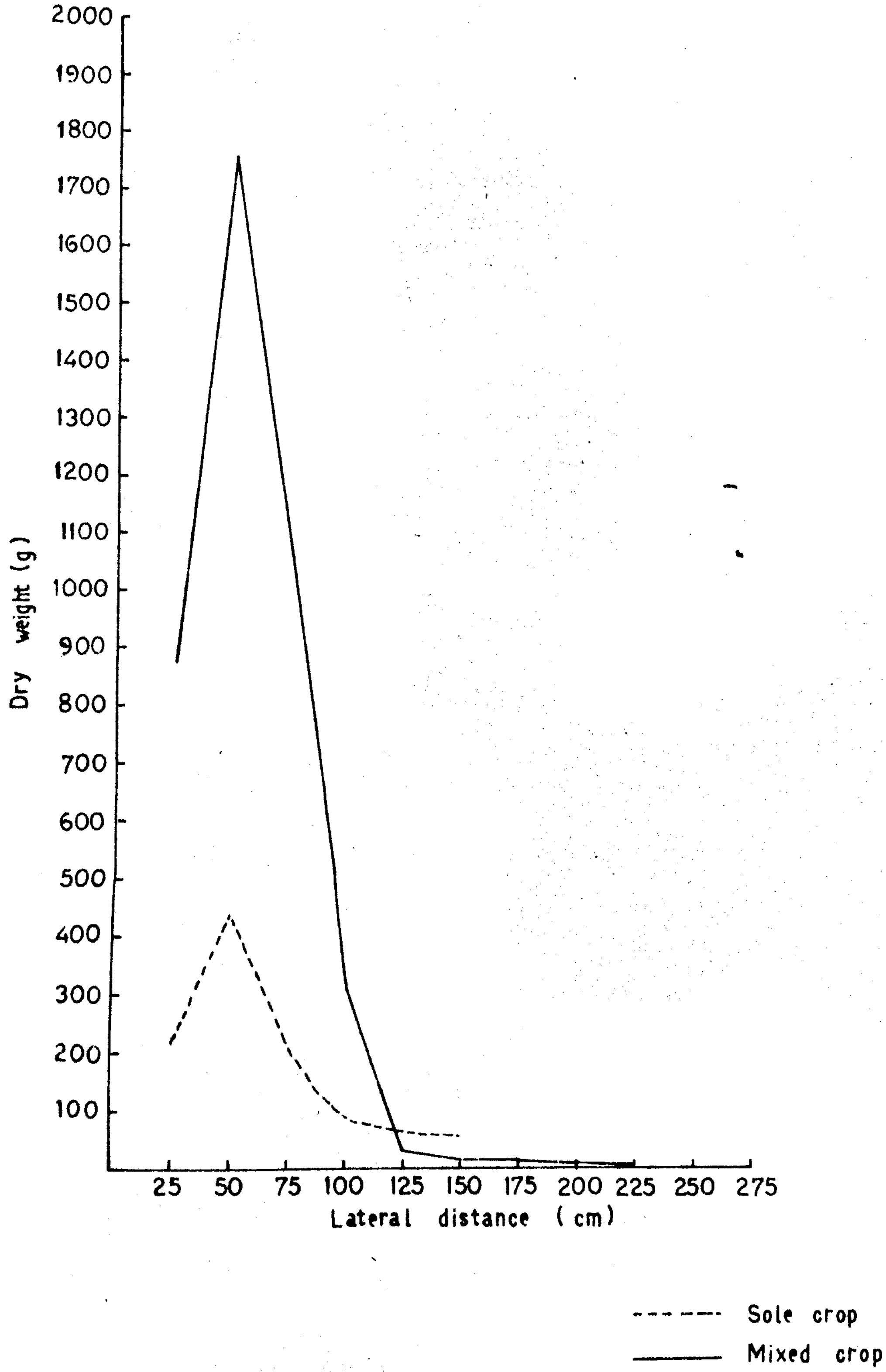


FIG 10 VERTICAL DISTRIBUTION OF ARECANUT ROOTS

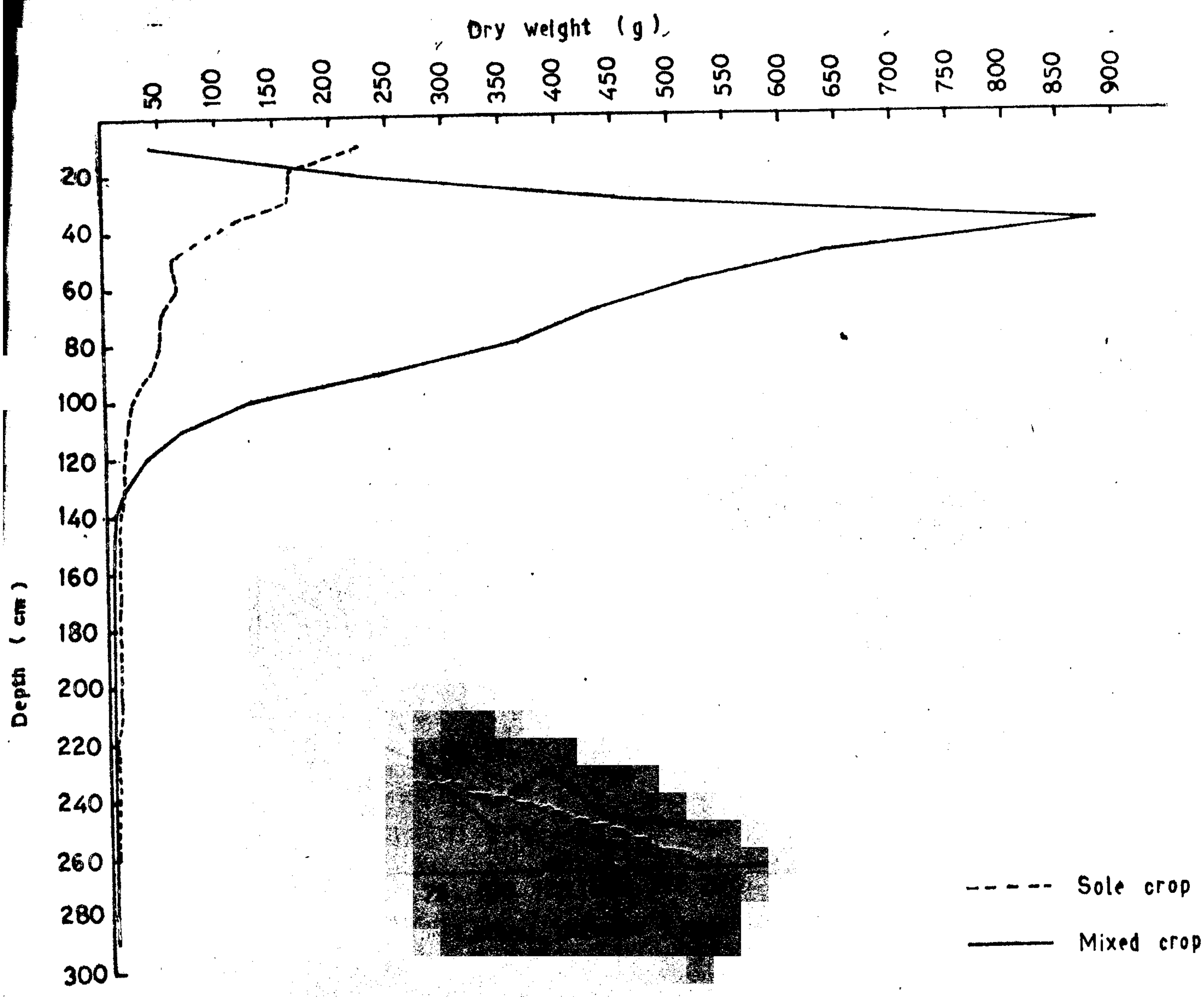


FIG.11. LATERAL DISTRIBUTION OF CACAO ROOTS

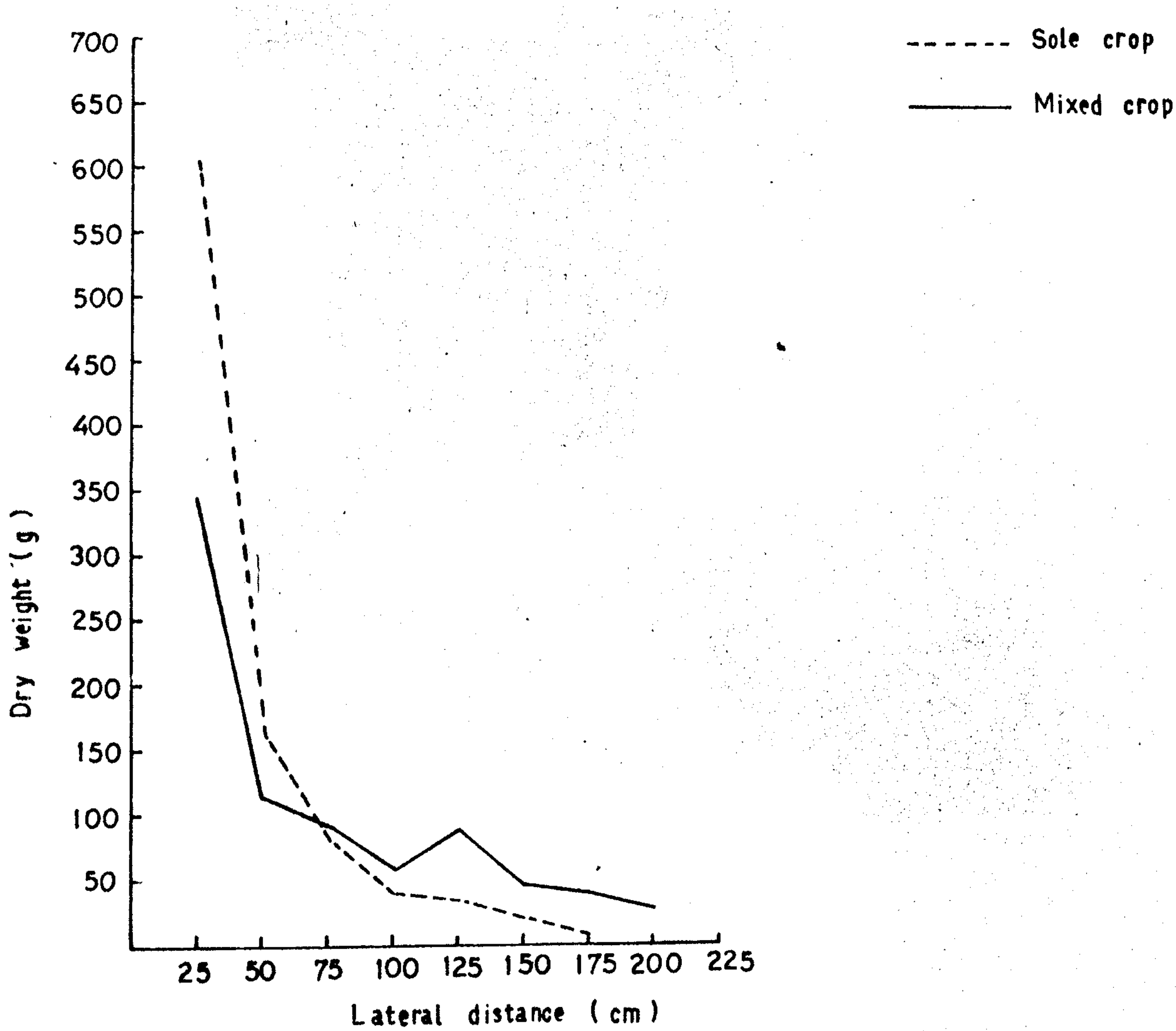
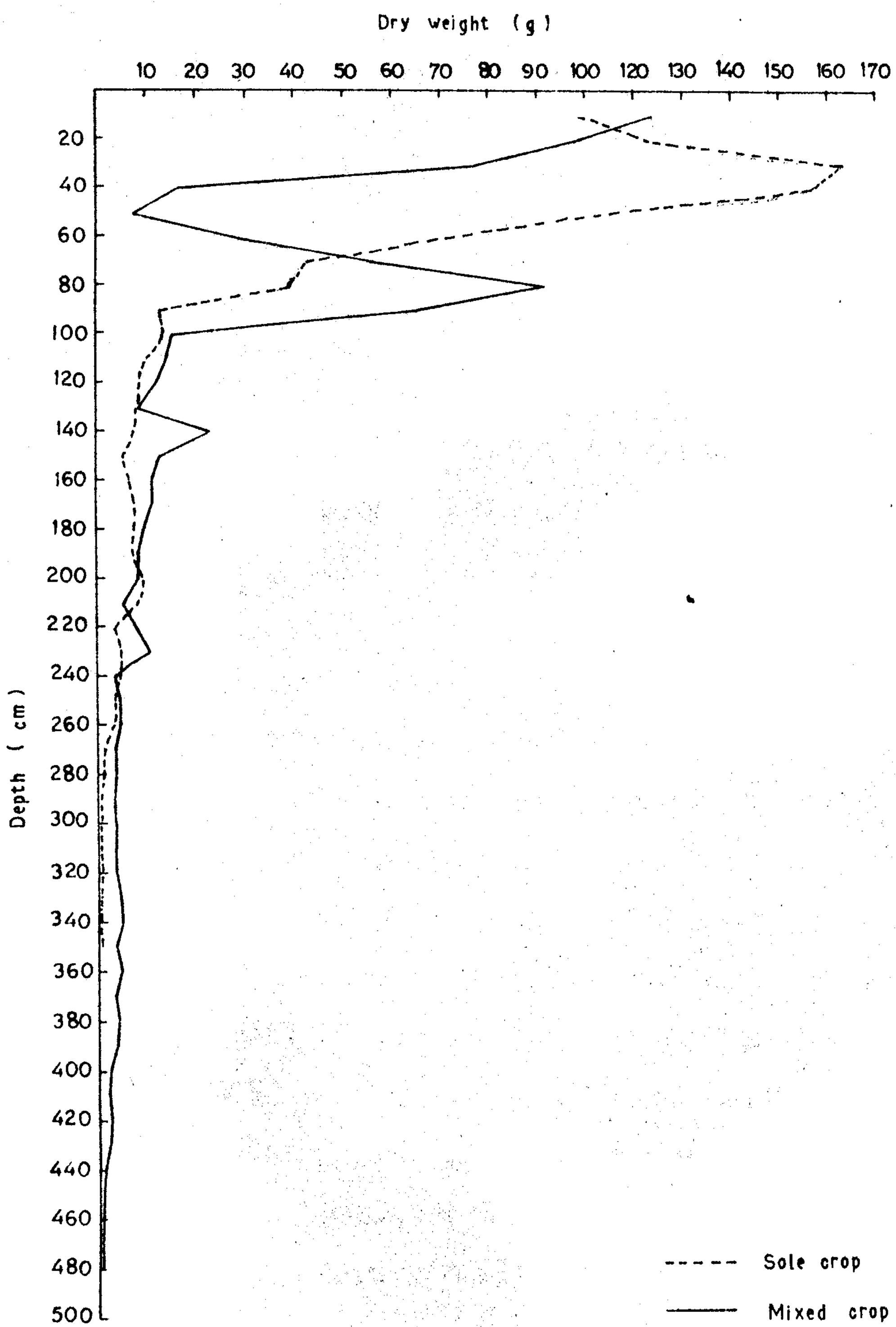


FIG. 12. VERTICAL DISTRIBUTION OF CACAO ROOTS



ramification of fine roots is comparatively very much greater, with about 90 per cent, occupying the upper zones (up to 200 cm below ground level) in the case of a sole crop of cacao as against the same quantity (per cent) of roots spreading up to 350 cm depth in mixed crop condition.

The orientation of tree roots is known to be affected by several factors, some will have a direct effect, for example, soil hardness, aeration, temperature, moisture or nutrient status. Other presumable factors like light intensity, pruning, competition from developing fruits or shoots, through their indirect effect also influence in modifying the root systems of perennial woody trees (Rogers and Head, 1968). These many factors can influence individually or may interact giving a complex effect. The orientation of the root system of mature apple trees under orchard conditions consists generally of horizontal main lateral roots 25 to 30 cm below the surface commonly spreading from 1½ to 3 times as far as the branches, with sinker roots descending down to 2.75 m or more (Rogers and Vyvyan, 1934). Rogers and Head (1968) state that the size and shape of the root system is, however, very much modified by soil condition.

Excavations at East Malling have revealed that vertical penetration is limited by hard rock or by compact layers of soil, such as iron pan. Rodriguez-Ortiz and Crosby (1956) have shown limitation of root growth in soil compacted by vehicle traffic. In the case of cacao McCreary et al. (1943) have drawn distinction between "physiologically shallow" and "physiologically deep" soils in which the features of the root systems are different and characteristic. Physiologically shallow soil is represented by compact clay soils occupying both flat and undulating topography and sandy soils seen in low-lying sites. In this case the shallowness is due to drainage impedence caused by impervious soil structure or by a high water-table. Physiologically deep soil is represented by crumby clay soils and sandy soils occupying elevated undulating topography. In such situations the under-drainage is free and water-table low. In physiologically shallow soils, the cacao root system is mainly superficial (being confined to the top 15 cm). It is characterised by (i) a dense mat of superficial fibrous roots closely associated with leaf litter or organic mulch (ii) long, thin, forked tap-root, and (iii) long laterals, which diminish in length and thickness with depth. The root system seen in physiologically deep soils is well ramified. It is characterised by (i) the absence of a superficial root mat, (ii) short, thick tap-root, (iii) short laterals, arising in whorls to the full depth of humic soil, and (iv) free branching of laterals ending in tufts of fibrous rootlets evenly distributed throughout the porous soil. Work in Sao Tome on the root systems of cacao trees grown in clay soils derived from basalts on steep slopes (30° to 45°) shows that under these conditions the distribution of the root system is very different. The tap-root remains dominant, the laterals have a restricted growth which descend obliquely downwards towards the parent rock at depths of 90 to 120 cm, and there is no root mat at the surface (da Silva, 1960). A high water table causing poor aeration is another limiting factor to root growth (Rogers and Vyvyan, 1934).

Root growth as well as the stem : root ratio are influenced by soil fertility. Apple trees excavated from a loam soil at East Malling showed a stem : root weight ratio of about 2 : 1, irrespective of different tree size induced by different rootstocks. Similar trees excavated from a poor sandy soil had a stem : root ratio of about 1 : 1, showing that it required about twice the amount of root to support a given amount of top growth on the poor soil as on the fertile loam (Rogers and Head, 1968).

Among the factors listed by Rogers and Head (1968) to affect the growth of the roots of perennial woody species is the soil nutrient status. Poor nutrient status alters the character of root growth by increasing the development of extension roots at the expense of lateral roots. Conversely, high levels of soil organic matter, high ion concentrations or local fertiliser application have encouraged branching. In some cases variations in nitrogen level has been associated with differences in root auxin levels and this has been held to be the cause of different root morphology (Bosemark, 1954). Cahoon et al. (1959) showed that various nitrogen fertiliser treatments affect the concentration of roots of mature citrus trees in the first 120 cm of soil. On the other hand, too high fertiliser concentrations may depress root growth. Ford et al. (1957) found with citrus trees that continued application of high levels of nitrogen fertiliser for 8 years resulted in a greatly decreased root weight between 13 and 79 cm from the soil surface. Falade (1977) investigated the effect of continued application of nitrogen fertiliser at 0.0, 45.0, 90.0 and 180.0 kg per hectare as urea on the spatial distribution of cacao roots. He found the vertical distribution of roots to be greatly affected by the fertiliser treatments. The treatment either decreased, increased or did not affect the quantity of roots depending on the fraction, soil depth and dose of nitrogen considered.

Under field conditions variations in water supply are frequently the principal causes of differences in the spread of roots, particularly the depth they attain in soil. Weaver (1926) illustrated contrasting rooting patterns in comparable soils due to climatic differences. In a similar manner, extension of root system is usually greater in drier soils than in wetter ones. Drying of the soil on the other hand, may temporarily reduce root growth (Rogers, 1934). Newman (1966) has demonstrated an often enhanced growth of lower parts of root system when water shortage inhibits growth nearer the soil surface.

Similar to the factors like soil fertility and soil moisture are those of competition between roots of neighbouring plants of the same or different species which can modify the orientation of roots. Raper and Barber (1970) reported a striking example of this effect. When soyabean plants (Glycine max) were grown in single-plant plots the attitude of the primary lateral branches of roots was different than when they were planted in rows. The primary branches tended to leave the tap root at progressively greater angles of inclination in single-plant plots and continued downwards through the soil with relatively uniform slope. In the row plants, the primary branches extended outward and at a constant slope towards the center of the rows for varying lengths and then turn sharply downward as they approach an inhospitable zone created by the roots of adjacent plants of the same species. Such "exclusion" mechanism which can restrict the interpenetration of root systems is also suggested by Mitchell, 1969 and Baldwin and Tinker, 1972. Cevallos and Alvim (1967) reported that the spread of the lateral roots of cacao is influenced by the presence of shade tree, Erythrina glauca. The lateral roots of cacao trees situated near the Erythrina grew to a depth of 60 cm. This was not found with cacao trees located further away from the shade trees. This is attributed to the higher content of soil moisture near the Erythrina.

Plants exhibit a wide variation in root growth and does not mean that it is a random process (Russell, 1977). The work of May and his colleagues (May et al., 1965, 1967) who analysed in great detail the development of barely root systems revealed that for a consistent or co-ordinated pattern of root growth uniformity of medium is necessary. Hackett (1969 and 1971) also found a comparable pattern in barely root systems grown in solution culture. According to Russell (1977) this orderly programme of root growth occurs only when the environment is relatively constant as is possible in the laboratory or to some extent in glass house conditions. Under field conditions the situation is quite different. The root growth is very much modified by the conditions of soil and weather. It is under such conditions the roots develop their capacity for compensatory growth. If the growth of one part of the root system is reduced or inhibited, that of other root members which are in more favourable conditions is frequently enhanced. Crossett et al. (1975) illustrated compensatory responses of barely plants to unfavourable root temperature and to the dislocation by dry air. According to Russell (1977), these compensatory responses can be explained to some extent to 'source-sink' relationships, the 'sink' capacity of the favourably placed roots get enhanced and draw an increased supply of metabolites than the roots in an unfavourable zone. Jan Jenik (1978) while describing the development of roots and root systems in tropical trees mentioned that due to genotypic adaptation there is an inherent tendency among different species "to create a particular root form, subsystem and overall root system. This genetic potential is, however, not necessarily expressed in every instance". Extreme environmental factors and age of trees cause phenotypic modifications in the development of root system.

The present study has not only shown the ramification and penetration of cacao roots to greater depths but also production of arecanut roots in larger quantities under mixed crop conditions than when the two components are planted as pure crops. The enhanced quantity of arecanut roots produced might be due to its association with the cacao roots which cannot be ruled out. For McCreary et al. (1943) and Hardy (1944) while describing the root system of cacao have stated based on the discovery announced by Dr. F.W. Went of the California Institute of Technology, that possibly the fibrous rootlets of cacao possess a special function in providing a growth-promoting hormone. Laycock (1945) also described the association of a phycomycetous endotrofic mycorrhiza in cacao roots.

Thus from the foregoing discussions it is quite evident that plant roots get modified under different environmental and edaphic conditions. The present study has revealed that cacao is no exception to this and that it too has a good adaptable type of root system if not an 'exclusion' or 'compensatory' growth mechanism. The various parts, tap, lateral and sinker in the root system of cacao are all capable of absorbing water and nutrients from the soil has been shown by Hurd (1961).

V. EFFECT OF ARECANUT AND CACAO COMMUNITY ON MICROCLIMATE

EFFECT OF ARECANUT AND CACAO COMMUNITY ON MICROCLIMATE

Introduction

The dependance of plant kingdom on the world around it is often referred to from ancient times and recorded in old documents. Theofrastos, (quoted by Akerberg, 1973) who lived 300 years before Christ, had in his paper clearly described the relationship between plant and its habitat. One of his works gives a detailed description of the dependance of plants on environment. It is through experience and knowledge accumulated through generations about the plants and their response to the environment that man was able to evolve a system of crop husbandry for the cultivated plants. It is this knowledge of crop, climate, and soil interaction that made him possible to select and cultivate crops which are season bound. It is again brought out clearly by the way cultivation of plants have been extended throughout the world under different ecological conditions. A further extension of this knowledge can be witnessed in the selection of crops in different countries or locations. In India, for example, crops like coffee, tea or rubber and spice yielding tree crops are adapted to the warmer and humid environments available in the western Ghats in contradistinction to cereals like paddy or wheat to the lower plains where the specific climatic demands of these crops are met with. However, this may not apply in all the cases and man has indeed been exploiting the natural resources without giving adequate attention to the ecological requirements not without failures in his attempts.

The alarming rise in world population demands increased production both to meet its food requirements and needs of the industry from the limited available cultivable land. To achieve this we have to understand more about the plant and its environmental interactions so as to enable us to chose plants suitable to the given environment or to ameliorate the environment to suit the needs of the required plant. This means that increased attention must be paid to ecological research in future agricultural scientific research. We have to also understand more about the specific demands of cultivated plants on its environment in addition to the climatic conditions.

Earlier ecological studies were confined to the major climatic zones or regions and vegetation of whole continents. But "to day, the relationships between single leaves and their boundary layer or the pathway from the chloroplast to the environment reflect the intensive nature of contemporary studies. Intermediate between these extremes is the analysis of plant-environment interaction" with cultivated crops (Lammoore et al, 1973). Among the environmental factors which influence crop development, crop production and quality of product, climate has vital role to play. Climate combines factors like radiation, temperature, precipitation, etc. In considering the interactions between climate and plant growth or biomass production from an agricultural point of view, two important growth-limiting process are to be reckoned with and are classified as primary and secondary ones. The primary processes are directly involved in the synthesis of organic matter in its widest sense and in the distribution and storage of these plant constituents within their bodies. The secondary process influence these activities only in an indirect manner, such as by counteracting an external stress. Nevertheless these secondary processes may often limit plant productivity in an adverse way and thereby demand careful consideration. Among the primary process, two basic processes viz., photosynthesis and respiration on which the trapping and conversion of energy from the sun to ultimate biomass, play the key roles. Both photosynthesis and respiration are profoundly influenced by the climatic conditions prevailing. Thus a knowledge of the climatic conditions in a cropped area is imperative in view of the interactions occurring between photosynthesis and respiration on one side and climate on the other part.

With regard to secondary process which relate to the response of the plants to external stress of one kind or another, three important kinds of stresses, viz., temperature, water and nutrients can be identified. Clearly the first two of these are influenced by climatic conditions. For successful agriculture or high production, it is important that the cultivated plants are able to survive or withstand the sudden, adverse changes in climatic condition, not to mention even production of normal crop. It is for this reason that production of varieties with increased resistance to climatic stress of various kinds becomes important. Alternatively, it must be possible to ameliorate the climatic conditions by either irrigating or by conserving available moisture by taking measures like using chemical antitranspirants or by providing shelters. In order to assess the usefulness or otherwise of these different agronomic approaches it is essential to have a thorough knowledge of the interactions between plant and what is below it in the underground consisting mostly of soil on the one hand and what is the above ground which are mainly climatic factors on the other.

Crop combinations or plant communities have modifying effect on the local climate of the area (Raman, 1943; Aiyer, 1949; Rosenberg, 1974). Ramadas (1960) reported that investigations carried out at Poona and at agricultural research stations in India show that if one records the air temperature, humidity, wind velocity, evaporation, etc., inside environments like standing crops and orchards and compare these with the observations recorded simultaneously in a neighbouring open space, the microclimates of these environments show significant and typical deviations from the conditions in the open space.

Now before further going into the details of micro-climate an attempt is made here to delineate and distinguish the various terms commonly used in the study of climate. In general meteorology one studies climatic conditions in an open, well-exposed level and bare plot of ground which is representative of the particular part of the country. In synoptic meteorology, the disturbing influence of the ground surface is avoided as far as possible by recording air temperature, humidity, wind velocity, etc. at some distance above ground. These observations recorded represent broadly the general or macro climate of the area. Macroclimate, in other words means the climate within larger or smaller regions. There is, besides, the concept of local climate within more limited (restricted) regions. As against these, there is the micro-or bio-climate that gives information about the climatic factors which form around living plants (Akerberg,

1973) has to be. Nair (1979) preferred to use the term ecoclimate in his discussions on microclimate to denote the climate which is influenced by the crops. Ramdas (1969) recognised four types of microclimates.

Type A: This is met with during clear weather when winds are feeble and the sun shines on a level stretch of bare soil, in solation and its disposal at the ground surface by conductive, convective and radiative processes accounting for the large variations of temperature and humidity with time of day as well as with height above ground.

Type B: In this case the surface of the ground is covered by an unirrigated crop. Here the solar radiation falls partly on the foliage which in turn acts as a secondary surface for the disposal of solar energy. The deviation of the climate of the crop from that of the 'open' depends upon the density of plant population, the height of crop and the amount of the vertical and horizontal distribution of the foliage.

Type C: This occurs due to the influence of a horizontal flow of air on Types A and B. The resulting types may be considered as AC and BC.

Type D: This condition, which is more complex, is brought about in types A, B and C when the ground is irrigated.

Type E: These are complicated cases met with during the incidence of cloudiness, rainfall, etc.

The general climatic and environmental conditions under which arecanut or cacao are cultivated have been discussed earlier. The microclimates within these crops fall under type B or BD. Practically very little information is available on the microclimate of arecanut gardens. Cacao which is found mostly as an understorey tree admist tall growing forest trees, has received much attention in regard to its environment. Evans and Murray (1953) in Trinidad, Cunningham and Lamb (1959) in Ghana and Alvim (1967) in Costa Rica were among the pioneers to examine critically the role of shade and light on the physiology and nutrition of cacao. Smith (1954) made a study of the soil temperature and soil moisture in a shaded cacao plantation in Trinidad. He reported that shade has exerted a considerable effect on soil temperature. Kowal (1959) studied the effect of spacing on the microclimate of cacao under Nigerian conditions. He reported that the most striking difference between sheltered and exposed soil conditions is the gradual decline of soil moisture content with depth, under cacao or forest, irrespective of season and spacing as against increase of soil moisture content with depth under cultivated soil conditions. He further reported a positive correlation between soil moisture and the tree density. The percentage of light intensity falling inside cacao also gets increased progressively as the spacing of trees is increased and this is well reflected in the appearance of cacao trees. It was reported that cacao trees on plots giving readings of 87 and 60 per cent light intensity had a bushy and symmetrical habit of growth and were not so high as those trees on plots giving lower readings for light intensity (Kowal, 1959). The trees in the latter conditions were of an asymmetrical and elongated type. Differences in depth of shade under close and wide spaced cacao were paralleled by differences in air temperature and relative humidity, specially during the dry weather period. Cornwell (1960) studied two factors, temperature and evaporation rate, contributing to the microclimate within cacao. He reported that the temperature at the top of the cacao canopy exceeded that at ground level between 9 am and 7 pm, but lower during hours of darkness. According to him temperature below the canopy were buffered against diurnal and day today fluctuations which was indicative of the existence of a more stable environment under the canopy. Atmometer measurements of evaporation rates compared in a standing cacao plantation and in a small cleared area also showed much variations. In the clearing, the evaporation rate increased linearly with height above ground, but within the cacao canopy the evaporation reduced considerably. Gerard (1959) made a comparative study of the climatic conditions in a mature cacao plantation shaded by forest trees and that in an open air in Ghana. The main differences in the climate recorded in the cacao plantation and in open air were that in the shaded site the air temperatures were lower except for the minima during the coldest periods, the soil temperatures were much lower the relative humidities were much higher, wind flow was much less and rain reaching the ground was less uniform. In India the pattern of light interception by cacao in single and double hedge systems planted under coconut was studied by Nair and Balakrishnan (1976) as also microclimatic studies of cacao grown under the coconut shade were made by Nair and Balakrishnan (1977). They reported that the crop combination ecoclimate showed a buffering effect against marked diurnal variation and differences between the average daily maximum and minimum temperatures and relative humidity to be considerably less than in monocrops of coconut or over uncropped soil. Evaporation was only about 30 per cent of that from uncropped soil. Bonaparte and Ampofo (1977) interestingly had even attempted measuring air temperatures, soil temperatures and relative humidity of cacao under three shade regimes at Ghana.

From the foregoing it is evident that information available on the microclimate of cacao is mostly in relation to its environment under the shade of tall growing forest trees or under monocrop cacao plantations except for the condition under coconut reported by Nair and Balakrishnan (1976, 1977). However, there is no information whatsoever on the climatic parameters of arecanut and cacao mixed gardens. Investigations on the interaction between these two trees and the micro climate within them is of very considerable value in view of the contrasting morphological features of the trees involved for the better understanding of the intricate problems in the culture of arecanut and cacao under mixed cropping system. As a first step studies on certain aspects of microclimate were therefore undertaken.

Materials and Methods

Observations were made in the mixed cropping (arecanut and cacao) experimental garden at the CPCRI, Regional Station, Vittal, details of which had been given earlier. The factors studied were (i) evaporation rate (ii) wind velocity (iii) soil temperature (iv) relative humidity (v) vapour pressure (vi) air temperature, and (vii) light interception pattern.

(i) Evaporation rate was studied using cup evaporimeter method described by Balakrishnan et al. (1976), daily at 14-30 hr, during the months of December, 1979 and January to May, 1980. The observations were recorded under nine different conditions, six of them under six differently spaced combinations of arecanut and cacao one in each of mono crop of arecanut and cacao and one in an open area without any vegetation as a sort of control. Under each condition three cups were placed in different locations.

(ii) Wind velocity was recorded by fixing an anemometer under each of three conditions, viz., sole crop of arecanut, mixed crop of arecanut and cacao and open fully exposed ground. The anemometers were fixed uniformly at a height of one meter above ground level. The readings were recorded daily at 7-30 hr for a period of ten months commencing September 1980 to June,1981. The position of each anemometer was changed monthly to eliminate slight differences in the performance of instruments.

(iii) Soil temperatures were recorded by fixing soil thermometers at two depths, 15 cm and 30 cm, under four conditions, viz., open, sole crops of arecanut and cacao and mixed crop of arecanut and cacao. Two thermometers were used for each of the four conditions. Temperatures were recorded daily at 07-30 and 14-30 hr during hot weather months of March, April and May, 1981.

(iv) Relative humidity and vapour pressures were recorded using Assman's psychrometer daily at 7-30 and 14-30 hr during the hot weather months.

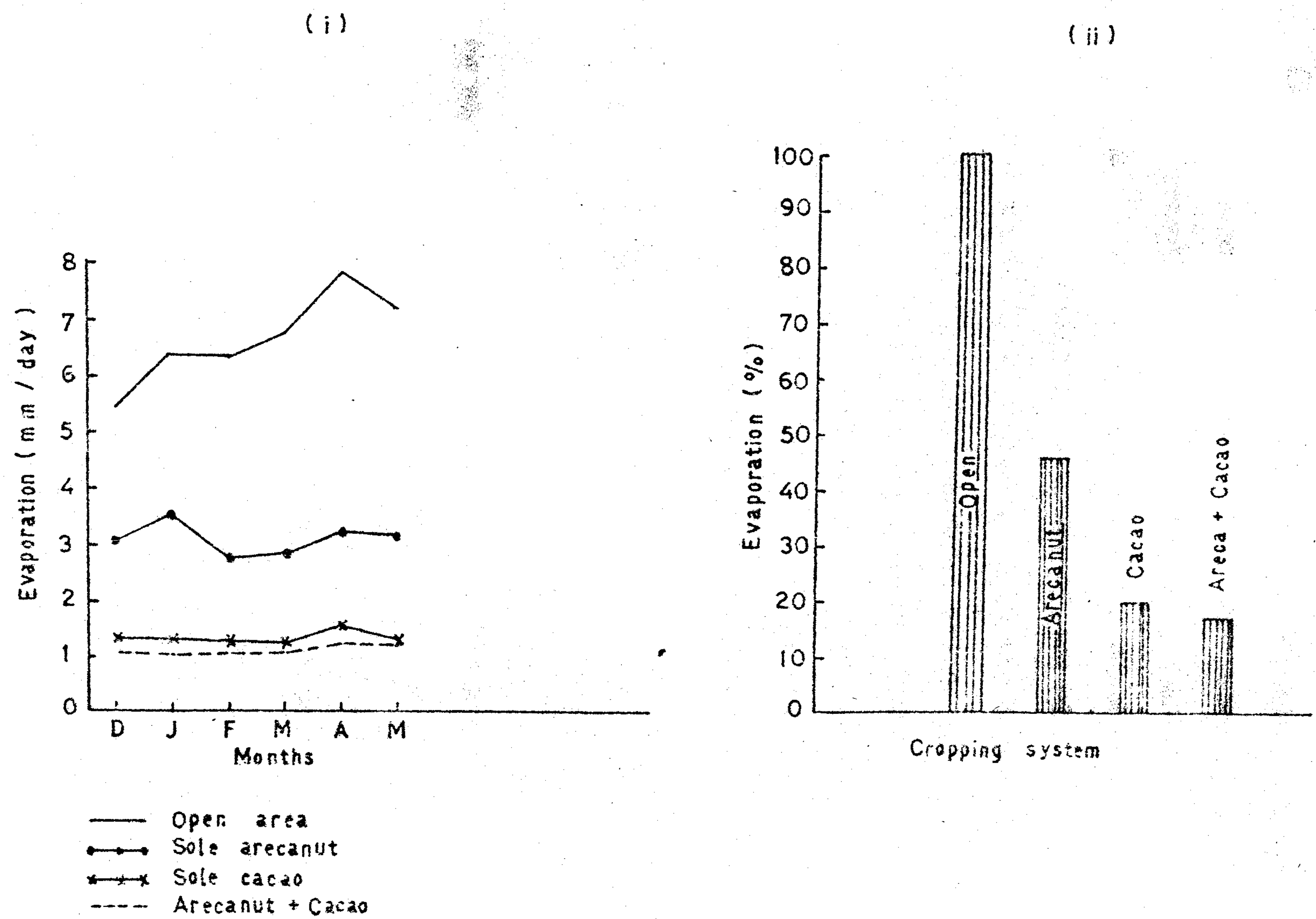
(v) Light intensities were measured during 1980 and 1981 under two conditions (1) in the mixed garden of arecanut and cacao, and (2) in the sole crop of arecanut using a portable luxmeter. In the mixed garden light was measured at three levels (i) below the crown of arecanut palm or just above the cacao canopy (ii) below the canopy of cacao trees, and (iii) above the canopy of arecanut palm. In the sole crop of arecanut also light intensities were recorded at three levels, above the canopy of arecanut, below the crown of arecanut and at ground level inside the garden.

Results

Evaporation rate

The results presented in Fig. 13(i) show that the variation in evaporation rate under different conditions is marked. The mixed crop of arecanut and cacao has the maximum effect in reducing the evaporation rate, closely followed by the sole crop cacao and to a lesser extent by the sole crop of arecanut throughout the period observed. It is noteworthy that the fluctuation in the rate of evaporation during different months is also least in the mixed crop of arecanut and cacao and in the sole crop of cacao when compared to the open condition. The rate of evaporation

FIG. 13. EVAPORATION UNDER DIFFERENT CROPPING SYSTEMS



values expressed as percentages of the values from the open area are given in Table 33. It is seen that there is no appreciable difference in the rates of evaporation within arecanut + cacao combinations of different densities tested, though it is slightly more in a widely spaced plot where the spacing for cacao is 5.4 x 5.4m. Here the canopies of trees though well spread had not covered the ground fully. However, the evaporation in the crop combination is only 17 per cent of that from the open area and 37 per cent of that from the sole crop of arecanut. In the sole crop of arecanut it is 46.5 per cent of that of open area. The percentage of evaporation in the sole crop of cacao was slightly more than that from the mixed crop (Fig. 23(ii)).

Wind velocity

The wind velocity recorded for the three types of situations during November 1980 to June 1981 is given in Table 34. It is clear that invariably the velocities are very much reduced by both the sole crop of arecanut or by the crop combination. The mean wind velocity under the arecanut garden is 0.72 km per hr and 0.20 km in arecanut + cacao combination when the velocity in the open is of the order of 2.15 km per hour thereby showing that the speed of wind under arecanut is reduced to as low as 33 per cent and under the mixed crop it is 9 per cent that of the corresponding velocities in the open. Thus the effect of

Table 33. Evaporation under different cropping systems (mean mm/day)

System		Months						Mean
		December 1979	January 1980	February 1980	March 1980	April 1980	May 1980	
Arecanut + Cacao	S_1	1.02(18.9)	1.00(15.8)	0.97(15.5)	1.05(15.7)	1.08(13.9)	0.96(13.3)	1.01(15.3)
	S_2	1.08(20.0)	1.05(16.6)	0.98(15.7)	1.07(16.0)	1.15(14.8)	1.17(16.2)	1.08(16.4)
	S_3	1.34(24.8)	1.35(21.4)	1.37(21.9)	1.30(19.5)	1.29(16.6)	1.40(19.4)	1.34(20.3)
	S_4	1.18(21.9)	1.10(17.4)	1.08(17.3)	1.17(17.5)	1.34(17.3)	1.25(17.3)	1.19(18.0)
	S_5	1.11(20.6)	1.14(18.0)	1.09(17.4)	1.14(17.1)	1.12(14.4)	1.11(15.4)	1.12(17.0)
	S_6	1.14(21.1)	1.08(17.1)	1.07(17.1)	1.11(16.6)	1.13(14.6)	1.23(17.0)	1.13(17.1)
	Mean	1.14(21.1)	1.12(17.7)	1.09(17.4)	1.14(17.1)	1.18(15.2)	1.19(16.5)	1.15(17.4)
Sole cacao		1.32(24.4)	1.31(20.7)	1.25(20.0)	1.22(18.3)	1.54(19.8)	1.33(18.4)	1.33(20.2)
Sole arecanut		3.05(56.8)	3.49(55.2)	2.75(44.0)	2.82(42.2)	3.22(41.5)	3.08(42.7)	3.07(46.5)
Open area		5.40(100.0)	6.32(100.0)	6.25(100.0)	6.68(100.0)	7.76(100.0)	7.22(100.0)	6.60(100.0)

1. Figures in parentheses are evaporation expressed as percentages of evaporation from open area
2. S_1–S_6 -- for legend, see Table 8.

Table 34. Variations in the wind velocity (km/hr) under different cropping systems

Month	Arecanut	Arecanut + Cacao	Open Area
November 1980	0.13 (8.1)	0.15 (9.4)	1.60
December 1980	0.23 (15.3)	0.20 (13.3)	1.50
January 1981	0.50 (27.8)	0.21 (11.7)	1.80
February 1981	0.64 (32.0)	0.18 (9.0)	2.00
March 1981	0.75 (26.8)	0.23 (8.2)	2.80
April 1981	1.53 (49.4)	0.25 (8.1)	3.10
May 1981	1.54 (57.0)	0.28 (10.4)	2.70
June 1981	0.42 (23.3)	0.10 (5.6)	1.80
Mean	0.72 (33.3)	0.20 (9.3)	2.16

Figures in parentheses are per cent over open area arecanut + cacao combination is maximum in reducing the speed of wind.

Soil temperatures

Temperatures at 7-35 and 14-35 hr at 15 cm and 30 cm in the soil are given in Table 35. The mean monthly temperature at 15 cm depth at both 7-35 and 14-35 hr is highest in open followed by sole crop of arecanut, cacao and mixed crop of arecanut and cacao in the order of lower temperatures. The above trend is seen at 30 cm depth also. The mean monthly temperatures of soil at 15 cm depth are 4.8°C to 13.5°C lower in the mixed crop condition than in the open and at 30 cm depth also they are 4.7°C to 13.3°C lower than in the open space. The diurnal variations in soil temperatures both at 15 cm and 30 cm are in the order of 9.7°C maximum in the open and 1.0°C to 1.1°C minimum in the mixed crop condition.

Relative humidity

The values of relative humidity for the different systems and under open condition are given in Table 36. As could be anticipated, the relative humidity is lower in the afternoons than in the forenoons. During the dry period, when the observations are made, the difference in the relative humidity between the forenoon and afternoon is lesser in the cropped areas than in the open. The mixed crop of arecanut and cacao has apparently influenced to a considerable degree in bringing down the difference.

Table 35. Variations in the soil temperature (°C) under different cropping systems*

Month	Depth	Open		Sole arecanut		Sole cacao		Arecanut + cacao	
		7.35	14.35	7.35	14.35	7.35	14.35	7.35	14.35
March	15 cm	32.0	40.8	28.6	29.7	27.3	28.2	26.7	27.6
	30 cm	31.9	40.7	28.6	29.7	27.2	28.2	26.6	27.5
April	15 cm	30.9	41.1	28.9	31.8	28.0	30.1	26.2	27.3
	30 cm	30.7	40.9	29.0	31.5	28.1	30.1	26.1	27.3
May	15 cm	30.6	40.8	28.5	31.8	28.0	30.6	26.2	27.4
	30 cm	30.5	40.5	28.6	31.8	28.1	31.2	26.1	27.3
Mean	15 cm	31.2	40.9	28.7	31.1	27.8	29.6	26.4	27.4
	30 cm	31.0	40.7	28.7	31.0	27.8	29.8	26.3	27.4

* at 7.35 h and 14.35 h

Table 36. Relative humidity (%) in the microclimate of mixed and sole crops and open area*

Month	Arecanut+ cacao		Arecanut		Cacao		Open area	
	7.30	14.30	7.30	14.30	7.30	14.30	7.30	14.30
January	90	40	89	37	90	39	93	38
February	90	51	90	47	91	50	93	42
March	90	54	90	53	89	53	93	48
April	92	54	92	52	93	53	90	53
Mean	90	50	90	47	91	49	92	45

* at 7.30h and 14.30 h

Vapour pressure

Table 37 summarises the vapour pressure reading. There is not much difference in the readings recorded under different conditions except that the figures are higher in the mornings than in the afternoons.

Air temperature

Table 38 shows the average readings in the air temperature during January to April, 1980 in the morning and afternoon at one meter height above ground level. Though the difference in the morning and afternoon temperatures is not very wide under the different conditions, the areas cropped with cacao (either as sole crop or as mixed crop) has revealed its influence in bringing down the difference by 0.5 to 1.7°C.

(vi) Light interception. The intensity of light reaching at various levels measured is given in Table 39. These values plotted in a semi-log scale to bring out the diurnal variations in the intensity of light are presented in Fig. 14 . In general, the shape of the curves is almost similar. The intensity of light increased from 8.00 hr to 12.00 hr and thereafter it declined. The percentages of total sunlight intercepted by the canopies of coconut and cacao in the mixed crop are given in Table 40. The variation in the percentage intercepted during different hours of the

Table 37. Vapour pressure (mm Hg) in the microclimate of mixed and sole crops and open area*

Month	Arecanut + cacao		Arecanut		Cacao		Open area	
	7.30	14.30	7.30	14.30	7.30	14.30	7.30	14.30
January	15.83	14.02	15.27	14.39	16.78	14.01	15.74	14.05
February	18.60	18.29	18.46	18.06	19.41	19.39	18.36	16.83
March	21.31	21.11	21.19	21.49	21.72	21.18	20.86	19.81
April	24.00	22.40	23.91	22.88	24.43	22.46	23.25	22.39
Mean	19.94	19.21	19.71	19.41	20.58	19.26	19.55	18.27

* at 7.30 h and 14.30 h

Table 38. Variations in air temperature (°C) in the microclimate of mixed and sole crops and open area*

Month	Arecanut + cacao		Arecanut		Cacao		Open area	
	7.30	14.30	7.30	14.30	7.30	14.30	7.30	14.30
January	20.0	31.6	19.7	33.3	20.9	31.9	19.3	32.6
February	22.7	33.1	22.6	34.2	23.2	33.3	21.7	34.1
March	24.9	33.7	24.6	34.4	25.2	34.0	23.9	34.7
April	26.5	34.7	26.5	35.9	26.7	35.2	26.3	35.1
Mean	23.5	33.3	23.4	34.5	24.0	33.6	22.8	34.1

* at 7.30 h and 14.30 h

Table 39. Intensity of light (lux) at different positions under mixed cropping system

Position	Time of measurement (h)						Mean
	8.00	10.00	12.00	14.00	16.00	18.00	
				MARCH 1980			
1	32,500	55,000	65,000	62,500	45,000	11,250	45,208
2	6,500	30,000	50,000	42,500	27,500	7,500	27,333
3	950	1,750	2,500	4,000	1,750	660	1,935
				APRIL 1980			
1	36,625	59,125	66,875	59,000	39,125	9,680	45,072
2	11,470	35,000	51,750	41,000	17,030	6,020	27,045
3	1,240	2,790	3,875	4,370	2,220	780	2,546
				MAY 1980			
1	41,250	61,800	67,200	52,600	40,400	11,170	45,737
2	12,760	45,400	52,600	35,850	24,900	6,370	29,647
3	1,710	5,300	4,100	3,590	2,690	875	3,044
				SEPTEMBER 1980			
1	42,400	46,700	64,600	43,200	34,375	5,680	39,493
2	18,500	31,610	41,750	28,375	19,275	4,060	23,928
3	2,950	3,365	4,380	3,960	3,150	815	3,103
				OCTOBER 1980			
1	40,670	62,670	63,670	46,335	17,035	4,730	39,322
2	11,085	36,710	37,375	27,545	10,075	2,690	21,047
3	2,400	4,885	4,020	4,285	2,640	660	3,288

1 - Over the canopy of arecanut
2 - Over the canopy of cacao
3 - Light reaching the ground

IG. 14. LIGHT INTENSITY (LUX) IN MIXED GARDEN OF ARECANUT AND CACAO

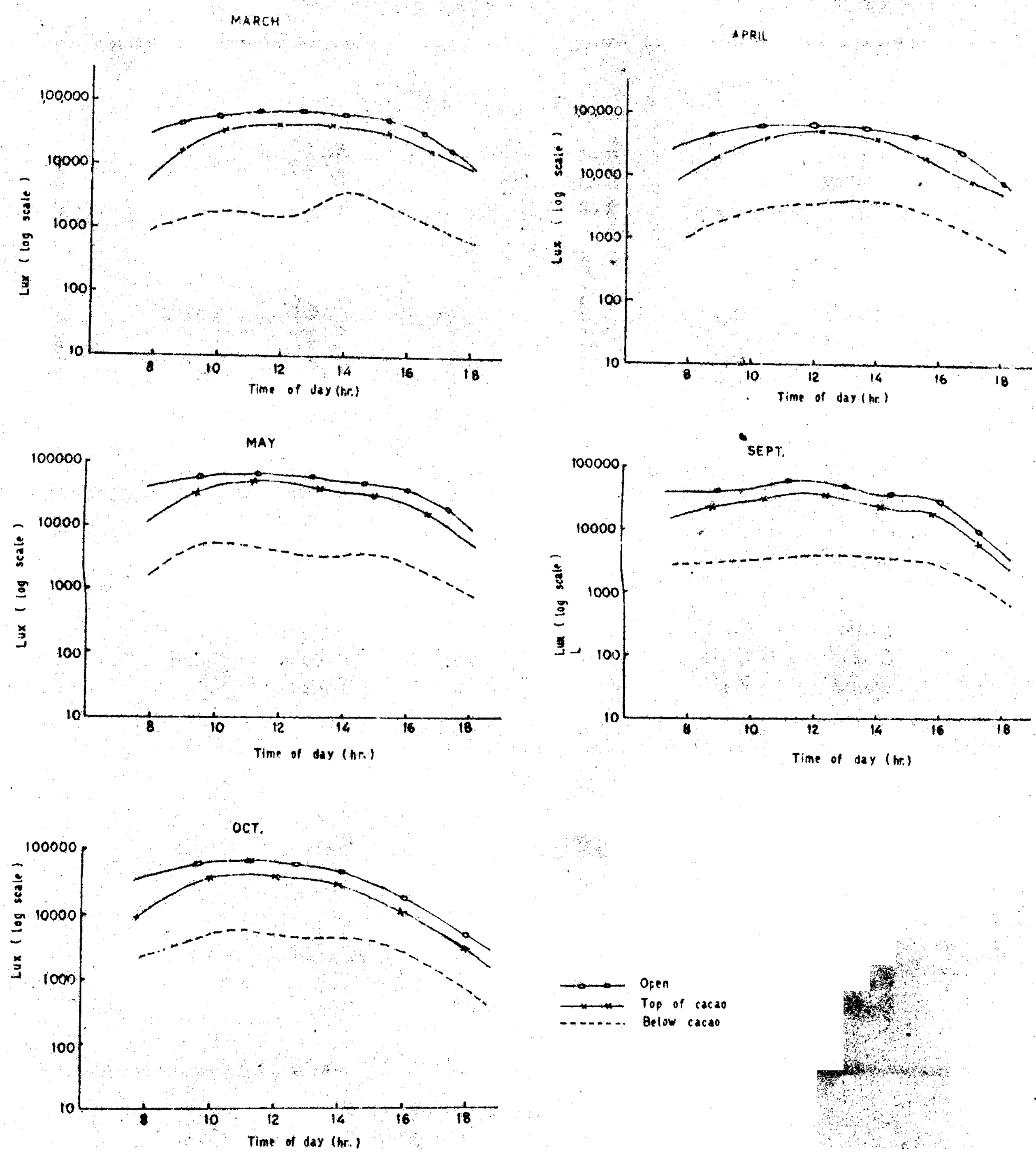


Table 40. Percentage interception of total sunlight by the canopies of arecanut and cacao under mixed cropping system

Position	Time of measurement (h)						Mean
	8.00	10.00	12.00	14.00	16.00	18.00	
MARCH 1980							
1	80.00	45.4	23.1	32.0	38.9	33.3	42.1
2	17.1	51.4	73.1	61.6	57.2	60.8	53.5
3	2.9	3.2	3.8	6.4	3.9	5.9	4.4
APRIL 1980							
1	68.7	40.8	22.6	30.5	56.5	37.8	42.8
2	27.9	54.5	71.6	62.1	37.8	54.1	51.3
3	3.4	4.7	5.8	7.4	5.7	8.1	5.9
MAY 1980							
1	69.1	26.5	21.7	31.8	38.4	43.0	38.4
2	26.8	64.9	72.2	61.4	54.9	49.2	54.9
3	4.1	8.6	6.1	6.8	6.7	7.8	6.7
SEPTEMBER 1980							
1	56.4	32.1	35.4	34.3	43.9	28.5	38.4
2	36.6	60.7	57.8	56.5	46.9	57.2	52.6
3	7.0	7.2	6.8	9.2	9.2	14.3	9.0
OCTOBER 1980							
1	72.7	41.6	41.2	40.6	39.0	43.4	46.4
2	21.3	50.6	51.2	50.2	46.2	42.7	43.7
3	6.0	7.8	7.6	9.2	14.8	13.9	9.9
AVERAGE FOR THE YEAR							
1	69.4	37.2	28.8	33.8	43.3	37.2	41.6
2	25.9	56.5	65.2	58.4	48.6	52.8	51.2
3	4.7	6.3	6.0	7.8	8.1	10.0	7.2

1 - Canopy of arecanut
2 - Canopy of cacao
3 - Light reaching the ground

day as well as by the two crops involved is clearly evidenced. The mean share of interception of total light by the arecanut was 41.6 per cent, that of cacao 51.2 per cent the balance of 7.2 per cent being accountable to its reaching the floor of the plantation. Regarding efficiency of use, arecanut utilised or cuts off 41.6 per cent of available light whereas cacao cuts off 87.3 per cent of available light (i.e. when the light falling the canopy as the maximum available 100 per cent) (Table 41). The results thus show that by the interaction of arecanut and cacao, there is a better utilisation of light than when arecanut alone is cropped with 92.8 per cent of total light utilised by the two crops together as against only 41.6 per cent when arecanut alone is raised as a pure crop.

Discussion

The traditional practice is to grow cacao under the shade of larger forest trees. This is based on the concept which regards cacao as a typical shade-loving species. The need for shade in present day production of cacao like that of coffee and tea is often questioned (Willey, 1975). However, Alvim (1967), Alvim and Alvim (1980) have concluded that the advantage of shade in cacao cultivation is not to provide a low light intensity considered optimal for growth and yield, its main function is to counteract unfavourable ecological factors, such as low soil fertility, wind damage, high transpiration leading to moisture stress and increased

Table 41. Percentage interception of available sunlight by the canopies of arecanut and cacao, individually and collectively

Position	Time of measurement (h)						Mean
	8.00	10.00	12.00	14.00	16.00	18.00	
MARCH 1980							
1	80.0	45.4	23.1	32.0	38.9	33.3	43.1
2	85.4	94.2	95.0	90.6	93.6	91.2	91.7
3	97.1	96.8	96.3	93.6	96.1	94.1	95.6
APRIL 1980							
1	68.7	40.8	22.6	30.5	56.5	37.8	42.8
2	89.2	92.0	92.5	89.3	87.0	87.0	89.5
3	96.6	95.3	94.2	92.6	94.3	91.9	94.1
MAY 1980							
1	69.1	26.5	21.7	31.8	38.4	43.0	38.4
2	86.6	88.3	92.2	90.0	89.2	86.3	88.8
3	95.9	91.4	93.9	93.2	93.3	92.2	93.3
SEPTEMBER 1980							
1	56.4	32.1	35.4	34.3	43.9	28.5	38.4
2	84.0	89.4	89.5	86.0	83.7	79.9	85.4
3	93.0	92.8	93.2	90.8	90.8	85.7	91.0
OCTOBER 1980							
1	72.7	41.4	41.2	40.6	39.0	43.4	46.4
2	78.0	86.7	87.1	84.4	75.7	75.5	81.2
3	94.0	92.2	92.4	90.7	85.2	86.1	90.1
AVERAGE FOR THE YEAR							
1	69.4	37.2	28.8	33.8	43.3	37.2	41.6
2	84.6	90.1	91.3	88.1	85.8	84.0	87.3
3	95.2	93.7	94.0	92.2	91.9	90.0	92.8

1 - Arecanut canopy
2 - Cacao canopy
3 - Combined canopy of arecanut + cacao

insect attack. According to them moderate shading appeared to be the safest in most regions, specially in regions where water supply is limiting. Owusu (1980) also based on his studies on the light requirements of cacao and weighing the benefit of shade against the drawbacks of full exposure, gave the version that shade cannot be completely avoided. Whether cacao requires shade or not is not the major question to be answered in the present studies. Here cacao has been introduced with arecanut with a view mainly to increase the overall income from arecanut plantations. The shade provided by the arecanut is incidental. Yet how far arecanut has been able to contribute and interact with cacao and played its role as a shade or shelter tree is worth examining.

The most important effect of shading per se is that it reduces the amount of light available to the shaded crop. The problem is further complicated because of the extremely variable shade cast by shade trees in the traditional system where forest trees are taken advantage as shade trees. Vernon (1967a) found in Ghana that though the average degree of shading in cacao was a reduction to about 40 per cent light, it ranged from 8 to 70 per cent light between different plantations. Added to this the 'degree' of shading is so variable that it may be either from an irregular pattern of trees left during forest clearing or from a regular pattern of systematically spaced trees raised for the purpose of shading. The present studies have revealed that the reduction of light by the arecanut tree is on an average about 42 per cent of full sunlight, that means about 58 per cent is still available to the cacao canopy below. The exposure available to cacao even then appears to be quite adequate in view of the results obtained by Lemee (1955) in his studies on the influence of light intensity on the photosynthetic rate of cacao leaves. He found that apparent photosynthesis increased from 7 to 22 mg CO_2-dm2/day when light intensity increased from 2 to 25 per cent of full exposure, but further increases in light intensity up to 100 per cent exposure caused a relatively small increase in the rate of apparent photosynthesis. Further, when observations were made on very clear days, photosynthesis was found to decrease in full sunlight, particularly where the intensity of radiation was above 0.5-0.75 cal/cm^2/min. The leaves developed in the shade showed the depression effect of direct sunlight at lower radiation intensities. According to Lémee (1955) some degree of shading was beneficial to photosynthesis. As against this, there is a strong view that after passing the juvenile stage, or when the leaf canopy is sufficiently developed to provide some self-shading, cacao growth and production are usually higher with little or no shade than when plants are shaded (Alvim, 1967; Alvim and Alvim, 1977; Asomaning et al. 1971; Cunningham and Arnold, 1962; Hurd and

Cunningham, 1961; Murray, 1957). The present studies, however, reveal how much of cacao can be grown advantageously by suitably adjusting the population of either of arecanut and cacao components, about which more will be discussed in later chapters.

Another well established effect of shading is that it can reduce the diurnal range of air temperatures. Hardy (1962) reported that where unshaded cacao in Ghana had a diurnal range of 12°C, it was reduced to 9.3°C by shading, likewise, in Trinidad a range of 11.8°C in lighely shaded cacao was reduced to 8.3°C by heavier shading. Hardy considered this reduction important because according to him when the range exceeded 9°C there resulted in too frequent leaf flushing which was detrimental to the yield of cacao pods.

Shading also reduces soil temperatures. This has been established in the present studies with arecanut and arecanut mixed crop with cacao when compared to open conditions. One advantage of this is that it helps to lower the air temperature within the crop. However, how far this has influenced the yield of the crops involved is to be examined. High soil temperature may also be undesirable because of the effects upon the soil itself. The rate of moisture evaporation from the surface layers and the rate of organic matter breakdown are both increased, which in turn be followed by loss of structure and increased susceptibility to erosion. A crop of arecanut mixed with cacao has proved more efficient in reducing evaporation than either a sole crop of cacao or arecanut which by themselves are effective in minimising evaporation than in open.

Another effect of shading associated with the reduced temperature is a rise in the relative humidity and a reduction in transpiration (Willey, 1975). In the mixed crop of arecanut and cacao there is a reduction in the air temperature in the afternoon by about 0.8°C than in the open which is accompanied by an increase in the relative humidity from 45 in the open to 50 inside the mixed crop. Clearly the rise in relative humidity had a reducing effect on the overall water requirement of the crop and consequently lower the water stress problem. Fordham (1971) who measured the leaf moisture status in cacao indeed found that a shaded crop had a better water balance.

The shade trees also have another important function by way of providing shelter for the crop below. Protection against strong winds during the south-west monsoon period as well as hot dry winds during summer in the cacao growing regions of south India is important, both to reduce physical damage and to reduce high transpiration rates. The speed of wind in the arecanut and cacao mixed garden is cut by 90.7 per cent than in the open which might have helped in reducing the rate of evaporation (Tables 33 and 34). It is further reported that cacao is very wind-sensitive and in areas exposed to frequent breezes cannot be grown without wind breaks. The main effect of excessive wind is in causing defoliation or premature leaf fall (Leite, 1978 quoted by Alvim and Alvim, 1980). *However, restricting* air movement by the shade trees or inside the garden during the wet weather periods (June to September) may have some adverse effect on the crops. Fruit surfaces of both arecanut and cacao may not get rid of the moisture deposit as quickly as possible after the rains, which may thus form a congenial microclimate for the spread of Phytophthora which causes fruit rot in arecanut and blackpod disease in cacao. In fact, Cunningham and Lamb (1959) had observed that the higher humidity under shade favoured black pod disease of cacao.

The present study has brought out to the fore certain changes in the microclimate under the mixed crop of arecanut and cacao which is sharply different from either of the crop when individually planted. The changed microclimate has brought out certain advantages in bringing down the evaporation, soil temperature and wind speed. The likely ill effects in the changed situation in favouring the spread of certain diseases is not ruled out, but this requires further investigation.

VI. INTERACTIONS BELOW GROUND — UTILIZATION OF MAJOR NUTRIENTS

INTERACTIONS BELOW GROUND - UTILIZATION OF MAJOR NUTRIENTS

Introduction

The environmental resources which sustain plant growth are principally the light, water and soil-nutrients, besides carbon dioxide and oxygen (Harper, 1961; Donald, 1963; Risser, 1969). Carbon dioxide required for photosynthesis and oxygen for respiration have seldom competition from plants (Trenbath, 1974). Monteith (1963) stated that competition for CO_2 is probably absent because the air within the canopy is surrounded by air of approximately the same CO_2 concentration. Similarly, except in almost waterlogged soils, the diffusion of oxygen in soil is usually fast enough to maintain adequate supplies to all roots (Greenwood, 1969). Temperature and humidity which affect plant growth are not usually in finite supply and so are not the subject of competition (Donald, 1963). Barring the relatively small number of instances where chemical secretions by one species are considered to have influenced the growth of another, results of mixed crop experiments show that the neighbour effects are due to competition for light, water or one of the major nutrients, viz., nitrogen, phosphate and potassium (Trenbath, 1974). Studies involving competition for light and other interactions which occur between the component species above ground under mixed cropping conditions have received much attention (Trenbath, 1974;

Allen et al. 1976). However the nature of competition below ground for water and nutrients remains largely unknown (Sanchez, 1976; Snaydon and Harris, 1981).

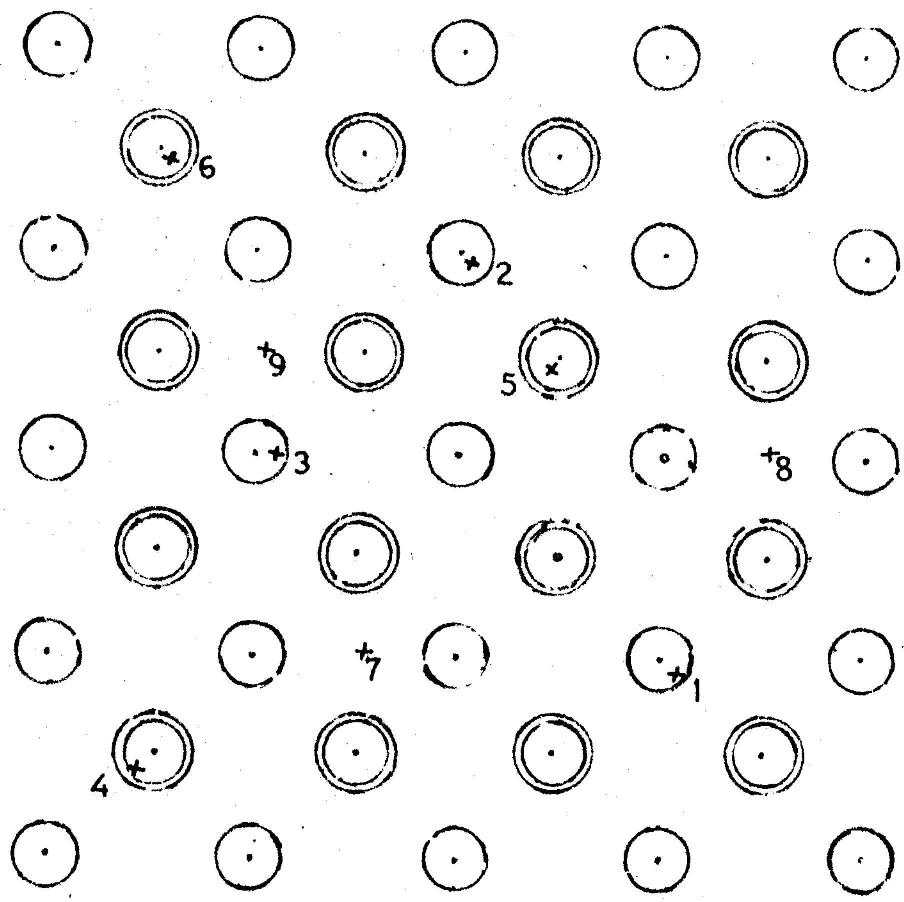
There are evidences that certain intercropped systems accumulate more nutrients from the soil than the component crops raised separately as sole crops and in some cases a more efficient utilisation of nutrients is reported (Sanchez, 1976). When two or more crops are raised either in the mixed cropping system or when one of the crops is a shade tree, there is possibility of deposition of large quantities of leaf litter. Besides reduction of soil temperatures and protection afforded against erosion by this litter it has other associated beneficial effects like increase in organic matter and nutrients in the soil. Hadfield (1963) suggested that up to 8000 kg per hectare per year of litter could be deposited by shade trees in tea plantations. Varghese et al. (1978) reported that under the mixed cropping system of cacao and coconut the biomass added to the soil through shed leaves and prunings of cacao was found to range between 818 kg to 1785 kg/ha/year depending upon the population of cacao trees. They estimated that this litter could return to the soil about 30 kg nitrogen, 11 kg phosphoric acid and 35 kg potash/ha/year. There is another possibility that component crops may exploit different soil layers specially when these crops have different root systems and thus in totallity they may exploit a greater and total volume of soil or nutrients (Trenbath, 1974). Release of nutrients in the soil and uptake by component plants can also be influenced by the rhizosphere microorganisms. Nair and Rao (1977a) found that there was increased microbial activity in the rhizosphere of coconut with which cacao was planted as mixed crop. The available phosphorus content in the coconut rhizosphere wherein cacao was grown ranged from 41 ppm to 48 ppm as against 30 ppm in the rhizosphere of sole crop of coconut (Nair and Rao, 1977b).

The above conditions, viz., competition among component crops, addition of leaf litter or decayed roots, association of microorganisms and differential root habits and subsequent exploitation of different soil layers and thereby aid in recycling nutrients can bring in changes in the nutrient status of soils under the mixed cropping system. The objective of the present study therefore was to assess the major changes, if any, in the nutrient status of the soil due to continued growing of the two crops for a fairly long period.

Materials and Methods

Soil samples were collected from three locations (Fig. 15), viz., cacao base, arecanut base and from the interspace between the crops. Moreover, samplings were made from three depths viz., 0-25 cm, 25-50 cm, and

FIG. 15. SOIL SAMPLING SITES (REPRESENTATIVE PLOT)



LOCATION

⊙ Arecanut palm — base

◎ Cacao tree — base

Arecanut cacao interspace

x Sampling sites (1 — 9)

50-100 cm in 1980 from all the treatment plots in the experimental garden (whose design and layout details have been given earlier). For each location, within a plot, samples collected from three spots were pooled and made into a composite sample. Soil samples were also taken from vacant, fallow field contiguous with the cropped area since the experimental garden did not contain uncultivated land as a treatment. Samples were also collected from sole crop arecanut and cacao plots. The samples were air-dried slightly crushed and sieved, and the fraction passing through 2 mm sieve was used for analysis.

Soil pH: Soil pH was measured in a soil-water suspension (1 : 2) using a pH meter (model pHM 64 Research pH meter).

Organic carbon: Organic carbon was estimated by the method of Walkley and Black (Jackson, 1967).

Available phosphorus: Available phosphorus was extracted by Bray-1 reagent (Jackson, 1967) and estimated colorimetrically by the method of Watanabe and Olsen (1965) using a Klett-Summerson photo-colorimeter.

Available potassium: Available potassium was extracted with neutral normal ammonium acetate (Jackson, 1967) and estimated by flame photometer (Model: Corning 400).

Results

1. Soil pH: The results pertaining to the changes in soil pH or acidity as influenced by the mixed cropping are presented in Table 42. It is clear that spacing, location and depth of sampling influenced soil pH significantly. The mean pH under different spacings ranged from 5.0 to 5.3. The spacing S_4 (arecanut and cacao both at 3.9m x 3.9m) it may be noted, recorded highest pH of 5.3. The pH of samples from different locations ranged from 4.9 to 5.3, the highest pH (5.3) recorded being at location-2, i.e., base of arecanut palms. The sample from central space between cacao and arecanut trees (L_3) has the lowest pH value of 4.9. The pH between depths ranged from 5.0 to 5.2. There is significant interaction between location and depths of sampling. In locations 1 and 2, the pH value decreased with depth, whereas in location 3, it is the reverse. The interactions between locations and manurial levels and spacing and manurial levels are also significant. The pH of soil under fallow land, arecanut and cacao as sole and mixed crops is given in Table 43. Interestingly the pH is lower in fallow land in all the 3 depths. Cultivation of arecanut or cacao either as sole crop or mixed crop in particular decreased the acidity.

2. Organic carbon: The values for organic carbon are given in Table 44. It may be observed that there is

Table 42. Effect of mixed cropping on soil pH

Table of means

Treatments	L_1	L_2	L_3	D_1	D_2	D_3	F_1	F_2	Mean	Location	D_1	D_2	D_3	F_1	F_2
S_1	5.0	5.3	4.9	5.1	5.0	5.1	5.1	5.0	5.1	L_1	5.3	5.0	5.0	5.1	5.1
S_2	5.0	5.3	4.8	5.1	4.9	5.0	5.0	5.1	5.0	L_2	5.4	5.2	5.2	5.2	5.3
S_3	5.0	5.2	5.0	5.1	5.1	5.0	5.1	5.1	5.1	L_3	4.9	4.9	5.1	5.0	4.9
S_4	5.3	5.4	5.1	5.4	5.2	5.2	5.3	5.2	5.3						
S_5	5.0	5.3	4.9	5.2	5.0	5.1	5.1	5.1	5.1	F_1	5.2	5.0	5.1		
S_6	5.2	5.2	4.9	5.2	5.1	5.1	5.1	5.1	5.1	F_2	5.2	5.0	5.1		
Mean	5.1	5.3	4.9	5.2	5.0	5.1	5.1	5.1	5.1						
SE/plot									0.2						
CV(%)									4.3						
CD (P=0.05)															
for location									0.05						
for spacing									0.06						
for depth									0.05						
for LF interaction									0.06						
for LD interaction									0.09						
for SF interaction									0.10						

S_1–S_6, for legend see Table 8,

Location
L_1 – Cacao base
L_2 – Arecanut base
L_3 – In between arecanut and cacao

Depth
D_1 – 0–25 cm
D_2 – 25–50 cm
D_3 – 50–100 cm

Fertilizer level
F_1 – 100g N, 40g P_2O_5 and 140g K_2O
F_2 – 200g N, 80g P_2O_5 and 280g K_2O

ANOVA in Appendix, Table 42(1)

Table 43. Effect of cropping system on soil pH and organic C content

Cropping system	pH				C%			
	D_1	D_2	D_3	Mean	D_1	D_2	D_3	Mean
1. Sole crop								
i) Arecanut base	5.3	5.1	5.1	5.2	1.43	1.00	0.81	1.08
ii) Cacao base	5.3	4.9	4.9	5.0	1.33	0.64	0.59	0.85
2. Mixed crop								
i) Arecanut base	5.4	5.2	5.2	5.3	1.57	1.03	0.66	1.09
ii) Cacao base	5.3	5.0	5.0	5.1	1.40	0.75	0.61	0.95
iii) Inter space	4.9	4.9	5.1	5.0	0.79	0.57	0.38	0.58
3. Fallow land	4.6	4.7	4.8	4.7	0.93	0.44	0.47	0.61

significant variation in the percentage of organic carbon in different spacings, locations and depths. The mean value ranged from 0.79 per cent to 0.92 per cent for different spacings. The highest percentage is under the spacing 3.9m x 3.9m and lowest under 2.7m x 2.7m (for both the crops). With regard to location, the percentage of organic carbon is significantly maximum under the arecanut base and minimum in central in between space. Interestingly, the organic carbon content decreased with depth up to 100 cm, the highest percentage is on the top 25 cm layer, irrespective of the location and spacing. The interaction between location and depth is also significant. The organic C content in fallow land, in arecanut and cacao (both as sole and mixed crops) is presented in Table 43. It is seen that there is some increase in the organic C content in the bases of crops when compared to fallow land, more markedly on the surface 25 cm soil.

3. Available phosphorus: The values for available phosphorus are given in Table 45. The values differed significantly between locations and depths. It is highest under the base of arecanut palms, followed by the value for the cacao base and significantly lowest in the central in between place. The average values ranged from 1.8 ppm to 27.3 ppm for locations. Though the values differed under different spacings, they are not significantly so. The available P

Table 44. Organic carbon content of soil under mixed cropping (arecanut and cacao)

Table of means

Treatments	L_1	L_2	L_3	D_1	D_2	D_3	F_1	F_2	Mean
S_1	0.86	0.99	0.53	1.21	0.72	0.45	0.75	0.84	0.79
S_2	0.93	1.09	0.63	1.23	0.83	0.59	0.82	0.95	0.89
S_3	0.95	1.08	0.57	1.29	0.77	0.55	0.88	0.86	0.87
S_4	0.98	1.21	0.58	1.38	0.83	0.57	0.89	0.96	0.92
S_5	0.99	1.05	0.61	1.33	0.80	0.52	0.91	0.85	0.88
S_6	1.00	1.12	0.56	1.25	0.79	0.64	0.90	0.89	0.89
Mean	0.95	1.09	0.58	1.28	0.79	0.55	0.86	0.89	0.87

Treatments	D_1	D_2	D_3	F_1	F_2	Treatments	F_1	F_2
L_1	1.48	0.76	0.61	0.94	0.97	D_1	1.26	1.30
L_2	1.57	1.03	0.66	1.06	1.11	D_2	0.77	0.81
L_3	0.79	0.57	0.38	0.57	0.59	D_3	0.54	0.56

SE/plot	0.2
CV (%)	24.8
CD (P=0.05)	
for location	0.050
for spacing	0.071
for depth	0.050
for LD interaction	0.087

S_1–S_6, for legend see Table 8

ANOVA in Appendix, Table 44(i)

Table [illegible]. Available phosphorus (ppm) content of soils under mixed cropping (arecanut and cacao)

Table of means

Treat-ments	L_1	L_2	L_3	D_1	D_2	D_3	F_1	F_2	Mean
S_1	33.6	26.5	5.3	43.7	15.6	6.2	23.6	20.1	21.8
S_2	24.3	28.2	1.0	39.4	11.0	3.1	14.4	21.3	17.8
S_3	22.0	25.9	1.0	32.7	12.1	4.1	13.6	19.0	16.3
S_4	16.2	28.4	1.0	29.9	11.4	4.3	16.8	13.5	15.2
S_5	29.5	21.6	1.9	38.0	11.9	3.5	22.1	13.6	17.8
S_6	16.0	33.0	0.7	31.6	13.4	4.7	13.9	19.2	16.5
Mean	23.7	27.3	1.8	35.9	12.6	4.3	17.4	17.8	17.6

Treat-ments	D_1	D_2	D_3	F_1	F_2	Treat-ment	F_1	F_2
L_1	53.57	12.92	4.53	24.10	23.24	D_1	34.5	37.3
L_2	50.49	23.21	8.09	27.28	27.25	D_2	12.5	12.6
L_3	3.59	1.55	0.30	0.79	2.68	D_3	5.3	3.4

SE/plot	17.8
CV (%)	101.3
CD (P=0.05)	
for location	4.11
for depth	4.11
for LD interaction	7.13
for SF interaction	8.23

S_1–S_6 for legend see Table 8.

ANOVA in Appendix, Table 45(1)

decreased with depths, the values ranged from 4.3 to 35.9. There is no significant difference between two levels of manuring. The interactions between location and depth and spacing and manure levels are also significant. The available phosphorus in fallow land and under the crops is given in Table 46. Evidentally cultivation of crops increased the P availability.

4. Available potassium: The data on available potash are given in Table 47. Both location and depth influenced significantly the available potash levels. Though the available potash levels varied under different spacings, the difference is not significant. The available potash content between different locations varied from 54.9 ppm to 120.7 ppm. It is highest under the base of cacao and lowest under the central place. The available potash content decreased with depth in all the locations, though difference is not significant between the two lower depths. The data on available potash in fallow land, and in cultivated plots are given in Table 46. It is seen that the available potash has considerably increased in all depths under the mixed crop condition.

Discussion

It is evident from the results that high pH was recorded in the soils collected from arecanut base

Table 46. Effect of cropping system on available P and K content of soil

Cropping system	P ppm				K ppm			
	D_1	D_2	D_3	Mean	D_1	D_2	D_3	Mean
1. Sole crop								
i) Arecanut base	61.6	26.7	11.8	33.4	15.0	13.0	12.0	13.3
ii) Cacao base	15.6	1.8	1.1	6.2	15.0	8.0	6.0	9.7
2. Mixed crop								
i) Arecanut base	50.5	23.2	8.1	27.3	137.6	90.1	82.1	103.4
ii) Cacao base	53.6	12.9	4.5	23.7	153.8	120.3	112.1	128.7
iii) Inter-space	3.6	1.5	0.3	1.8	62.0	50.5	52.1	54.9
3. Fallow land	3.2	0.3	0.6	1.4	13.0	8.0	6.0	9.0

Table 67. Available potash (ppm) content of soil under mixed cropping (arecanut and cacao)

Table of means

Treatments	L_1	L_2	L_3	D_1	D_2	D_3	F_1	F_2	Mean
S_1	134.9	113.7	73.5	123.0	103.8	95.3	128.3	86.5	107.4
S_2	122.5	105.8	48.0	115.1	84.5	76.6	94.7	90.4	92.1
S_3	126.3	100.9	66.0	125.2	89.9	82.0	88.9	106.5	97.7
S_4	120.2	107.7	45.7	116.7	80.6	75.8	96.8	85.2	91.0
S_5	150.1	94.8	45.5	119.0	87.7	82.9	90.0	103.6	96.8
S_6	118.5	98.3	50.7	107.0	79.2	81.1	81.7	96.5	89.1
Mean	128.7	103.4	54.9	117.8	87.0	82.3	95.1	94.3	95.7

Treatments	D_1	D_2	D_3	F_1	F_2	Treatments	F_1	F_2
L_1	153.8	120.3	112.2	119.5	137.9	D_1	117.6	118.1
L_2	137.7	90.1	82.6	107.5	99.0	D_2	88.4	87.5
L_3	63.0	50.5	52.1	58.2	51.6	D_3	81.6	83.2

SE/plot	43.6
CV (%)	45.6
CD (P=0.05)	
for location	10.07
for depth	10.07
for LF interaction	14.24
for LD interaction	17.44
for SF interaction	20.14

S_1-S_6, for legend see Table 8

ANOVA in Appendix, Table 47(i)

presumably due to buffering action brought about by the supply of extraneous organic material at the rate of 20 kg/palm per year. It has been established that the intermediary decomposition products of organic material tend to chelate active Al in the soil thereby inhibiting its hydrolysis and contribution as a source of proton. However, a higher pH has also been recorded in 3.9 x 3.9m spacing of arecanut-cacao where high production of biomass, particularly of cacao, could be expected and the recycling of such crops residues would have resulted in a similar mechanism, as explained earlier. A low pH has been recorded in soils collected from either fallow land or interspace compared to cropped area. This may be due to the insufficiency of Al-chelating factor resulting in the high Al activity and low pH. Application of fertilisers continuously for a period of ten years has influenced the soil pH markedly due to the fact that most of the fertilisers are acid forming chemicals. In arecanut and cacao bases where both organic and inorganic sources of manures are applied, the acidity slightly increases with depth probably due to leaching of organic and other associated acids released from the manures (fertilisers, organic matter and litter). However, a reverse trend was observed for fallow land and interspace where the leaching of bases from the surface soil could have decreased the acidity with depth.

Organic carbon

The results showed a high organic carbon content in the soil sampled from arecanut base, obviously due to contribution from the addition of compost and green leaf manures every year. The high biomass production from cacao and its recycling in 3.9 x 3.9 m spacing might be the major contributing factor for increased soil organic carbon content. The low organic carbon content in fallow land and interspaces might be due to the lack of extraneous sources. The results further revealed that the organic carbon content increased in cropped soils in lower depths compared to fallow land and this indicates the possibility of movement of organic fractions to lower depth apart from the contribution from *in situ* addition of organic matter in sub soil. The eluviation and illuviation processes may be expected in such situations in porous, laterites.

Available Phosphorus

Almost a similar trend of results as that of organic carbon has been recorded for available soil phosphorus. A high concentration of Bray's P was extracted from soil sampled from arecanut base followed by cacao; however the difference is not significant. This increased P concentration in the cropped soils is probably due to repeated P fertilisation in 10 years which resulted in considerable build up. A low content of P in the soils from the interspace shows that the native P status of soil has not been altered due to continuous cultivation. Cropping was found to enhance the subsoil P compared to fallow land; this indicates the movement of P either along with the organic matter (Mohapatra, 1977, 1982) or mechanically (Khan, unpublished).

Available Potassium

The high available K content was found in soils of cacao base followed by arecanut. This may be presumed to be due to two reasons, viz., additional contribution of K through crop residues of cacao on one hand and high absorption of K by arecanut on the other. In general the palms, coconut and oil palm (Mameiot et al., 1979(a), 1979(b) have been reported to be heavy feeders of K and this may be true with arecanut too. The interaction between spacing and fertiliser has significantly influenced the available K status of these soils. It is also evident from the data that downward movement of K has taken place to enrich the subsoil while lateral movement has also occurred probably due to the cultivation.

The results of studies suggest the feasibility of staggering of P fertilisation either to cacao, arecanut or its combination for a period of few years till the available soil P comes down to about 20 ppm. Also, since downward and lateral movement of P is very much restricted, the method of application of P fertilisation for perennial crops like cacao or arecanut may require reexamining. Finally application of organic manures to acid laterite soils has a beneficial effect by stabilising the pH of the soils through probable inactivation of Al. Under mixed cropping conditions of perennial crops when the additions of organic matter, either by recycling or external are reasonably large, the existing rates of fertiliser applications need rethinking. Generating more information on the aspects studied may be helpful in economising the revenues spent per unit of produce.

VII. EFFECTS OF ARECANUT AND CACAO INTERACTIONS ON YIELD

EFFECTS OF ARECANUT AND CACAO INTERACTIONS ON YIELD

Introduction

It is an established fact that density of planting influences both the performance of individual trees as well as the yield of trees collectively per unit area. Arecanut is no exception to this. Bhat, et al. 1972 cited by Bhat, 1978(b) based on the results of a spacing experiment reported that the yield per arecanut palm increased progressively with spacing when the spacing given to the palm ranged from 1.8m x 1.8m to 3.6m x 3.6m, though the maximum yield harvested per unit area was from palms spaced at 2.7m x 2.7m under sole cropping system. Plant population per unit area has influenced the performance of cacao too. Benstead and Wickens (1958) reported that the yield of pods per tree and dry cacao per unit area fell as density increased from 200 to 2800 trees per acre. Kowal (1959) reported the effects of seven spacings on the growth and performance of Trinitario and Amelonado cacao types under Nigerian conditions based on the results of experiment carried out during 1941-56. According to him density of stand profoundly affected the establishment and yield of cacao trees. Soenarjo (1974), based on the results of spacing trial of cacao in Java reported that wet and dry bean yield per hectare was the highest when the density ranged from 2000 to 3000 trees per hectare, whereas in another trial, the highest yields were obtained at the closest spacing employed, viz., 2.0 x 2.5m or 2000 trees per hectare. Bonaparte (1975, 1978) also held the view that plant density caused yield variability and crop distribution in *Theobroma cacao*. These and similar modifications in the behaviour of the two crops are proof enough to say that they are prone to intraspecific competition when planted as sole crops. The effect of growing annual crops in arecanut gardens and the overall performance of the components have been reported by several workers which have been reviewed by Bhat (1978b) and Sannamarappa and MuraliCharan (1982). There are sufficient evidences to show that intercropping in arecanut though in general is not harmful, can bring in reduction in yield of arecanut under certain situations. Adverse effect of intercropping with banana on the yield of arecanut was observed in the experiments conducted at CPCRI, Research Centres at Hirehalli and Kahikuchi, whereas under the conditions prevailing at Vittal no such deliterious effect was noticed even after 10-15 years of association of the two crops.

Cacao has received far more attention with regard to its behaviour and yield habits as influenced by several other species of plants, particularly on the effect of various species of shade trees. Bonaparte (1967) reported instances of interspecific competition between cacao and shade trees like *Terminalia ivorensis*. Yields of cacao trees at three distances (7.07, 15.01 and 21.2 feet) from *Terminalia* shade trees were compared. The trees nearest to the shade trees recorded the lowest yields. Yields of cacao trees increased almost linearly with increasing distance from the shade trees. Chok (1971) pointed that removal of competing plants like _Leucaena glauca_, _Gliricidia maculata_, _Albizia falcata_, _A. chinensis_ and _Parkia javanica_ resulted in substantial yield increases in the cacao plantations. The above, besides several other publications (Murray, 1954; 1955(a), 1955(b); Smith, 1954; Havord et al. 1955; Cunningham and Lamb, 1959; Havord, 1959; Cunningham and Burridge, 1960; Asomaning and Kwakwaye, 1964; Quansah, 1964; Sajoso, 1965; Murray and Nichols, 1966; Alvim, 1967, 1977; Vernon, 1967(b); Ahenkora and Akrofi, 1968; 1977; Mainstone, 1971, 1972; Wyrley-Birch, 1971) relate to the influence of shade trees and regulation of shade on the performance of cacao trees. The studies/observations reported were not in relation to mixed cropping of cacao with other crops for its usefulness or in consideration of the advantageous or otherwise expected of mixed cropping.

Cacao as a mixed crop with coconut, rubber, or oil palm was thought of from early 1950s as a support to the income of small holders in Papua, New Guinea and Malaysia (Henderson, 1951; Hunter and Camacho, 1961; Blencowe, 1968). Intercropping of cacao with coconut and the association between these crops has been regarded as superior to many other agriculture enterprise in the tropics (Leach et al. 1971; Blencowe, 1968). Lee and Kasbi (1980) stated that the success of cacao/coconut intercropping has stimulated interest in the mixed cropping of oil palm and cacao. They further mentioned that with suitable hedge-planting of oil palm, intercropping of cacao is feasible. Recently Afolami and Ajobo (1983), reported that even after giving due allowances for losses due to pests and diseases, the yield from cacao planted in combination with oil palm is greater than pure stands of cacao. Introduction of cacao as mixed crop with arecanut is of recent innovation. Only preliminary reports on the performance of the two crops under the mixed cropping system are available (Bhat and Leela, 1968; Bhat and Bavappa, 1972; Bhat, 1974(a), 1979).

The present study covers the first twelve year orchard life of the two crops and in assessing the resultant interaction due to mixed cropping, the production of fruits (yield) for the component crops has been taken into consideration. In assessing the yield advantageous of intercropping (mostly of annual crops) various indices have been adopted in the evaluation of superiority, efficiency, economic returns, productivity, etc. These include the land equivalent ratio (LER), land utilisation index (LUI), calorie equivalent, protein equivalent, gross returns, net returns, diversity index (DI), multiple cropping index (MCI), harvest diversity index (HDI), simultaneous cropping index (SCI), cultivated land utilisation index (CLUI) and crop intensity index (CII) (IRRI, 1974; IRRI, 1975; Strout, 1975; Trenbath, 1976; Francis, 1978; Menegay et al. 1978). Other related criteria include relative yields (RY) (van den Berg, 1968) and relative crowding coefficient (RCC) (de Wit, 1960). Willey (1979, 1981) has discussed at length the criteria for the yield advantage in intercropping and in doing so he recognised three situations viz., (1) where the combined intercrop yield must exceed the yield of the higher-yielding sole crop; (2) where intercropping must give full yield of a "main" crop plus some additional yield of a second crop, and (3) where the combined intercrop yield must exceed a combined sole crop yield.

In presenting the results of the study now conducted the approach is through annual yield, cumulative yield of component crops on per tree as well as unit area basis. Land equivalent ratio and monetary returns of the mixed cropping systems are also worked out.

Materials and Methods

The observations pertaining to yield of the component crops viz., arecanut and cacao were made in the experimental garden whose details are given earlier. Harvesting the ripe fruits were made periodically for both the crops from the first bearing. The number and wet weight of fruits for individual trees at each harvest were recorded. In the case of cacao only healthy good pods were taken into account for computing yield. Representative samples of arecanut from different seasons were taken, dried and husked (pericarp was removed) and dry weight of kernel recorded. Data on the wet weight of pods, number of beans per pod, wet and dry weight of beans were collected by taking representative sample of pods from each plot during different months of harvest. Beans from the sample pods were processed and dried separately.

Results

1. Progress in the yield

(a) Arecanut: The arecanut palms commenced to yield fruits from the fourth year from planting in the field. The palms can be considered to have reached to the near full capacity of production on the ninth year (Table 49).

(b) Cacao: The cacao trees commenced to yield fruits from the second year of planting and can be considered to have assumed to near full capacity from sixth year (Table 49), in as much as it is still continuing to show improved trend.

2. Cumulative yield

(a) Arecanut: The data on average yield per year for the period from 1977-78 to 1981-82 for arecanut planted under different densities under the mixed cropping are presented in Table 50. The yield, both weight and number, per palm is maximum under treatment S_3 and minimum for S_1. The number of nuts (fruits) per palm is significantly more under S_3, S_4 and S_5 treatments than under S_1. The weight of nuts per palm is not significantly different under different spacings.

Table 48. Progress in the production of arecanut

Age of palms from planting (year)	Av. number of nuts/palm
4	1.9
5	32.8
6	89.0
7	144.5
8	102.3
9	245.5
10	203.0
11	249.1

Table 49. Progress in the production of cacao

Age of trees from planting (year)	No. of pods/tree
2	7.3
3	19.8
4	44.7
5	49.7
6	69.7
7	68.4
8	59.0
9	79.9
10	65.7
11	45.1

Table 50. Average yield of [redacted]

Table of means

Treatment	Av. No. of nuts/tree			Av. wet wt. of nuts (kg)/tree			No. of nuts/('000)/ha			Wet wt. of arecanut ('000) kg/ha		
	F_1	F_2	Mean	F_1	F_2	Mean	F_1	F_2	Mean	F_1	F_2	Mean
S_1	118.0	174.9	146.4	4.1	5.6	4.8	161.9	239.9	200.9	5.6	7.7	6.6
S_2	156.4	200.5	178.4	5.0	6.4	5.7	214.6	275.1	244.8	6.8	8.8	7.8
S_3	233.9	210.3	222.1	7.3	6.9	7.0	320.9	288.5	304.7	9.9	9.4	9.6
S_4	189.3	231.1	210.2	6.1	7.5	6.8	124.4	151.8	138.1	4.0	4.9	4.5
S_5	182.3	201.6	192.0	5.6	7.0	6.3	176.2	185.1	180.6	5.4	6.4	5.9
S_6	190.3	187.5	188.9	6.1	5.9	6.0	195.8	192.9	194.4	6.3	6.0	6.2
Mean	178.4	201.0	189.7	5.7	6.6	6.1	199.0	222.2	210.6	6.3	7.2	6.8
SE/plot		44.49			1.45			56.25			1.85	
CV (%)		23.45			23.68			26.71			27.25	
CD (P=0.05)												
for spacing		45.49			-			57.52			1.89	
for fertilizers					0.85			-			-	
for FxS		-			-			-			-	

ANOVA in Appendix, Table 50(i)

On per hectare basis the yield is significantly maximum under S_3 which has recorded significantly more yield than all other spacings except S_2. The yield is lowest under S_4.

(b) Cacao: The data on average yield per year for the period from 1977-78 to 1980-81 are given in Table 51. The average number of pods per tree is maximum under S_3 (5.4m x 5.4m for cacao) which is significantly more than all other spacings except S_6 (3.6m x 5.4m). The spacing S_1 (2.7m x 2.7m) has recorded minimum number of pods per tree which is significantly lowest than all other spacings. On hectare basis S_5 (3.3m x 3.3m) recorded maximum yield (both in number and weight of pods). This is significantly more than all other spacings except S_1 (2.7m x 2.7m). The lowest yield per hectare is under S_3 (5.4m x 5.4m) which is significantly lower than all other spacings.

(c) Combined yield of arecanut and cacao: The density of planting has significant influence on the combined yield (wet weight of fruits) of the two components (Table 52). The spacing S_5 (with both arecanut and cacao at 3.3m x 3.3m) has given the highest yield closely followed by S_1 (both arecanut and cacao at 2.7m x 2.7m) (Fig. 16). These two densities have recorded significantly higher total yield than all other densities except S_2 (arecanut at 2.7m x 2.7m and cacao at 2.7m x 5.4m).

(d) Fertilizer and yield: Application of F_2, higher levels of fertilizer to cacao trees reflected on the weight

Table 51. Average yield of cacao/year (1977-78 to 1981-82)

Table of means

Treat-ments	Av. no. of pods/tree			Wet wt. of pods/tree			No. of pods ('000)/ha			Wet wt. of pods ('000) kg/ha		
	F_1	F_2	Mean	F_1	F_2	Mean	F_1	F_2	Mean	F_1	F_2	Mean
S_1	41.8	34.7	38.2	14.1	11.7	12.9	57.3	47.6	52.5	19.3	16.1	17.7
S_2	60.7	69.4	65.0	20.9	22.9	21.9	41.7	47.6	44.6	14.3	15.7	15.0
S_3	68.0	98.6	83.3	21.8	31.7	26.7	23.3	33.8	28.6	7.5	10.9	9.2
S_4	60.9	61.5	61.2	20.8	20.5	20.7	40.0	40.4	40.2	13.7	13.5	13.6
S_5	57.8	67.2	62.5	20.3	21.4	20.9	53.0	61.7	57.4	18.7	19.7	19.2
S_6	74.6	70.6	72.6	25.7	24.7	25.2	38.4	36.3	37.3	13.2	12.7	13.0
Mean	60.6	67.0	63.8	20.6	22.2	21.4	42.3	44.6	43.4	14.4	14.9	14.6
SE/plot		15.63			5.25			8.16			3.07	
CV (%)		24.[illegible]			24.56			18.79			21.03	
CD (P=0.05) for spacings		15.98			5.37			8.34			3.14	

S_1-S_6. for legend see Table 8.

ANOVA in Appendix, Table 51(i)

Table 52. Combined average yield of arecanut and cacao/year (1977-78 to 1981-82)

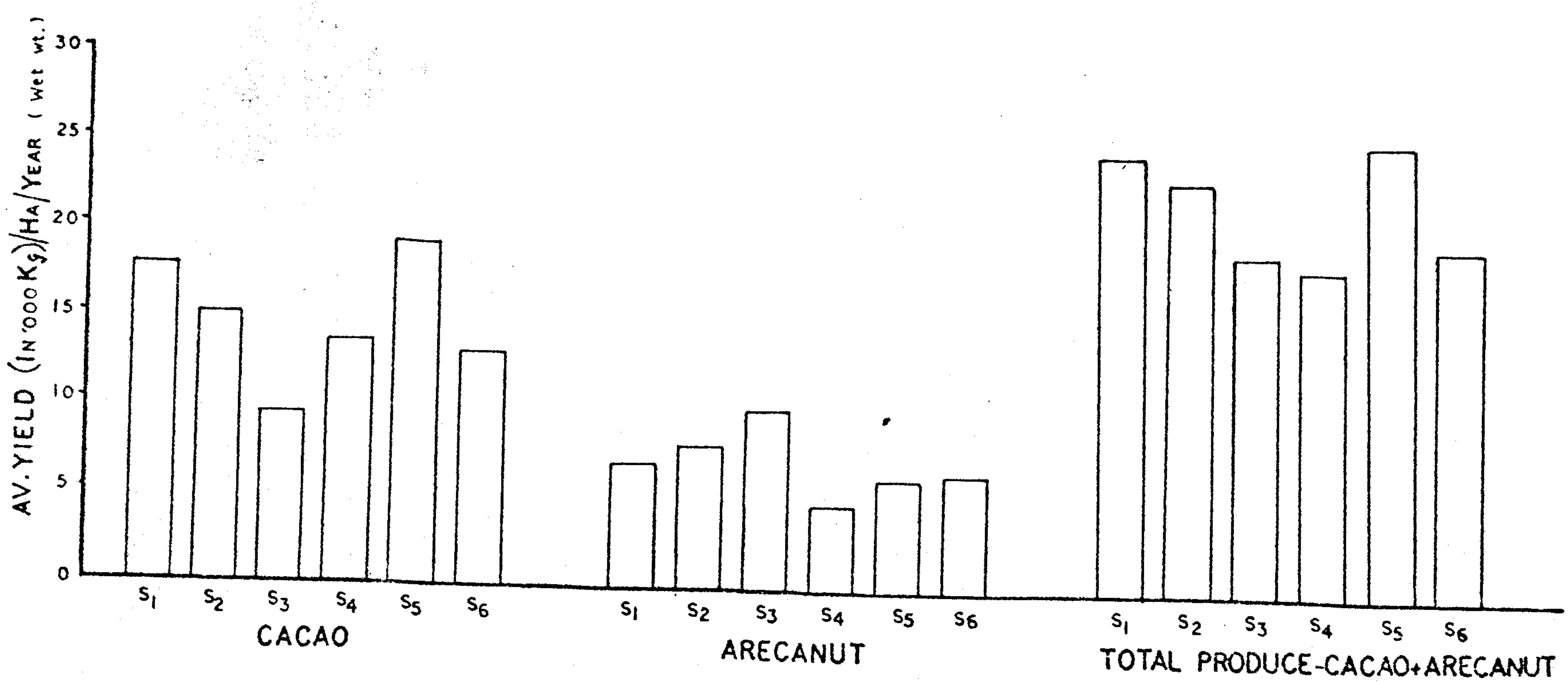
Table of means

Treat-ments	Net wt. of total produce ('000) kg/ha Cacao + Arecanut		
	P_1	P_2	Mean
S_1	24.8	23.8	24.3
S_2	21.1	24.5	22.8
S_3	17.4	20.3	18.8
S_4	17.7	18.4	18.0
S_5	24.1	26.1	25.1
S_6	19.5	18.8	19.1
Mean	20.8	22.0	21.4
SE/plot		3.83	
CV (%)		17.93	
CD (P=0.05) for spacing		3.92	

S_1-S_6, for legend see Table 8

ANOVA in Appendix, Table 52(i)

FIG. 16. YIELD OF CACAO AND ARECANUT IN DIFFERENT TREATMENT COMBINATIONS

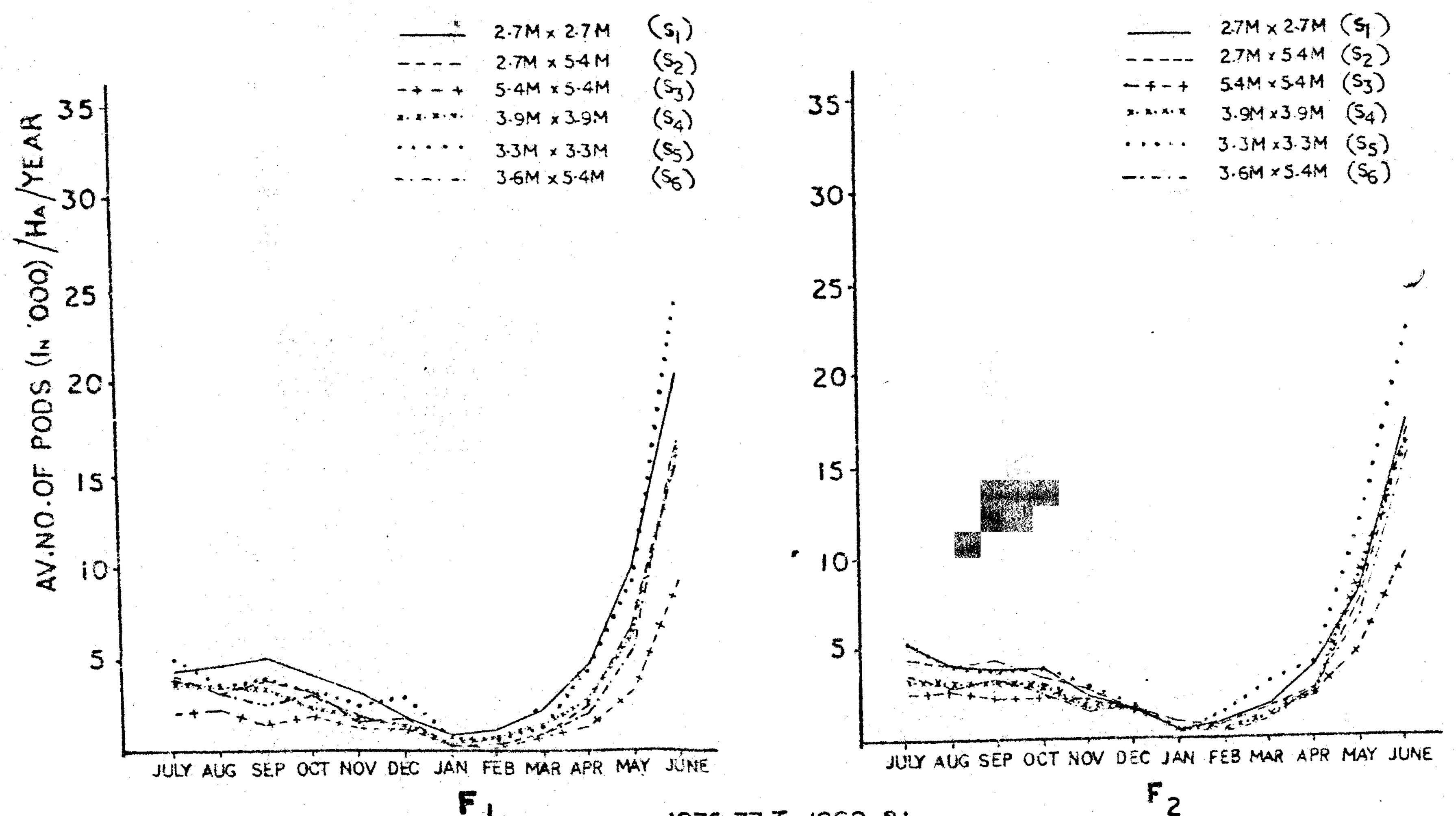


of arecanut (Table 50). At F_2 level the average number of nuts per palm is more than that at F_1 level (though not reached to significant level). But the mean weight of nuts per palm is significantly more under F_2 than in F_1 level. As regards cacao the mean yield of pods per tree as well as per hectare is slightly more in F_2 level of fertilizer, though the difference in the yield at the two levels of fertilizer is not significant (Table 51).

3. Seasonal variations in the harvest of cacao

The average number of cacao pods harvested during different months for four years (1977-78 to 1980-81) pooled for the entire period of four years is presented in Fig. 17. It is observed that cacao comes to harvest in almost all the months except for a small crop in January and February. The monthly harvests go on increasing from February onwards reaching a peak in June and thereafter there is a sudden fall in July. The harvests come down from July slowly, touching lowermost level in January-February. Though the crop is available almost throughout the year, on an average 55.1 per cent of the fruits are harvested during the south-west monsoon period (June to September), 16.2 per cent between October and January and the remaining 28.7 per cent between February and May (Table 53). Density of planting does not seem to have much influence on the quantity harvested during different months.

FIG. 17. MONTHLY VARIATIONS IN THE HARVEST OF CACAO



1976-77 To 1980-81

Table 53. Seasonal variations in the quantity of cacao pods

Treatments	June-September Mean No. of pods ('000)/ha	%	October-January Mean No. of pods ('000)/ha	%	February-May Mean No. of pods ('000)/ha	%	Total No. of pods ('000)/ha
			(i) 1977-1978				
S1	31.72	47.26	18.74	27.93	16.65	24.81	67.11
S2	25.81	51.56	14.10	28.33	10.06	20.10	50.05
S3	12.36	39.63	8.62	27.62	10.22	32.75	31.19
S4	28.98	53.95	12.29	22.88	12.44	23.16	53.71
S5	40.57	50.06	19.50	24.06	20.98	25.88	81.04
S6	28.83	55.99	12.34	23.96	10.33	20.05	51.50
Mean	28.05	50.29	14.28	23.60	13.45	24.11	55.77
			(ii) 1978-1979				
S1	24.28	55.51	4.40	10.05	15.06	34.44	43.73
S2	21.59	55.63	5.71	14.70	11.51	29.66	38.80
S3	10.71	47.27	3.38	14.93	8.56	37.80	22.65
S4	20.42	55.38	3.42	9.26	13.04	35.36	36.87
S5	26.70	55.03	4.27	8.80	17.55	36.17	48.51
S6	21.20	58.43	4.41	12.15	10.68	29.42	36.29
Mean	20.82	55.06	4.27	11.28	12.73	33.68	37.31

Contd.....

Treat-ments	June-September Mean No. of pods ('000)/ha	June-September %	October-January Mean No. of pods ('000)/ha	October-January %	February-May Mean No. of pods ('000)/ha	February-May %	Total No. of pods ('000)/ha
			(iii) 1979-1980				
S1	25.74	47.71	2.92	5.40	25.30	46.89	53.95
S2	22.22	50.29	2.73	6.18	19.24	43.53	44.19
S3	12.87	51.76	2.46	9.88	9.54	38.36	24.86
S4	18.54	47.18	2.33	5.91	18.43	46.91	39.29
S5	32.90	52.48	3.13	5.46	26.37	42.06	62.69
S6	20.50	52.61	2.59	6.65	15.88	40.75	38.96
Mean	22.13	50.30	2.74	6.23	19.13	43.48	43.99
			(iv) 1980-1981				
S1	41.00	60.75	13.77	20.40	12.71	18.83	67.47
S2	39.18	65.16	10.32	17.16	10.63	17.68	60.13
S3	25.49	66.60	8.60	22.46	4.19	10.94	38.27
S4	31.81	61.97	8.15	15.87	11.37	22.16	51.32
S5	44.40	63.30	11.65	16.60	14.10	20.10	70.14
S6	28.57	66.12	7.28	16.84	7.37	17.04	43.21
Mean	35.08	63.67	9.96	18.08	10.06	18.26	55.09
			(v) Average yield/year (1977-78 to 1980-81)				
S1	30.69	52.85	9.96	17.15	17.43	30.01	58.07
S2	27.20	56.33	8.24	17.06	12.86	26.63	48.29
S3	15.36	52.53	5.77	19.73	8.13	27.80	29.24
S4	24.94	55.06	6.55	14.46	13.82	30.50	45.30
S5	36.14	55.09	9.71	14.80	19.75	30.11	65.60
S6	24.78	58.32	6.66	15.67	11.07	26.05	42.49
Mean	26.52	55.06	7.81	16.21	13.84	28.73	48.17

S_1-S_6, for legend see Table 8

4. Influence of environment on pod and bean characters

The season of harvest, spacing and fertiliser levels have influenced one or more characters of pod and beans (Table 34). The mean wet weight of single pod, number of beans per pod, wet and dry weights of beans and pod value have been significantly influenced by the season of harvest. Weight of pods harvested in February, March is significantly more than those harvested either in May or June, July. The weight is minimum for May pods. February, March harvests give significantly more number of beans per pod than pods harvested during May or June, July. The wet weight of 100 beans is significantly more for June, July crop, followed by February, March crop and minimum for May harvest. The dry weight of 100 beans is significantly more for May crop than June, July crop. The mean dry weights of beans of February, March harvests and May do not differ significantly. The pod value, i.e., the number of pods required to produce one kg of dry beans is significantly more (34.0) for the June, July crop, followed by May crop (with 28.8) and minimum for February, March harvest (26.0).

Spacing also has significantly influenced the weight of pod and pod value. The spacing S_4 has more pod weight as compared to S_1 spacing and is on par with the remaining spacings. Regarding pod value, S_1 has higher value (31.4) than rest of the spacings except S_2.

Fertilisers at higher level significantly reduced the mean number of beans per pod and increased the pod value.

Table 54. Influence of environment on pod and bean characters

Table of means

Treatments	February-March	May	June-July	Mean	F_1	F_2
			Wt./pod (g)			
S_1	372.5	297.6	332.1	334.1	335.3	332.9
S_2	372.0	294.1	338.1	334.8	335.8	333.7
S_3	345.0	281.8	298.5	308.7	309.9	307.5
S_4	385.3	304.9	340.6	343.6	326.8	360.4
S_5	394.2	288.1	335.2	339.2	367.1	311.3
S_6	390.4	305.1	328.8	341.4	341.7	341.2
Mean	376.7	295.3	328.9	333.7	336.1	331.2
F_1	375.1	300.1	333.1			
F_2	378.3	290.5	324.7			
SE/plot				36.60		
CV (%)				10.97		
CD (P=0.05)						
for seasons				14.82		
for spacings				20.96		
for spacings x fertilizers				29.65		

Contd.....

Table 54 (Contd.)

Treatments	February-March	May	June-July	Mean	F_1	F_2
			No. of beans/pod			
S_1	40.4	37.1	36.1	37.9	38.0	37.8
S_2	38.0	36.5	35.5	36.7	36.8	36.5
S_3	42.4	34.7	34.7	37.3	38.7	35.9
S_4	42.4	36.8	35.7	38.3	37.6	38.9
S_5	41.3	35.8	35.4	37.5	38.1	36.9
S_6	39.9	38.4	36.0	38.1	40.5	35.7
Mean	40.8	36.5	35.6	37.6	38.3	36.9
F_1	41.3	38.0	35.6			
F_2	40.3	35.1	35.5			
SE/plot				3.35		
CV (%)				8.91		
CD (P=0.05)						
for seasons				1.36		
for fertilisers				1.10		
for spacings x fertilisers				2.71		

Contd.....

Table 54 (Contd.)

Treatments	February-March	May	June-July	Mean	F_1	F_2
			Wet wt. of 100 beans (g)			
S_1	220.7	207.8	248.5	225.7	225.4	226.0
S_2	234.6	208.6	244.7	229.3	233.7	224.9
S_3	227.6	217.9	227.2	224.2	237.0	211.5
S_4	218.4	215.3	252.5	228.7	225.1	232.4
S_5	227.4	215.4	257.0	233.3	242.2	224.3
S_6	245.2	228.6	252.3	242.0	235.0	249.1
Mean	229.0	215.6	247.0	230.6	233.1	228.0
F_1	233.8	219.5	245.9			
F_2	224.2	211.7	248.2			
SE/plot				23.85		
CV (%)				10.34		
CD (P=0.05)						
for seasons				9.66		
for spacings x fertilisers				19.32		

Contd....

Table 54 (Contd.)

Treatments	February-March	May	June-July	Mean	F_1	F_2
			Dry wt. of 100 beans (g)			
S_1	95.6	95.2	87.2	92.7	92.9	92.4
S_2	96.0	95.2	82.2	91.1	92.3	90.0
S_3	94.1	99.0	77.8	90.3	93.1	87.6
S_4	90.9	98.7	85.6	91.7	89.1	94.3
S_5	96.9	94.7	85.9	92.5	97.3	87.7
S_6	101.9	101.8	84.3	96.0	95.0	96.9
Mean	95.9	97.4	83.8	92.4	93.3	91.5
F_1	98.1	97.7	84.1			
F_2	93.8	97.2	83.6			
SE/plot				8.97		
CV (%)				9.70		
CD (P=0.05) for seasons				3.63		

(Contd.....

Table 54 (Contd.)

Treatments	February-March	May	June-July	Mean	F_1	F_2
			Pod value			
S_1	26.2	28.8	32.1	29.0	29.0	29.0
S_2	27.7	29.4	34.5	30.5	29.9	31.1
S_3	25.6	30.4	38.0	31.4	29.1	33.6
S_4	26.1	27.8	33.0	29.0	30.3	27.7
S_5	25.3	30.3	33.2	29.6	27.8	31.4
S_6	24.8	26.3	33.2	28.1	26.8	29.3
Mean	25.0	28.8	34.0	29.6	28.8	30.4
F_1	25.1	27.7	33.7			
F_2	26.8	30.0	34.3			
SE/plot				3.44		
CV (%)				11.61		
CD (P=0.05)						
for seasons				1.39		
for spacings				1.97		
for fertilisers				1.14		
for spacings x fertilisers				2.79		

S_1-S_6, for legend see Table 8

ANOVA in Appendix, Table 54(i)

There is also significant interaction between spacing and fertiliser level. At S_4 the higher level of fertiliser increases the pod weight and at S_5 spacing, lower level of fertiliser increases the pod weight. The mean number of beans per pod is less under higher level of fertiliser. At S_6 spacing the higher dose of fertiliser resulted in more wet weight of beans whereas at S_3 spacing the reverse is observed. The adverse effect of higher level of fertiliser is more pronounced in S_3 and S_5 spacings. The pod values are also significantly higher for higher level of fertilisers at S_3 and S_5 spacings.

5. Land Equivalent Ratio

The LER worked out under different densities and levels of fertiliser application is presented in Table 55. Application of higher level of fertiliser has increased the LER for spacings S_2, S_3, S_4 and S_5 indicating the advantage of higher dose of fertiliser under these spacings. At lower level of fertiliser S_1 has the highest LER and S_5 has the second place, but at higher level of fertiliser the order gets reversed. When the average is considered S_5 has the highest LER, closely followed by S_1. The LER in the order of merit for various spacings based on the average values (of two fertiliser levels) is $S_5 > S_1 > S_2 > S_6 > S_3 > S_4$.

6. Gross revenue

The total revenue or return from different spacing combinations of the component crops under different price situations for cocoa (dry beans) and arecanut (dry kernel)

Table 55. Land equivalent ratios (LER) for different combinations of cacao and arecanut at different fertilizer levels

Treat-ments	Population ratio Cacao: arecanut	Mixed crop Cacao yield ('000) kg/ha)	LER Cacao	Mixed crop Arecanut yield ('000)kg/ha	LER Arecanut	Total LER
			F1			
S_1	1 : 1	19.27	1.64	5.57	0.51	2.15
S_2	1 : 2	14.33	1.22	6.80	0.62	1.84
S_3	1 : 4	7.47	0.64	9.88	0.90	1.54
S_4	1 : 1	13.68	1.16	4.03	0.37	1.53
S_5	1 : 1	18.65	1.58	5.43	0.50	2.08
S_6	1 : 2	13.21	1.12	6.30	0.58	1.70
			F2			
S_1	1 : 1	16.11	1.37	7.69	0.70	2.07
S_2	1 : 2	15.70	1.33	8.82	0.81	2.14
S_3	1 : 4	10.87	0.93	9.40	0.86	1.79
S_4	1 : 1	13.45	1.14	4.91	0.45	1.59
S_5	1 : 1	19.66	1.67	6.44	0.59	2.26
S_6	1 : 2	12.72	1.08	6.04	0.55	1.63
			Average (F1 & F2)			
S_1	1 : 1	17.69	1.51	6.63	0.61	2.11
S_2	1 : 2	15.02	1.28	7.81	0.71	1.99
S_3	1 : 4	9.17	0.78	9.64	0.88	1.66
S_4	1 : 1	13.56	1.15	4.47	0.41	1.56
S_5	1 : 1	19.16	1.63	5.93	0.54	2.17
S_6	1 : 2	12.96	1.10	6.17	0.56	1.67

Sole crop yield ('000 kg/ha)
Cacao - 11.75
Arecanut - 10.93

S_1-S_6. For legend see Table 8

is presented in Table 56 and is represented in Fig. 18. Maximum gross revenue per hectare can be expected from S_5 combination until the price of arecanut is almost equal to that of cacao. At 1:1 price ratio, the gross revenue from S_1 also equals to that of S_5. When the ratio of cacao and arecanut price reaches to 1:1.25, the gross revenue is maximum under S_2 spacing. With further increase in the price of arecanut and with the price ratio reaching to 1:1.5 and above the gross revenue is maximum from S_3.

Discussion

Arecanut cultivation, in general, is in the hands of small farmers. It is grown in fairly rich soils with either adequate soil moisture or in areas where irrigation facility is available. The normal spacing (about 7.3 m2 space/palm), the morphology and the growth habit of the palms have given scope for multiple cropping in arecanut gardens. The highly fluctuating and undependable price of the commodity as well as the crop losses due to incidence of pests and diseases also support the idea of raising other crops in the arecanut gardens. Cacao has been introduced into the agricultural system of the country in recent years. It has been repeatedly pointed out that though cacao produced more pods under exposed conditions, shade cannot be completely avoided in view of the benefits that weigh against the drawbacks of full exposure (Alvim and Alvim, 1978; Owusu, 1980). As pointed out earlier arecanut and cacao have quite differing growth and morphological habits. The

Table 56. Total revenue (Rs./ha) from treatment combination under different price situation (on dry wt. basis) for cacao and arecanut

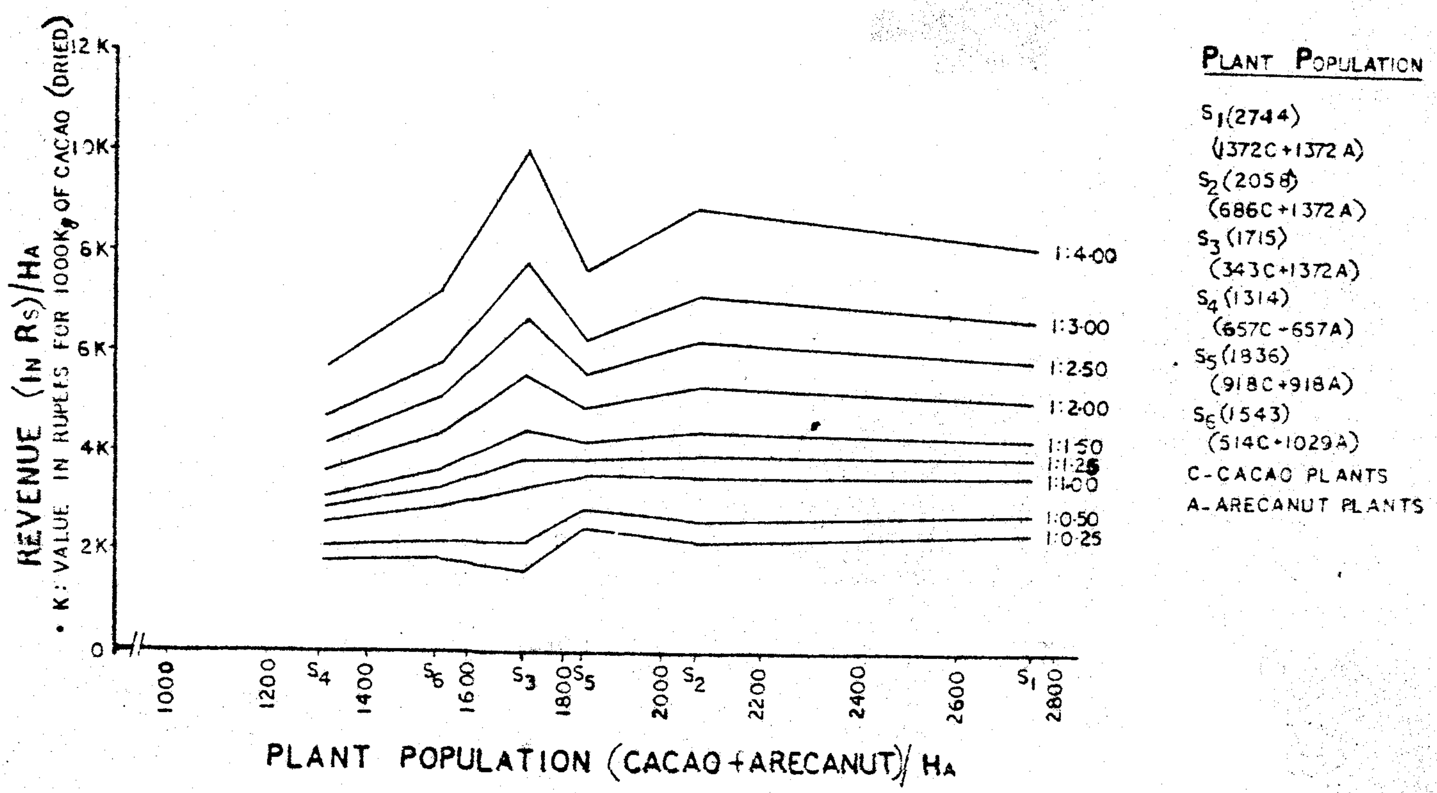
Cacao : arecanut

Price ratio	S_1	S_2	S_3	S_4	S_5	S_6
1 : 0.25	2.34	2.11	1.58	1.75	2.46	1.79
1 : 0.50	2.73	2.57	2.14	2.02	2.80	2.15
1 : 1.00	3.50	3.49	3.27	2.54	3.50	2.88
1 : 1.25	3.89	3.95	3.84	2.81	3.85	3.24
1 : 1.50	4.28	4.40	4.41	3.07	4.20	3.60
1 : 2.00	5.06	5.32	5.54	3.59	4.90	4.32
1 : 2.50	5.84	6.24	6.67	4.12	5.59	5.05
1 : 3.00	6.62	7.16	7.81	4.64	6.29	5.77
1 : 4.00	8.18	8.99	10.07	5.69	7.69	7.22

Values inside the table has to be multiplied by a 'K'
Where K = Value in Rupees for 1000 kg of cacao (dry beans)

S_1–S_5. for legend see Table 8

FIG.18. TOTAL REVENUE FROM TREATMENT COMBINATIONS UNDER DIFFERENT PRICE SITUATIONS ON DRY WEIGHT BASIS FOR CACAO & ARECANUT



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above considerations have suggested the idea of introducing cacao as a mixed crop with arecanut. The initial observations (Bhat and Leela, 1969; Bhat and Bavappa, 1972) indicated the possible compatability of the two crops in a mixed cropping system. Further information on the optimum proportion and density of the components were lacking. The present studies revealed not only more information on the growth habits of the two species both in the above ground and below ground portions but also indicated the yielding pattern of the partners resulting out of various interactions.

The density of planting has profound influence both on the yield of individual palms as well as on the yield per unit area. The lowest yield per palm is under spacing (S_1) where both arecanut and cacao have been spaced at 2.7m x 2.7m. The highest yield per palm is under S_3 spacing where arecanut is given a spacing of 2.7m x 2.7m and cacao at 5.4m x 5.4m. Under the three uniform spacings for arecanut (i.e., treatments S_1 to S_3), the yield per palm has progressively decreased as the number of cacao trees increased per plot. There is thus an indication that at least in treatments S_1 and S_2 there is over crowding of trees to some extent which resulted in the reduction in the per palm yield. Again the lower yield in S_2 may not be due to the presence of cacao trees alone is also evident because under S_4 and S_5 where almost an equal or more number of cacao trees are present the yield per palm is more than what is recorded under S_2. On hectare basis the yield of arecanut is highest under S_3 spacing which is not significantly more than S_2 spacing. This suggests that if the spacing for arecanut is 2.7m x 2.7m, cacao can be planted at 2.7m x 5.4m spacing.

As regards cacao pods per tree is concerned, the yield is lowest under the closest of 2.7m x 2.7m and highest under the widest spacing of 5.4m x 5.4m. There appears to be a progressive increase in the yield per tree from the closest spacing to the widest spacing, though there is no appreciable difference in the yield per tree when the population of cacao trees per hectare ranged from 657 to 918 (i.e., under spacings S_4, S_2 and S_8). On unit area basis, S_5 (with cacao at 3.3m x 3.3m) has the highest yield which is significantly more than all other spacings except S_1. The highest estimated dry bean yield per hectare is 2107 kg. Incidentally it may be mentioned that this yield compares well with the yield reported from other important cacao growing countries. Alvim (1977) reported that in most producing areas where traditional methods are used the mean yield varies from 300 to 500 kg of dry beans per hectare per year. With high yielding cultivars and improved cultural practices or in places with exceptionally fertile soils, according to him, it is possible to obtain a crop of 2000 to 3000 kg per hectare per year.

Under a mixed cropping system it is the combined yield of component crops that is important than the individual crop yields. The spacing S_5 (both arecanut and cacao spaced at 3.3m x 3.3m) has recorded the highest combined yield closely followed by S_1 (both arecanut and cacao at 2.7m x 2.7m), though they are not significantly more than S_2 spacing.

The yields of cacao pods are not significantly different under the two levels of fertiliser application. The higher level of fertiliser, though has significant influence on the mean weight of arecanuts produced per palm, it has not been reflected in the weight of nuts per hectare. The indication is, therefore, that a higher level of fertiliser may not be necessary for the combined cropping system at least in the initial years of orchard life.

The results of studies on the seasonal variations in the harvests of cacao have shown that more than 55 per cent of cacao crop comes to harvest during the south-west monsoon period from June to September. Hassan et al. (1981) also report similar peak harvests during the rainy season for cacao grown along with coconut in Kerala (India). The present studies have further showed the influence of season on the quality of pods and beans. The pod value is significantly more for the monsoon (June-July) crop than the crops harvested in other seasons (February, March or May). During the monsoon 5 to 8 pods more are required for production of one kg dry beans than pods harvested during other periods. Similarly the mean dry weight of 100 beans is also lesser for monsoon crop than for the beans of other seasons. Several of the characters of the cacao pods and beans viz., fat content, number of beans per pod, bean weight, shell percentage, pod and bean values etc., are reported to vary with both season and variety (Glendinning, 1963; Glendinning and Martinson, 1968; Toxopeus and Wessel, 1970; Egbe and Owolabi, 1972; Jacob and Atanda, 1973). A high degree of variation in the number of beans per pod and pod value is also attributed to the inconsistancy of natural pollination and to incompatibility (Toxopeus and Jacob, 1968, 1970; Jacob and Toxopeus, 1971).

Land equivalent ratio (LER) is a measure for evaluating land productivity in physical terms under sole crop vs. multiple crops. The LER for the cacao component is found to be influenced both by the level of fertiliser applied as well as the density of planting. The average LER for cacao under the two levels of fertiliser for different spacings ranged from 0.78 to 1.63. Similarly the LER for arecanut ranged from 0.41 to 0.88. The total LER ranged from 1.56 to 2.17 under different densities, thereby indicating the yield advantage for the mixed cropping.

Another criteria for measuring the production from multiple cropping is the value of the total produce. Hildebrand (1976) emphasises that the only way to realistically compare the system is by the market value of the produce. The gross revenue that can be expected is maximum for S_5 combination until the price of arecanut is about equal to that of cacao. When the ratio of cacao and arecanut price is 1 : 1.25, the total revenue is maximum under S_2, though not very much higher than S_1, S_5 and S_3 combinations. When the ratio in the price of cacao and arecanut is 1 : 1.5 and above, S_3 combination gives maximum total revenue. It is indicated that it is necessary to have some flexibility in selecting a system in view of the fluctuating prices of the component crops. Under the above circumstances, the net income may also require to be considered.

One advantage in mixed cropping is that at the time of low prices or crop loss of one crop, the value realised from the other crop can minimise the risk involved. Another advantage in growing arecanut and cacao in a mixed crop system is in the balanced distribution of revenue to the farmer throughout the year. The peak harvesting period for arecanut is from November to February (when 87 per cent of the annual crop is harvested-Table 57), and for cacao between June and September. In other words, maximum harvest of arecanut is during the months when cacao has the lean harvest and cacao has the maximum crop ready for harvest when arecanut is in the off season. This contrasting harvesting and processing periods also further help in a better utilisation of labour throughout the year.

While the advantages of mixed cropping arecanut and cacao are many as described earlier, the likely disadvantages of growing the two crops are not ruled out. There are reports (Thorold, 1959; Turner, 1965; Vernon, 1966; Newhall and Dias, 1967; Tarjot, 1971; Rocha and Machado, 1972) that

Table 57. Arecanuts harvested during different months

Month	% of total
January	30.0
February	15.3
March	4.4
April	0.6
May	0.1
June	0.1
July	0.1
August	0.5
September	1.3
October	5.7
November	14.5
December	27.4
Total	100.0

the incidence of black-pod disease of cacao caused by *Phytophthora palmivora* is more with closely spaced and shaded plots. Arecanut is also susceptible to *Phytophthora* diseases. It may thus be worthwhile to get more information on the cross transmissibility of the disease from one crop to the other. There are some insect pests, like mealy bugs (*Planococcus* sp.), cockchafer beetles etc., common to both arecanut and cacao whose role in the cropping system requires to be studied.

VIII. SUMMARY AND CONCLUSIONS

SUMMARY AND CONCLUSIONS

Mixed cropping is one of the methods suggested for increasing agricultural productivity. The patterns or components of these mixtures are usually different crop species or sometimes varieties. Mixed or intercropping is widely practiced among farmers in Asia and Africa (Ayer, 1949; Andrews and Kassam, 1976). Reasons for mixed cropping include (1) increased efficiency in the utilisation of environmental factors, viz., light, nutrients, water, etc., (2) more efficient utilisation of labour; (3) reduction of the adverse effects of diseases, pests and weeds; (4) cover the risk of crop failure; (5) higher gross returns, and (6) protection of the soil against soil erosion etc. Several complex interspecific, intervarietal and interplant interactions (annidation, allelopathy, etc.) that occur in this system of farming have been discussed by Trenbath (1976). These interactions depend on plant density and spacing, planting patterns, canopy types, root systems, and differential demands on environmental factors at different growth stages. Considerable information is available on the various types of interactions involved in annual crop species. Like information on plant behaviours involving perennial crops is scanty.

In the traditional system of cultivation several annual and perennial crops are seen growing admixed with arecanut (*Areca catechu* L.) in India. Whereas cacao (*Theobroma cacao* L.), which is normally seen under the shade of forest trees in its original habitat, has been thought of as a probable mixed crop with arecanut in this country only in recent years. Arecanut is a single stemmed, tall, monocot palm with fibrous root system whereas cacao is a dicot with a much branched canopy with a different root system- a plant which has not been tried for its impact on the other. Studies were, therefore, carried out to understand the various types of interactions between arecanut and cacao, both above and below ground involving a system of mixed cropping. The results of the study on the above aspects are summarised in the following pages.

The studies were made in an experimental garden planted at Central Plantation Crops Research Institute, Regional Station, Vittal (Karnataka) with arecanut and cacao having six densities and two levels of fertilisers replicated four times. Studies on the above ground included growth patterns and utilisation of radial and vertical space by the component crops, microclimatical changes in the garden, distribution and utilisation of solar energy, rate of evaporation, and finally on the production behaviour of the crops. Below ground studies were confined to the rooting pattern of the components and the effect of the cropping on the nutrient status of the soil.

An important aspect of study on the above ground portion was on the changes in the growth of the trees involved. Periodical measurements made on the height and girth of arecanut palms showed that introduction or presence of cacao at different densities had no significant influence on the rate of growth of the palms. The rate of spread of the arecanut canopy (crown) was very rapid till fourth year from planting which later got reduced. Similar data collected on the rate of growth (height, girth, spread of tree east-west and north-south) of cacao trees from the time of planting till tenth year showed a significant variation due to the density of planting. The height of cacao trees under the highest density of 2.7m x 2.7m spacing was maximum from sixth year till tenth year whereas it was minimum under the widest spacing of 5.4m x 5.4m. The average height of cacao trees increased to 5.7 times the original height in ten years. Different densities of planting had no influence on the girth of main stem of cacao trees. In the combined system of arecanut and cacao planting, the ratio of height of arecanut and cacao trees which was 1 : 1 at the time of planting got changed to 1 : 0.6 at the end of seventh year. It was after seventh year of planting, that the entire canopy of arecanut trees got lifted up above the canopy of cacao trees. The rate of total coverage due to horizontal spread of cacao trees was almost uniform at different ages irrespective of the different densities up to eighth year. In so far as the coverage of space available per tree was concerned it was observed that the percentage of area covered increased with density of planting, obviously due to the larger number of trees in the closer spacings. Under the closest spacing of 2.7m x 2.7m, 52 per cent of the available space was covered within two years and within ten years the space covered was 306 per cent. The situation in the widest spacing of 5.4m x 5.4m was that to cover about 80 per cent of available space it took six years and the coverage was not full even after ten years.

Another aspect of study was on the flowering of the two species. With regard to arecanut palm neither the age at first flowering nor the progress in the number of trees flowered at different ages nor other characters like mean number of spadices produced, female flowers produced or fruits set had been influenced by density of planting or the presence of various levels of cacao population. Among cacao trees also the density of planting had no significant influence on the age of flowering or percentage set of fruits. The mean percentage of fruit set was 2.5 per tree.

The microclimate studies included evaporation rate, wind velocity, soil temperature, relative humidity, vapour pressure and air temperature. The mixed cropping system had profound influence on all these parameters. The rate of evaporation was minimum under the mixed crop, followed by the sole crop of cacao. The evaporation in the crop combination was only 17 per cent of that from the open area and 37 per cent of that from the sole crop of arecanut. In the sole crop of arecanut, the evaporation was 46.5 per cent that of open area. The evaporation from the sole crop of cacao plot was slightly more than that from the mixed crop plot. The cropping systems had marked influence on the wind velocity. The mean wind velocity inside the sole crop of arecanut garden was 0.72 km per hour and 0.20 km in the mixed crop when the wind speed was 2.16 km per hour in the open. The speed of wind inside the sole crop of arecanut was 33 per cent and inside the mixed crop 9 per cent that of the velocities in the open. The soil temperature at 15 and 30 cm depths had also been influenced by the cropping system. The mean monthly temperature of soil at 15 cm depth were 4.8°C to 13.5°C lower in the mixed crop condition than in the open. A similar trend was seen at 30 cm depth also. The mixed cropping system had also buffering effect in bringing down the diurnal variations of soil temperatures. It was only 1.0° to 1.1°C in the mixed crop condition when the variation was 9.7°C in the open. As could be anticipated, the difference in relative humidity between the forenoon and afternoon was lesser in the cropped areas than in the open. The difference was least inside the mixed cropping plots. The cropping systems did not exert appreciable influence on vapour pressure. The difference in air temperatures between morning and afternoon hours below the canopy of cacao trees was minimum.

The light interception studies revealed a maximum possible utilisation of solar energy under the mixed cropping system.

The arecanut having tall raised up umbrella like crown canopy cuts 41.6 per cent of sun light allowing the balance to be utilised by the cacao canopy underneath. Cacao in its turn cuts off 51.2 per cent of the total sun light leaving only 7.2 per cent to reach the ground. This means arecanut palm cuts off 41.6 per cent of available light whereas cacao canopy cuts off 87.3 per cent of light reaching it. The study thus showed that with cacao as a lower storey crop with a well spread broad canopy together with arecanut having limited canopy size has a tremendous scope for maximum utilisation of solar energy.

One of the underground studies made was on the root spread of the component crops under the sole crop condition as well as under the mixed crop situation when the trees were 10 years old. When arecanut was planted as a sole crop 61 per cent of all (total) roots, 70 per cent of thick roots and 51 per cent of fine roots were radially spread within 50 cm distance from the centre of the palms. In the second zone lying between 51 to 100 cm radius, the concentration of total, thick and fine roots were 28, 23 and 33 per cent respectively. Vertically the roots of arecanut were found to traverse as deep as 1.6 m, though 66 per cent of total roots, 61 per cent of thick roots and 73 per cent of fine roots were within 50 cm depth. The second horizon between 51 to 100 cm contained 21 per cent of all roots, 28 per cent of thick roots and 13 per cent of fine roots. The zone lying beyond 100 cm had only 13 per cent of all roots, 12 per cent of thick roots and 14 per cent of fine roots.

With regard to cacao trees under the sole cropping condition the maximum concentration was within 25 cm radius from the tree. The lateral spread of all roots, thick and fine roots within 50 cm radius were 81, 86 and 69 per cent of total respectively. There was a sharp decrease in the dry weight of all categories of roots beyond 50 cm radius. Only three per cent of all roots had spread beyond 150 cm radius from the tree. The vertical penetration of cacao tree roots was up to 150 cm, though 68 per cent of all roots and 60 per cent of fine roots were within the first horizon of 50 cm depth. The zone up to 100 cm contained 87 per cent of total and 74 per cent of fine roots.

Under the mixed cropping condition, 65 per cent of all roots and 51 per cent of fine roots of arecanut were within 50 cm radius. The zone within 75 cm radius was occupied by 91 per cent of total roots and 86 per cent of fine roots. On the whole 99 per cent of total roots were within 100 cm from the palm. Depthwise, 55 per cent of total roots and 57 per cent of fine roots were within 50 cm from the ground. The second layer of 51 to 100 cm contained 41 per cent of total roots and 37 per cent of fine roots. The magnitude of roots traversing beyond 100 cm was low, though they could be seen up to 300 cm. With regard to cacao under the mixed cropping situation, 42 per cent of total roots and 24 per cent of fine roots were confined to 25 cm radius. The sector between 26 and 50 cm radius contained 14 per cent of total roots and 16 per cent of fine roots. In the third strata lying between 51 and 75 cm, there was 11 per cent of total and 15 per cent of fine roots. There was a rapid decrease in the spread of roots beyond 75 cm radius. The first 50 cm layer was occupied by 40 per cent of total and 30 per cent of fine roots. The second horizon between 51 and 100 cm depth had been occupied by 32 per cent of total and 13 per cent of fine roots. The ramification of all roots rapidly decreased beyond 100 cm depth, though they could be traced up to 480 cm below ground level.

A comparison of the rooting system of arecanut palm under the two systems of planting revealed certain interesting features. The sphere of spread of total roots though were confined to more or less to same distance both radially and vertically under the two systems, there was some difference in the percentages of distribution of different types of roots in different zones within the sphere of spread. Under the mixed cropping system, more than 96 per cent of thick roots were within 100 cm depth, whereas under sole crop condition only about 88 per cent were within the same depth. Interestingly, the quantity of fine roots in the top 50 cm layer was only 57 per cent under the mixed crop condition as against 73 per cent of similar roots in the top layer when planted pure. There was a better exploitation of the second layer between 51 to 100 cm by the fine roots under the mixed cropping condition than under the sole cropping system, the percentages of fine roots in the second layer under the two systems were 37 and 13 respectively. The roots of cacao traversed as deep as 480 cm under mixed cropping situation when the penetration was confined to 350 cm depth when it was a sole crop. The percentage of all roots was only 40 in the first 50 cm depth under the mixed cropping whereas it was 68 per cent under the sole cropping. In the same zone only 30 per cent of fine roots were traced in the mixed cropping whereas it was 60 per cent under the sole cropping. The overall situation was that when 90 per cent of the fine roots were within 200 cm below ground level under the sole cropping, it was seen that the same quantity (per cent) of roots was spread over to 350 cm depth under the mixed cropping, thereby indicating a deeper exploitation of soil by cacao roots under the latter condition.

The studies pertaining to the nutrient status of the soil revealed interesting results. It was seen that spacing, location and depth of sampling influenced soil pH significantly. The soil acidity was relatively high in soils where no crop was grown. A slight increase in pH was noticed when arecanut was grown as sole crop. This trend was not exhibited in the sole crop of cacao. The mean pH of fallow land was 4.7 and that of cacao or arecanut base ranged from 5.0 to 5.3

The data on the soil organic carbon status showed a low percentage of carbon content in the fallow soil compared to the cropped field. In the cultivated field, the samples from the bases of both arecanut and cacao contained a higher percentage of organic carbon when compared to the sample from the interspace. The sample from the interspace was comparable with that of fallow land in respect of organic carbon content. In all the locations the organic carbon content progressively decreased with the depth of soil sampling up to 100 cm. The percentages of organic carbon in the top 25 cm soil under the bases of arecanut and cacao ranged from 1.33 to 1.57, whereas in the lower depth (50-100 cm) it ranged from 0.59 to 0.81. The interspaces between arecanut and cacao trees contained 0.38 to 0.79 per cent organic carbon.

The available soil phosphorus was very low in the fallow soils compared to cropped ones. The available P in soils cropped with arecanut recorded high concentration in all the three depths (0-25 cm, 26-50 cm and 51-100 cm) as compared to cacao under sole crop condition. However, the trend was different under the mixed crop system. The available P in the top soil (up to 25 cm depth) under the bases of arecanut and cacao in the mixed cropping system ranged from 50.5 to 53.6 ppm. In the lower depth below 50 cm it was less than 10 ppm. The available P extracted from the interspaces of arecanut and cacao trees was comparable with that of fallow soils. The mean available P in the interspaces was 1.8 ppm and that in fallow land 1.4 ppm. The extractable P significantly decreased with the depth of soil sampling suggesting the anticipated immobile nature of P in the soil. The levels of fertiliser application did not yield significant variation in P content of soil. The interaction between spacing and fertiliser, location and depth of sampling significantly influenced the extractable soil P.

Available potassium did not show much variation in soils either fallow or cropped with either of the sole crops. In general, it was in low range (5.0 to 15 ppm). On the contrary under the mixed crop the level of available K got elevated to high level (up to 154 ppm). There was significant variation in the levels of K between different locations of sampling (arecanut base, cacao base, and in between the two). The available K in the inter space sample was not comparable either with fallow or sole crops. The high available K was recorded in surface samples in all the locations which decreased with depth of sampling. The K content at lower depths 26-50 cm and 51-100 cm was on par.

The data collected on the economic yield of the two crops as influenced by different densities of planting vis-a-vis sole cropping at different ages of the trees showed interesting and valuable information useful to the farming community. Spacing had significant influence on the yield (number) of fruits of arecanut both on per palm basis as well as unit area basis. The yield of arecanut per palm was influenced by the density of cacao trees planted with it as mixed crop. With regard to cacao also density of planting significantly influenced the mean number and weight of fruits (yield) per tree as well as per unit area harvested per year. Closest spacing had significantly minimum yield per tree and the widest spacing recorded significantly maximum yield per tree. However, the overall yield position from unit area depended on the yield per tree as well as the number of trees occupied per unit area depending upon the density of planting. The combined yield of the component crops per unit area was significantly higher when compared to the yield of individual crops under sole crop conditions. The results also indicated the optimum combination of the two crops to be planted for maximum returns.

The season of harvest, spacing and fertiliser levels had influenced the quantitative characters of pods and beans of cacao. Pods harvested during the monsoon period had higher pod value and lower dry bean weight than pods harvested during rest of the period. Of the total annual yield of cacao, on an average 55 per cent was harvested during the south-west monsoon period.

The average total land equivalent ratio for the different densities ranged from 1.56 to 2.17 which showed the advantage of mixed cropping of arecanut and cacao. The estimated gross revenue was maximum from S5 combination (i.e., with both arecanut and cacao spaced at 3.3m x 3.3m) until the price of arecanut was about equal to that of cacao. Another advantage of mixed cropping was due to the different periods of harvest of the two crops. About 87 per cent of the annual crop of arecanut was harvested between November and February and about 55 per cent of cacao between June and September. The availability of one or the other crop almost throughout the year and the extra labour required for harvesting and processing of the produces not only brought income to the farmer throughout the year but also generated additional employment under the mixed cropping system.

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* Original not seen.

APPENDIX

Table 8 (1). Growth of arecanut palms during initial 3 years

Summary of analysis of variance table (ANOVA) — Mean sum of squares (MSS)

Source	df	1970			1971			1972			
		No. of leaves	Girth	Height	No. of leaves	Girth	Height	No. of leaves	Girth	Height	No. of nodes
Replications	3	0.33	1.73	435.10	1.62	16.43	792.48	2.21	95.66	5653.20	1.77
Spacings	5	0.03	0.06	92.59	0.02	0.39	35.16	0.04	1.60	180.70	0.01
Error	15	0.02	0.42	179.45	0.08	0.60	27.83	0.07	2.70	135.13	0.03

Table 9 (i). Growth parameters of arecanut palms, 1976

Summary of ANOVA Table — (MSS)

Source	df	Height	Girth at FM	Girth at LEM	IND at FM	IND at LEM	No. of leaves	No. of nodes
Repl.	3	50420.60	133.69	208.23	36.29	29.64	3.24	87.17
Blocks within repl.	4	3665.40	5.98	5.68	4.73	2.32	0.13	8.67
Spacings (S)	5	744.90	7.14	5.18	2.90**	2.45**	0.20	5.69
Fertilisers(F)	1	0.00	0.16	2.43	0.14	1.28	0.06	0.29
S x F	5	2037.40	4.49	7.58	2.15*	1.40	0.07	5.46
Error	29	1084.61	4.00	4.30	0.60	0.68	0.11	4.10

* Significant at P = 0.05

** Significant at P = 0.01

Table 10 (i). Growth parameters of arecanut palms, 1978

Summary of ANOVA Table — (MSS)

Source	df	Height	Girth at PH	Girth at LSA	IND at PH	IND at LSA	No. of leaves	No. of nodes
Repl.	3	141363.90	87.53	95.47	37.34	23.72	1.23	184.98
Blocks within repl.	4	2750.90	4.25	4.73	0.71	0.50	0.40	10.69
Spacings (S)	5	1831.10	5.64	4.97	1.52	2.20	0.21	18.14
Fertilisers (F)	1	320.30	1.47	5.07	0.05	0.78	0.02	0.05
S x F	5	4075.60	4.61	8.08	3.77	1.28	0.11	19.26
Error	29	2023.50	3.28	5.36	1.88	1.29	0.13	8.92

Table 11 (i). Growth parameters of arecanut palms, 1980

Summary of ANOVA Table — (MSS)

Source	df	Height	Girth at PM	Girth at LSN	IND at PM	IND at LSN	No. of leaves	No. of nodes
Repl.	3	183653.40	60.06	111.21	24.31	1.22	1.73	329.69
Blocks within repl.	4	4826.00	2.15	5.69	4.64	1.29	0.25	51.45
Spacings (S)	5	1264.90	3.82	2.67	2.74**	1.31	0.17*	19.20
Fertilisers (F)	1	1045.30	0.03	0.05	0.67	0.07	0.21	0.59
S x F	5	7823.00**	4.38	12.66**	1.78*	3.04	0.24**	31.02*
Error	29	1480.10	2.04	3.00	0.68	1.57	0.06	10.93

* Significant at P = 0.05
** Significant at P = 0.01

Table 13(i). Growth of cacao trees during initial 3 years

Summary of ANOVA Table — (MSS)

Source	df	1970 Girth	1970 Height	1971 Girth	1971 Height	1971 Spread (NS)	1971 Spread (EW)	1972 Girth	1972 Height	1972 Spread (NS)	1972 Spread (EW)
Replications	3	1.46	867.16	1.77	208.12	57.79	123.96	18.48	214.57	1265.34	1176.17
Spacings	5	0.21	12.06	0.46	194.98	139.53	149.46*	0.86	67.53	320.01	230.06
Error	15	0.22	24.23	0.51	170.65	91.86	46.51	2.13	101.08	188.17	194.13

* Significant at P = 0.05

Table 14 (i). Growth parameters of cacao trees, 1976

Summary of ANOVA Table — (MSS)

Source	df	Girth	Height	Spread (NS)	Spread EW)
Replications	3	246.97	1309.39	3277.52	2064.97
Blocks within repl.	4	2.48	1606.79	3079.90	3180.23
Spacings (S)	5	5.22	7380.18**	748.37	2223.89
Fertiliser (F)	1	1.30	574.08	63.02	1111.69
S x F	5	1.08	1233.03	1076.27	448.19
Error	29	2.81	1730.01	1981.95	2767.79

**: Significant at P = 0.01

Table 15(1). Growth parameters of cacao trees, 1978

Summary of ANOVA Table —(MSS)

Source	df	Girth	Height	Spread (NS)	Spread (EW)
Replications	3	3.08	200	5600	5800
Blocks within repl.	4	6.02	2600	500	1600
Spacings (S)	5	7.56	5500**	700	2800
Fertilizer (F)	1	3.94	600	2200	5200
S x F	5	3.85	2400	1500	1300
Error	29	7.64	1200	700	1600

** Significant at $P = 0.01$

Table 16(i). Growth parameters of cacao trees, 1980

Summary of ANOVA Table — (MSS)

Source	df	Girth	Height	Spread (NS)	Spread (EW)
Replications	3	13.09	200	5300	5900
Blocks within repl.	4	18.27	4000	200	200
Spacings (S)	5	19.34	2500	3900	13000**
Fertilizer (F)	1	23.77	11400**	100	100
S x F	5	2.98	2000	1600	600
Error	29	10.09	1100	2000	1900

** Significant at P = 0.01

Table 21(i). Effect of density on flowering in arecanut (percentage of palms flowered)

Summary of ANOVA Table — (MSS)

Source	df	1973-74	1974-75	1975-76	1976-77	1977-78	1978-79
Replications	3	2.807	292.19	300.46	251.90	109.41	9.53
Blocks within repl.	4	0.0025	9.32	5.75	9.10	3.26	0.27
Spacing (S)	5	1.3557	19.18	6.63	31.32	12.38	0.41
Fertiliser (F)	1	0.3239	0.46	0.69	2.37	0.34	0.11
S x F	5	0.2879	28.39	20.61	24.58	5.18	3.46*
Error	29	0.5985	11.81	19.66	18.40	11.48	0.80

* Significant at P=0.05

Table 22(i). Production of spadices, female flowers and fruit set in arecanut

Summary of ANOVA Table — (MSS)

Source	df	No. of spadices	No. of ♀ flowers	No. set	% set (after arcsine transformation)
Replications	3	12.13	777931.49	183839.45	146.56
Blocks within repl.	4	0.75	22697.03	7404.51	24.78
Spacings	5	1.25	90801.68	23009.30	43.55
Fertiliser	1	0.34	28.72	8534.67	30.26
S x F	5	0.55	22708.86	7472.81	44.12
Error	29	1.11	51400.73	17079.11	57.12

Table 23(1). Effect of density on flowering in cacao (percentage of trees flowered)

Summary of ANOVA Table -- (MSS)

Source	df	1972-73	1973-74
Replications	3	608.80	145.58
Blocks within repl.	4	1.66	0.93
Spacing (S)	5	8.68	3.63
Fertilizer(F)	1	0.43	28.15
S x F	5	30.73	17.29
Error	29	25.55	10.88

Table 34(i). Effect of density on fruit set in cacao

Summary of ANOVA Table — (MSS)

Source	df	% Fruit set
Replications	3	10.08
Blocks within Repl.	4	1.31
Spacings (S)	5	1.18
Fertiliser(F)	1	0.08
S x F	5	2.88
Error	29	1.93

Table 42(i). Effect of mixed cropping on soil pH

Summary of ANOVA Table — (MSS)

SV	df	Soil pH
Replications	3	3.299
Blocks within repl.	4	1.179
Location (L)	2	3.882**
Spacing (S)	5	0.461*
Fertiliser (F)	1	0.003
Depth (D)	2	0.662*
L x S	10	0.106
L x F	2	0.191*
L x D	4	0.854**
S x F	5	0.142*
S x D	10	0.026
F x D	2	0.001
Error	381	0.049

* Significant at P=0.05
** Significant at P=0.01

Table 44(i). Organic carbon content of soil under mixed cropping (arecanut and cacao)

Summary of ANOVA Table — (MSS)

SV	df	Organic C (%)
Replications	3	1.455
Blocks within repl.	4	0.098
Location (L)	2	9.847**
Spacings (S)	5	0.141*
Fertilisers (F)	1	0.100
Depth (D)	2	20.041**
L x S	10	0.041
L x F	2	0.008
L x D	4	1.250**
S x F	5	0.092
S x D	10	0.050
F x D	2	0.009
Error	381	0.047

* Significant at P=0.05
** Significant at P=0.01

Table 45(i). Available phosphorus content of soils under mixed cropping (arecanut and cacao)

Summary of ANOVA Table — (MSs)

SV	df	Available P
Replications	3	3804.4*
Blocks within repl.	4	176.0
Locations (L)	2	27320.4**
Spacing (S)	5	383.8
Fertiliser (F)	1	16.0
Depths (D)	2	38617.9**
LxS	10	627.3
LxF	2	79.9
LxD	4	8346.9**
SxF	5	710.7*
SxD	10	198.6
FxD	2	204.4
Error	381	317.2

* Significant at P=0.05
** Significant at P=0.01

Table 47(i). Available potash content of soils under mixed cropping (arecanut and cacao)

Summary of ANOVA Table — (MSS)

SV	df	Available K
Replications	3	30813.2*
Blocks within repl.	4	25079.1*
Location (L)	2	202784.3**
Spacing (S)	5	3164.1
Fertilizer (F)	1	155.3
Depth (D)	2	53656.4**
L x S	10	2400.8
L x F	2	8010.7*
L x D	4	7176.5**
S x F	5	10003.8**
S x D	10	456.3
F x D	2	16.1
Error	381	1900.13

* Significant at P=0.05
** Significant at P=0.01

Table 50(i). Average yield of arecanut/year (1977-78 to 1981-82)

Summary of ANOV. Table (MSS)

Source of variation	df	Average No. of nuts/tree	Average wet wt. of nuts/tree	No. of nuts ('000/ha)	Wet wt. of nuts/ha
Replications	3	50652.54**	81.10**	72340.05**	99.58**
Blocks within repl.	4	1649.94	2.33	1570.66	2.23
Spacing	5	5550.75*	5.10	26465.67**	25.11**
Fertiliser	1	6124.01	8.84*	6491.37	9.33
S x F	5	1921.99	1.62	3362.24	2.40
Error	29	1979.07	2.09	3164.24	3.41

** Significant at P=0.01
* Significant at P=0.05

Table 51(i). Average yield of cacao/year (1977-78 to 1981-82)

Summary of ANOVA Table (MSS)

Source of variation	df	Av. number of pods/tree	Wet wt. of pods/tree	No. of pods ('000)/ha	Wet wt. of pods/ha
Replications	3	1898.69**	213.25**	857.77**	105.80**
Blocks within repl.	4	859.35*	68.45	350.28**	28.55*
Spacing	5	1793.61**	106.39**	873.33**	101.95**
Fertiliser	1	404.85	29.51	61.94	1.20
S x F	5	372.00	38.12	116.02	9.67
Error	29	244.24	27.56	66.59	9.42

** Significant at P=0.01
* Significant at P=0.05

Table 52(i). Combined average yield of arecanut and cacao/year (1977-78 to 1981-82)

Summary of ANOVA Table (MSS)

Source of variation	df	Wet wt. of produce/ha
Replications	3	396.04**
Blocks within repl.	4	41.24*
Spacing	5	75.76**
Fertilizer	1	17.24
S x F	5	7.03
Error	29	14.68

** Significant at P=0.01
* Significant at P=0.05

Table 54(1). Influence of environment on pod and bean characters

Summary of ANOVA Table (MSS)

Source	df	Wt./pod	No. of beans/pod	Wet wt. of 100 beans	Dry wt. of 100 beans	Pod value
Replications	3	6575.78	1.75	4185.59	305.26	25.64
Blocks within repl.	4	1150.61	33.26	2136.04	209.11	22.80
Seasons	2	80408.04**	366.90**	11939.69**	2657.22**	793.59**
Spacings	5	3906.12*	8.72	999.84	92.89	33.10*
Fertilizers	1	866.52	65.62*	913.65	114.92	84.58**
Seasons x Spacings	10	597.74	14.29	559.05	85.15	15.02
Seasons x Fertilizers	2	608.36	23.34	406.90	56.66	8.43
Spacings x Fertilizers	5	4933.59**	27.47*	1376.55*	167.55	39.33**
Seasons x Spacings x Fertilizers	10	1082.68	5.25	258.96	70.82	10.27
Error	101	1339.72	11.22	568.97	80.41	11.80

** Significant at P=0.01
* Significant at P=0.05