EFFECT OF SHADE AND MOISTURE REGIMES ON THE GROWTH OF COCOA (*Theobroma cacao* L.) SEEDLINGS

BY

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THESIS

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D E C L A R A T I O N

I hereby declare that this thesis entitled the "Effect of shade and moisture regimes on the growth of cocoa (Theobroma cacao L.) seedlings" is a bona-fide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

Vellanikkara,
20th February, 1981.

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CERTIFICATE

We, the undersigned, members of the Advisory Committee of Sri. R. Gopinathan, a candidate for the degree of Master of Science in Agriculture with major in Agronomy, agree that the thesis entitled the "Effect of shade and moisture regimes on the growth of cocoa (Theobroma cacao L.) seedlings may be submitted by Sri. R. Gopinathan in partial fulfilment of the requirement for the degree.

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Introduction

INTRODUCTION

In its centre of origin, cocoa has naturally developed under shade as a second tier under natural tree canopies. Its cultivation in the early years also had been under shade and it was generally classed as a shade-loving plant. Yet, experimental work in the major cocoa producing countries especially from the 1950's indicated a conspicuously contrasting response of this crop to shade. In the early work which mainly involved complete removal of shade there was conspicuous increase in yield of this crop because of shade removal which in some instances resulted in even near-doubling in the yield. There were still some problems in such a system of management especially those involving increased susceptibility to certain insect pests, decreased crop longivity etc. These defects could be generally counter balanced by further improvements in the crop management including insecticidal control of pests and added nutrient supply through fertilisers.

A notable feature in the shade response of cocoa that became apparent from experimental work in lateryears was the differences in the response of this crop to shade depending upon the stage of growth. Even with all the corrective measures that could amend the ill-effects of excessive illumination in established cocoa, young cocoa seedlings did perform better under a certain intensity of shade. The reasons for such a variation in shade-response of cocoa depending on the stage of growth has been indicated to be some sort of hormonal inhibition due to excessive illumination.

Other than the general indications that cocoa seedlings need shade, information on the optimum shade requirement of the crop based on experimental work involving regulated shade are scanty. Also, the effect of regulated shade on growth components of young cocoa has not been studied.

Soil moisture supply is a factor that is strongly linked with shade requirement as the inhibitory effect of excessive exposure could be counteracted by more frequent irrigations. By maintaining the plants at varying moisture levels and by studying the performance of the plants, the extent of involvement of this factor on shade response could be evaluated.

The present investigation was taken upto evaluate the response of young cocoa to varying shade levels and to assess the extent of involvement of moisture supply as a factor contributing to shade requirement. The study was

was conducted under artificial shade. The main objectives of the study were the following:

i) To study the response of cocoa seedlings to varying intensities of shade and to arrive at the optimum shade requirement.

ii) To study the effect of varying degrees of soil moisture depletion on the growth of cocoa seedlings and to evolve an irrigation schedule.

iii) To arrive at the extent of relation between shade and moisture levels in deciding the performance of the crop.

Review Of Literature

REVIEW OF LITERATURE

1. Effect of shade on general growth of plants

i) On cocoa

As early as 1896, Watt stressed the importance of shade and moisture for the better growth of cocoa seedlings and reported that young cocoa plants must be shaded and well watered. Freeman (1929), in the earliest recorded field experiment to determine the optimum degree of shade for cocoa, reported that lightly shaded cocoa gave the highest yield. Both the lightly shaded and unshaded cocoa had a lower incidence of black pod disease. According to Holland (1931), young cocoa must be shaded atleast for the first two three years. Humphries (1944) observed that shading influenced the canopy temperature of cocoa and when the mean weekly maximum temperature in the canopy dropped below 28.33°C no flushing took place. Greenwood and Posnette (1950) and Smith (1964) also reported similar results. Goodall (1950) observed that Leucaena glaucea, a leguminous shade tree, native of America is commonly used in nurseries and young plantations of cocoa and the light intensity under it was about 20 per cent of full day light. Evans (1951) described a shade experiment in which cocoa was grown under different artificial shade viz. 15%, 25%, 50%, 75% and 100%

of day light. Results during the first year showed that cocoa made the best growth at 25% to 50% sunlight but plants receiving 50% were of better shape. As plants became bigger and autoshading developed, the 75 per cent light plot improved its position. With increasing light intensity, the need for nitrogen fertilizers became more apparent. Murray (1953) in a shade and fertilizer experiment conducted in Trinidad showed that 50% shade gave the greatest early growth and highest initial yields. Evans and Murray (1954) from their studies on light and fertilizer requirements for young cocoa reported that optimum light intensity for young cocoa during the first year appears to lie between 25% and 60%. Intensities above 75% retarded the growth. There was some indication that the optimum light intensity increased with size of the plant and consequent self shading. They also added that greatest relative growth rate (RGR) had been observed at a light intensity between 30 - 60% of full day light. Under heavy shade (75 - 85%) irrespective of fertilizer application, yields were low. Goodall (1955) demonstrated that optimum growth of cocoa seedlings was attained in shade rather than in full day light. It was subsequently confirmed by further studies of Hurd et al. (1961) and Asomaning and Kwakwa (1965).

The most favourable light intensity for cocoa seedlings had been stated to be about 25% of full sunlight by Hardy (1958). He also reported that the amount of light may be gradually increased to full sunlight when complete leaf shading had been attained, the overhead shade being systematically removed. The growth in size of plant was generally least when light intensity was greatest. This was explained as due to the fact that, the activity of the 'auxins' was diminished or inhibited by direct sunlight. This was stated to be the reason for the larger size of the leaves of cocoa trees grown under shade. Similarly, the branches of shaded cocoa trees were thinner and longer and they jorqutted at a higher distance from the ground level than did branches of the shaded cocoa. The cocoa trees were found to grow mostly during the night just as other plants, because the cells of the cambial tissues enlarge greately in the absence of light, but cease growing when exposed to light of high intensity. Cunningham and Lamb (1959) reported spectacular increase in yield for cocoa by the removal of shade trees and it has been suggested that the highest yields can be achieved under unshaded conditions provided soil moisture and nutrients are adequate. Contradicting the views of Goodall, (1955) Frederick Hardy, (1958) Cunningham and Burridge (1960) stressed that high rates of growth may be attained by cocoa seedlings in full daylight provided fertilizer is applied to the soil and precautions are taken to maintain a favourable water balance and to minimise damage by wind and insect pests. They also observed that in particular circumstances shade may be benefitial in limiting insect pest damage, supressing weed growth and restricting the yield of cocoa and thereby permitting the use of soils of low nutrient status. Charles (1961) observed that removal of shade trees from mature plantations increased yields initially but eventually reduced them. Maliphant (1960-61) and Cunningham and Smith (1961-62) observed that in unshaded cocoa, yield can be substantially increased by adequate fertilizer application. Removal of shade resulted in a highly significant increase in the number of leaves on the tree, there being 62% more in November and 94% more in March. Unshaded cocoa had developed a lower habit of growth. This was stated to be presumably because much more light was received by these branches than the unshaded treatments. In approximately two years, the trunk diameter of the unshaded trees increased significantly compared with those under shade. Cunningham and Arnold (1962) got similar results. Longworth in 1963 noted that the initial growth and establishment of cocoa were better with artificial shading than with natural methods of shading. Studies in North-Africa on the economics of shaded very low producing cocoa and on shaded high yielding cocoa indicated that shade was necessary for the low yielding trees and some shade also for medium production (Longworth, 1963). Freeman (1964) observed that it was possible to bring cocoa into bearing without any permanent shade. But he concluded that establishment without shade required the "best establishment methods" and could not be recommended as a "sound commercial practice". Murray (1964) grew cocoa clone cuttings of ICS 95 for four months in constant environment room under similar light and humidity conditions at 20°C and 30°C. At lower temperature, apical flushes of 3 - 4 leaves were produced giving plants similar in appearance to plants grown in the field under fairly heavy shade. At the higher temperature, apical dominance was lost and large number of axillary flushes of small leaves were produced giving plants similar in appearance to plants grown in the field without shade. Murray & Nicholas (1966) reported that the ability of cocoa to perform well in the absence of shade under high nutrient conditions(Charles, 1961; Maliphant 1960-61; Cunningham & Smith 1961-62 and Cunningham & Arnold, 1962) may be related to the increased mutual shading which resulted from enhanced leaf production in response to nutrient application. Mc Culloch (1967) summarised from an experiment laid out in 1960, that in avenue planted cocoa farm light intensity had a marked effect on the growth of cocoa. Blencowe (1967) reported that lateral shading is a must for cocoa either through planting plantain or by artificial means, till the development of a proper canopy. Leach (1969) stressed that the nurseries are to be shaded compulsorily, the initial intensity of shade being about 80%. After first whorl of leaves is hardened, shade is to be progressively reduced until by the sixth week, the light intensity was similar to that of main field. According to Boyer (1970) provision for some shade is advisable for cocoa where canopy development was insufficiently dense. In a 30 year old Trinitario cocoa plantation, the flushing intensity, leaf number and total foliar surface per tree were greater in unshaded trees than those under light or moderate shade. Cambial activity measured as girth increment was also greater in unshaded trees. Boyer (1974) also reported similar results. Boyer in 1974 observed that in cocoa, the number of flower per tree was 60 - 70% more in moderately shaded trees than unshaded trees. But Buttrose (1974) reported reduced number of flower buds initiated in shaded cocoa. Yaw Ahankorah et al. (1974) in an Amelonado cocoa shade and manurial trial observed that trees without shade yielded three times as much as shaded trees on seventeen years of continuous cropping. But it was referred that the economic life of an unshaded cocoa farm may not last for more than ten years of intensive cropping. It was also stated that deterioration of cocoa was rapid under no shade condition partly because of the high loss of exchangeable bases and greater stress caused by the higher yield. Thus, under stress the trees tended to become more suceptible to insect pests and probably to diseases. The intensity of incident diffuse light and the humidity probably had a greater influence than the age of the tree on the development of mosses on the cocoa trunk and branches, and hence the rapid deterioration. Wood (1975) reported that cocoa nursery will require shade, water and protection from wind. He also reported that the initial shade was usually quite heavy, somewhat in excess of 50 per cent, but can be decreased as the seedlings grow. For young cocoa, shade is always recommended to ensure the right form of growth. The amount of light falling on young tree will influence the way it grows, low light intensity or heavy shade leading to long internodes and few side branches, high light intensities or little shade giving the opposite effect which leads to bushy growth. Too much light was therefore considered undesirable as it will delay the time when, at normal spacings a canopy will be formed. Okali & Owusu (1975) observed that application of nutrient solution twice a week caused leaf malformation in cocoa especially in plants at full day light. Maximum temperature and evapotranspiration rate were higher in exposed than shaded plots though evapotranspiration rate was similar for all plots. Both nutrient and shade treatments produced significant differences in relative growth rate (RGR) of cocoa. In the three shade regimes tried viz. zero, 63 per cent and 90 per cent shade, the highest RGR tended to occur in medium shade. Bonaparte and Ampofo in 1975 reported that the extent of solar radiation that penetrated the cocoa canopy varied among the no shade, medium shade and heavy shade regimes tried and between seasons. The magnitude of solar radiation incident on the cocoa tree was, as expected, highest in no shade regime and least in the heavy shade regime. Mainstone (1976) noted that where little or no shade has been established, the cocoa should have little leaf in relation to root at the time of planting. It was also reported that a shading plan with gliricidia stumps gave good results in the initial establishment of cocoa.

ii) <u>On other crops</u>

In 1903 Dugger elucidated the general effects of shading on plants. Plants under shaded conditions exhibited increased growth of main axis, reduced number of branches, lessened development of woody fibre and deficiency in sugar and carbohydrates. Again in another experiment by Duggar (1903), it was found that, shading either partial or complete was found to reduce the carbon-dioxide assimilation and thereby the available constructive materials for plants. Clark (1905) observed that for leaf development, low intensity of light was most favourable and intense light caused decreased leaf growth resulting in smaller and thicker leaves. In an experiment with peaches Gourley (1920) found that under shade the plants produced less number of branches which were willowy and slender. Kraybill (1922) observed decreased fruit bud formation in apple and peaches under shade. Vinson (1923) brought out the effect of shading on a number of horticultural plants such as apple, peaches, cherry, strawberry, tomato, radish, potato and geranium. Slender stems, greater length of internodes, leaves with larger and smaller cross section, increased moisture contents were all reported by him as general effects of shading on plant growth. Weaver & Clements (1929) reported that partial shading was useful to increase the succulance and delicacy of plant structures. Shade was reported to impart an extraordinary vigour to coffee bushes, increase in berry size and improvement in flavour (Anon. 1932). In clove seedlings, with a decrease in light intensity, there was an increased vegetative growth as measured in leaf area and both fresh and dry weight and a decrease in total amount of photosynthetics produced. Porter (1937) also reported similar results. In 1951, Elgueta & Bonilla showed that shading greately improved the success of transplanted coffee seedlings. Beinhart (1963) studied the effect of temperature and light intensity on the growth of clover and concluded that increased light intensity resulted in greater growth, increased branching and in turn greater leaf area production. It was also stated that light intensity had no influence on the mean number of leaves produced per plant. Edmond _et al._ (1964) conducted shading experiments in tomatoes, providing shade by nylon and muslin clothes. Maximum yield was obtained from plants receiving only 45 per cent of full sunlight and they explained the reason for low yield under increased light in three ways viz. (1) concerning with the chlorophyll content (2) concerning with the water supply or (3) concerning with the enzime activity. Edmond _et al._(1964) noticed the production of thinner leaves by shaded apple trees and the thickness of leaves in the open condition as due to the increased production of palisade tissues in the leaves. Streitberg & Hoffman

(1973) studied the effect of reduced light intensity on apple trees by covering them with nets and observed longer internodes and increased total shoot length under reduced intensities of light. Boardman (1977) described the general effect of shading on plants. According to him leaves of shaded plants were thinner showing poor development of palisade tissues and spongy mesophyll cell. Barden (1977) reported that apple trees exhibited supressed shoot growth and increased dry weight under 80% shade provided by screen chlote or slats. But shading was not found to influence the leaf area in this experiment. Radha (1979) revealed that number of leaves produced per plant in pineapple was not influenced by shading.

2. Effect of shade on leaf development

i) On Cocoa

Goodall (1950) observed in cocoa that the ratio of mean leaf area to mean plant dry weight reached a maximum at about twelve weeks and thereafter it declined. Hardy (1958) studied the nature of leaves of cocoa seedlings under varying intensities of light. He observed that the feature of cocoa leaves that had developed under different light intensities varies greately. Under full sunlight, leaves were small, pale and thick with short internodes and long stipules. They were shed very early. By contrast, leaves produced under heavy shade were much larger and often attained a length of 20 - 24 inches. Their colour was darker, they were thinner and heavier and contained higher proportionate amount of water as reckoned by dry weight. Less number of stomata per unit area as the epidermal cells were longer in leaves produced under shade was the reason attributed to the higher water content. Based on a study on the physiology of cocoa leaves, Hardy (1958) concluded against the possibility of cocoa being a shade loving plant. By applying the oil infiltration method for assessing the degree of stomatal closure, it had been shown that, the stomata of cocoa leaves exposed to full intense and direct illumination (13,500 foot candles) remained completely open and transpired freely as long as long as water supply was plentyful. By contrast the stomata of coffee leaves was reported to partially close whenever the intensity of illumination exceeded 8000 - 8500 ft. candles and in the shade they always remained open provided the light intensity was not so less - a characteristic phenomenon of shade loving plants. In the case of cocoa, the leaf stomata began to close when the light intensity was reduced to less than 500 - 700 ft. candles, which was about 5% of the full sunlight. He also observed that under ordinary circumstances, the cocoa stomata began to open at about 6 a.m. and maintained their maximum size between 8 a.m. and 4 or 5 p.m. after which time they began to close because of diminishing light intensity. This indicated, according to Hardy that if cocoa were a 'shade tree' the stomata would begin to close immediately after maximum illumination had been attained.

ii) <u>On other plants</u>

Johnson (1826) as quoted by Gardner <u>et al</u>. (1952) showed that light was the most important environmental factor influencing the daily opening and closure of stomata in plants. Rolfes (1903) reported that citrus plants which were grown under 50% shade developed thinner leaves with a greater leaf area but with considerably reduced total leaf area per plant. In many horticultural plants Clark (1905) observed that for leaf development low light intensity was most favourable and intense light caused decreased leaf growth resulting smaller and thicker leaves. Gourley (1920) reported that in apples shading resulting in the production of loosened mesophyll tissues and thinner epidermal cells in leaves and in increased leaf area. Gourley & Nightingale in 1921 observed an average leaf area increase of 224% when grown under 15% light intensity than those developed in full sunlight. Porter (1937) studied the effect of three light intensities viz. 1139.9, 583.1 and 261 foot candles on the photosynthetic efficiency of tomato plant. He observed that with a decrease in light intensity there was an increased vegetative growth as measured in leaf area and both fresh and dry weight. Holmgren (1968) reported that higher intensities of light during the growth of plants generally increased the stomatal frequency but there was no significant changes either in the length of stomatal pore or in the size of guard cells.

3. Effect of shade on chlorophyll content

i) On cocoa

Increased chlorophyll content in the leaves of shaded cocoa was first reported by Evans & Murray (1953). Guers (1971) studied the effect of light on the morphology and physiology of cocoa leaves. Preliminary observations revealed that, leaves exposed to direct sunlight were generally smaller and thicker and contained less moisture, chlorophyll and nitrogen than shaded leaves. Okali & Owusu (1975) in cocoa showed that the chlorophyll content per unit area of the leaf did not differ between shade regimes at different levels of nitrogen. But at the higher nitrogen level, chlorophyll content was significantly greater with shading. They also observed that chlorophyll content per unit leaf fresh weight was significantly greater in deep shade in all nutrient levels.

ii) <u>On other plants</u>

Clark (1905) observed that for chlorophyll production in plants certain optimum intensity of light was necessary. He found that direct sunlight of high intensity was resulting in destruction of chlorophyll and this effect was clearly noticed in strawberry. Priestly (1929) while discussing the biology of living chloroplast, stated that the chloroplasts in leaves would undergo changes in position according to the difference in light intensity. He pointed out that in leaves of plants grown under lower light intensities the plastids were limited in number and they were arranged at right angles to the light rays and were larger in size, thus increasing the area for light absorption. Gardener *et al.* (1952) reported that in general, the concentration of chlorophyll per unit area or weight of leaf increased with decreasing light intensities until the intensity was so low that it hazarded the survival of plants. Ramaswami (1960) and Venkatamani

(1961) got increased chlorophyll contents in tea under shade as reported by Evans and Murray (1953) for cocoa. Bjorkman and Holmgren (1963) also got more chlorophyll content per unit weight or per unit volume of leaf in the leaves of plants grown at lower light intensities, but the chlorophyll content per unit area of leaf surface was very often lower than the open grown leaves. Khossien (1970) noticed reduction in the leaf pigment and depression in the growth at high intensity of light in the case of bean plants. Bjorkman et al. in 1972 found fewer number of chloroplasts which were larger in size with more chlorophyll in leaf section of shaded plants. Skene (1974) found that shading resulted in thicker grana in chloroplast of apple leaves. Chlorophyll 'a' and 'b' and total chlorophyll contents of leaves were found to increase as the intensity of shade increased in pineapple (Radha, 1979).

4. Effect of shade on photosynthesis/dry matter accumulation

i) On cocoa

Hardy (1958) studied the rate of photosyntnesis in cocoa seedlings subjected to varying lengths of time to light of different intensities. The result obtained was expressed as net assimilation rate (NAR) in g dm^{-1} cm^{-2} of leaf surface produced per hour. The NAR was 0.042, 0.099

and 0.188 g dm^{-1} cm^{-2} hr^{-1} for 10,20 and 75% of full sunlight. He stated that the lower NAR of cocoa leaves grown at lower intensities of light indicated that photosynthesis was greately retarded by shading. On the other hand this reduction in NAR was compensated by greater leaf area produced under shade. Baker and Hardwick (1973) noted that at high light levels photosynthetic rate per unit chlorophyll was highest for leaves in the open which suggested that photosynthetic efficiency was increased by growth in full day light. Okali and Owusu (1975) observed that, even for open leaves of cocoa photosynthetic rate was depressed at highest exposure of light intensity of 50 K.lx. Similar results were observed in seperate experiments by Okali and Hardwick (unpublished work). Okali and Owusu (1975) also reported that at lower light intensities (0.1 and 6 K.lx.) net photosynthetic rate was least for plants grown in full day light, it being negative for two varieties of cocoa tried at 0.1 K.lx. The light compensation point for photosynthesis was also found to be higher for plants in open condition. In open condition net photosynthetic rate was maximal at 39 K.lx. whereas in the deep shade the rate gradually declined.

ii) <u>On other plants</u>

Duggar (1903) found that shading either partial or complete reduces the carbondioxide assimilation and thereby the available constructive materials for plants. Clark (1905) noticed that sugar content in plants was dependent on the intensity of illumination and he observed that in beets and sorghum development of sugar was in proportion to the intensity of illumination. Vinson (1923) observed that shading in horticultural plants increased moisture content and proportion of nitrogen to carbohydrates. Shirly (1932) as quoted by Gardner et al. (1952) reported that generally with increasing light intensities, there would be an increase in the per cent dry matter in trees. Porter (1937) in tomato observed, increased vegetative growth, decreased fruit production and decreased total amount of photosynthates with the decrease in light intensity. He also reported that these changes were not directly proportional to the decrease in light intensity. For instance, a reduction in light intensity by half resulted only in an one-fourth increase of vegetative growth. Radha (1979) noticed comparable dry matter acumulation in the leaves of pineapple both in shade and in open upto flowering stage. She also reported that the reduction in dry matter accumulation was not considerable in spite of shading upto 75%.

5. Effect of shade on growth measures of cocoa

Goodall (1950) found maximum net assimilation rate (NAR) for cocoa seedlings in the first seven weeks of growth, and noticed that the ratio of new leaf area to new plant dry weight reached a maximum at about 12 weeks and thereafter declined. He also reported that the greatest mean inter-harvest value of this ratio occured during the period (12 - 18 weeks) when the greatest relative growth rate (RGR) was recorded. Hardy (1958) observed lowest NAR at highest shade level and vice-versa on cocoa. He also stated that the lower NAR of cocoa leaves grown at lower light intensities indicated retarded rate of photosynthesis under shade. Okali and Owusu (1975) studied the growth measures of Amelonado and Amelonado x Scavina cocoa seed-lings under different levels of shades and nutrients. They found that relative growth rate was maximal for plants grown under medium shade and at highest nutrient levels. Net assimilation rates were little affected by shade even-though incident radiation varied over the range of 10-1 NAR was highest for leaves developed on full day light as a result of enhanced photosynthetic efficiency. It was also highest in plants maintained at highest nutrient levels. This nutritional differences disappeared when photosynthetic rate was based on chlorophyll content. It was also found that at each nutrient level, mean leaf area ratio (MLAR) was highest for plants in deep shade and lowest for plants in open. The response of RGR to shade and nutrient levels was influenced more by the res-ponse of NAR than by that of MLAR while the difference in two varieties in RGR was due mainly to the difference in MLAR.

6. Effect of shade on nutrient contents

i) On cocoa

Acquaye et al. (1965) observed by visual symptoms and soil plant analysis that young Amazon cocoa established on clean felled land was potassium deficient. The symptom became more severe with time. Leach (1969) reported deficiency of nitrogen in shaded cocoa seedlings which was corrected by weekly application of half oz. of urea in one gallen of water per 200 seedlings. Guers (1971) reported that cocoa leaves exposed to direct sunlight were smaller, thicker and contained less moisture and nitrogen than shaded leaves.

ii). On other plants

Kraybill (1922) observed higher contents of moisture and nitrogen in shaded apple leaves. Vinson (1923) reported that shading increased moisture content and the ratio of nitrogen to carbohydrates in a number of horticultural plants. American Holly plants exhibited higher amounts of potassium and magnesium in leaf tissues when the plants were grown at 92% shade (Fretz & Dunham, 1971) Cantliefe (1972) observed in spinach that the concentration of potassium in the tissue increased as reduction in the light intensity occurred. Anan and Nakgawa (1974) studied the effect of chemical constituents of shaded and unshaded tea. They observed that total nitrogen, amino acids and caffeine of newly shaded shoots increased at first and later decreased whereas the shoots from unshaded plants showed a decrease during the whole period. The aspartic acid content of shoots of shaded plants remained unchanged but that in shoots from unshaded plants rose gradually.

7. Effect of moisture on general growth of cocoa

Lemee (1955) found that photosynthesis in potted cocoa seedlings was depressed when available soil moisture fell below 60 - 70 per cent and was negligible near permanent wilting point. Greenwood and Posnette (1950) from their studies on cocoa reported that flushing was controlled by an endogenous system inherent in the plant, but atleast after the tree had passed the juvenile stage its onset was affected by environment. They also observed that, growth of cocoa trees occured in the dry month, while during wet season, when condition of rainfall and humidity were more stable little growth occured. Irrigation had not affected the frequency of flushing of individual tree. All the trees, irrespective of treatment differences, flushed at more or less regular intervals of 8 and 10 weeks. Alvim (1959) reported that, where rainfall was adequate and the dry season was not very severe or prolonged, irrigation seemed to have only a small effect on mature cocoa. Alvim (1960) showed that the stomata of container grown cocoa plant started to close when the available moisture fell to 70 per cent and closed rapidly as available moisture fell from 50 - 25 per cent. Burridge et al. (1964) observed that irrigation slightly decreased leaf nitrogen, phosphorus, calcium and magnesium in cocoa. Lockard and Burridge (1965) also got similar results on cocoa. Smith (1964) conducted a study on the effect of three soil moisture regimes on young Amazon cocoa. He found that irrigation increased growth rate and flower production, but did not affect the percentage of setting or wilting of cherreles. The interval between the growth flushes of individual trees remainded the same but irrigated trees ceased to flush in phase with each other. Irrigation, however had not affected the flushing of individual trees. All the trees flushed at more or less regular intervals of 6½ to 8½ weeks, which was rather less than the range of between 8 and 10 weeks as quoted by Greenwood and Posnette (1950) for rainfed cocoa. Smith (1964) concluded that, rainfall affected the flushing habit of cocoa Trees receiving only natural rainfall flushed more or less in phase with each other suggesting that the onset of flushing was influenced in part by water relationship in their environment. In Ghana in 1964 he found that irrigation applied to field grown seedlings from the age of six months to bearing improved establishment, early growth and bearing. The irrigated trees flowered earlier and produced greater numbers of flowers than did the un-irrigated trees, probably because of the increased size of irrigated trees and large number of cushion available for flower production. Murray (1966) had shown based on studies with cocoa cuttings grown in containers that, growth was best under constantly high soil moisture conditions. Similarly preliminary analysis of the girth measurements of cocoa seedlings revealed a significant effect with the increase in available moisture (Ahénkorah & Akrofi, 1968). Sale(1970) studied the growth, flowering and fruiting of young glass house grown clonal cocoa trees in weighable soil containers with different moisture regimes viz. 85% of available moisture (wet treatment) 50% available moisture (medium treatment) and 15% of available moisture (dry treatment). It was found that plants under dry treatment lost their apical dominance and flushed vigorously about 10 days after each watering although many flushes subsequently withered. Plants under retaning capacity. Studies on fine stages of the stem diameter of seedlings using dendrograph also suggested that stem girth was slower during the day following watering than during a day when the soil had begun to dry out. Alvim *et al.* (1972) observed that soil moisture stress may also stimulate flushing through its effects on leaf fall. Hutcheon, Smith and Asomaning (1973) showed that irrigation increased flower production on both the unshaded as well as shaded cocoa but this effect was greater on unshaded trees. Smith, 1964, Alvim *et al.* 1972 and Sale, 1970 also reported similar results. Water consumption of young cocoa during the dry season was studied by Jadin and Chauchard (1976) on nonirrigated, sprinkler irrigated and drip irrigated plots. Nonirrigated cocoa consumed 0.5 to 1.7 mm daily the level being limited by soil moisture deficit. Corresponding figures for sprinkler and drip irrigated plots were 1.72 and 5.88 mm respectively and these depended on potential evapotranspiration. Among various environmental factors studied in connection with flushing, moisture stress appeared to be the most critical factor (Alvim *et al.* 1977).

Materials and Methods

MATERIALS AND METHODS

The investigations were carried out in the College of Horticulture, Vellanikkara, Trichur during the year 1978-'80, to study the effect of shade and moisture regimes on the growth of cocoa seedlings.

1. Materials

1.1. Site and soil

The College of Horticulture, Vellanikkara is situated at 10° 32' N latitude and 76° 10' longitude at an altitude of 22.25 meters.

Sieved (through 5 mm metallic sieve) fertile top soil, was used for raising the seedlings. The sieved soil was of the following mechanical composition (expressed as percentages on moisture free basis).

Coarse sand	41.00
Fine sand	21.00
Silt	12.5
Clay	24.00

1.2. Seeds and seedlings

Seedlings were raised from uniform sized beans of well matured cocoa pods in 20 x 30 cms sized polythene bags.

Polythene bags were filled with 4 kg of the already prepared soil. Beans were sown in flat position for raising the seedlings and regularly watered. Each bag was provided with three or four pinholes at the bottom to facilitate drainage.

1.3. Fertilizers

As the bags were filled only with soil as growth medium and as the general growth appeared poor, the seedlings were given fertilisers at the rate of 0.5 : 1 : 1 g. each of N, P_2O_5 and K_2O. Nitrogen was supplied through ammonium sulphate, phosphorus through superphosphate and potassium through muriate of potash, all in solution form.

2. Methods

2.1. Layout of experiment

The trial was laid out in a completely randomised factorial design with four levels of shade and three levels of moisture with four replications. Each treatment combination consisted 27 plants. The duration of the experiment was five months.

2.2. Treatments

Treatments were the following:

Levels of shade

Shade level 1 (S_1) open (zero % shade)

Shade level 2 (S_2) 25 - 30% shade

Shade level 3 (S_3) 50 - 55% shade

Shade level 4 (S_4) 70 - 75% shade.

Levels of moisture

Moisture regime 1 (M_1) Irrigation at 75% available moisture.

Moisture regime 2 (M_2) Irrigation at 50% available moisture.

Moisture regime 3 (M_3) Irrigation at 25% available moisture.

2.3. Provision of shade

Loose gunny mat was used to give 70 - 75% shade and a type of handloom cloth was used for 50 - 55% shade. 'Calicloth' mosquito net was used to give a shade of about 25 - 30%. Selected shade materials were then stretched and tied tightly over the 'pandals' of size 10 M x 3 M by fixing wooden reapers on posts. The 'pandals' were erected in south west direction and a distance of 4 M was provided in between the treatments to avoid mutual shading between the shade treatments. Each 'pandal' was also covered with the respective shading material on all bags, averaged the weight of about 4.070 kg, 4.010 kg and 3.950 kg all the plants in that treatment in a particular shade level were irrigated to F.C. by giving the required amount of water (60 ml, 125 ml and 185 ml for 75, 50 and 25% available water).

There were three plants in each plot set apart as observational plants which were labelled and weighed daily along with the bag to find out loss in weight. These were irrigated with calculated quantities of water when the weights dropped down to the stipulated levels. The quantities of water to bring the soil back to field capacity were added in each case. The number of days required to reach the desired moisture regime was also recorded treatment wise to arrive at the frequency of irrigation for seedling cocoa under each shade and each level of moisture. To account for the increase in weight of the plants due to the growth, adjustments in weights were made based on the monthly average wet weight of harvested sample plants.

In the intense shade, the mean interval between irrigations varied from 1.43 and 1.83 days for M_1. For M_2 and M_3 it was 2.23 to 2.64 and 4.43 to 3.63 respectively. M_1 in the intermediate shade level recorded the least interval of 1.33 days towards the final stage of growth though for the initial month it was 2.17. In the case of M_2, it varied between 2.21 to 3.22 days and for M_3 it was 3.75 to 4.57 days. In the lowest shaded plants M_1 recorded a maximum interval of 2.21 and a minimum of 1.53 days. For M_2 and M_3 the corresponding values were 3.38 to 2.73 and 4.83 to 3.3 respectively. Open grown plants met with the least frequent irrigation in all the moisture regimes, the monthly average maximum interval being 2.36, 3.86 and 5.6 days respectively for M_1, M_2 and M_3 with the corresponding minimum values being 1.94, 3.20 and 4.43 days.

2.5. Plant protection

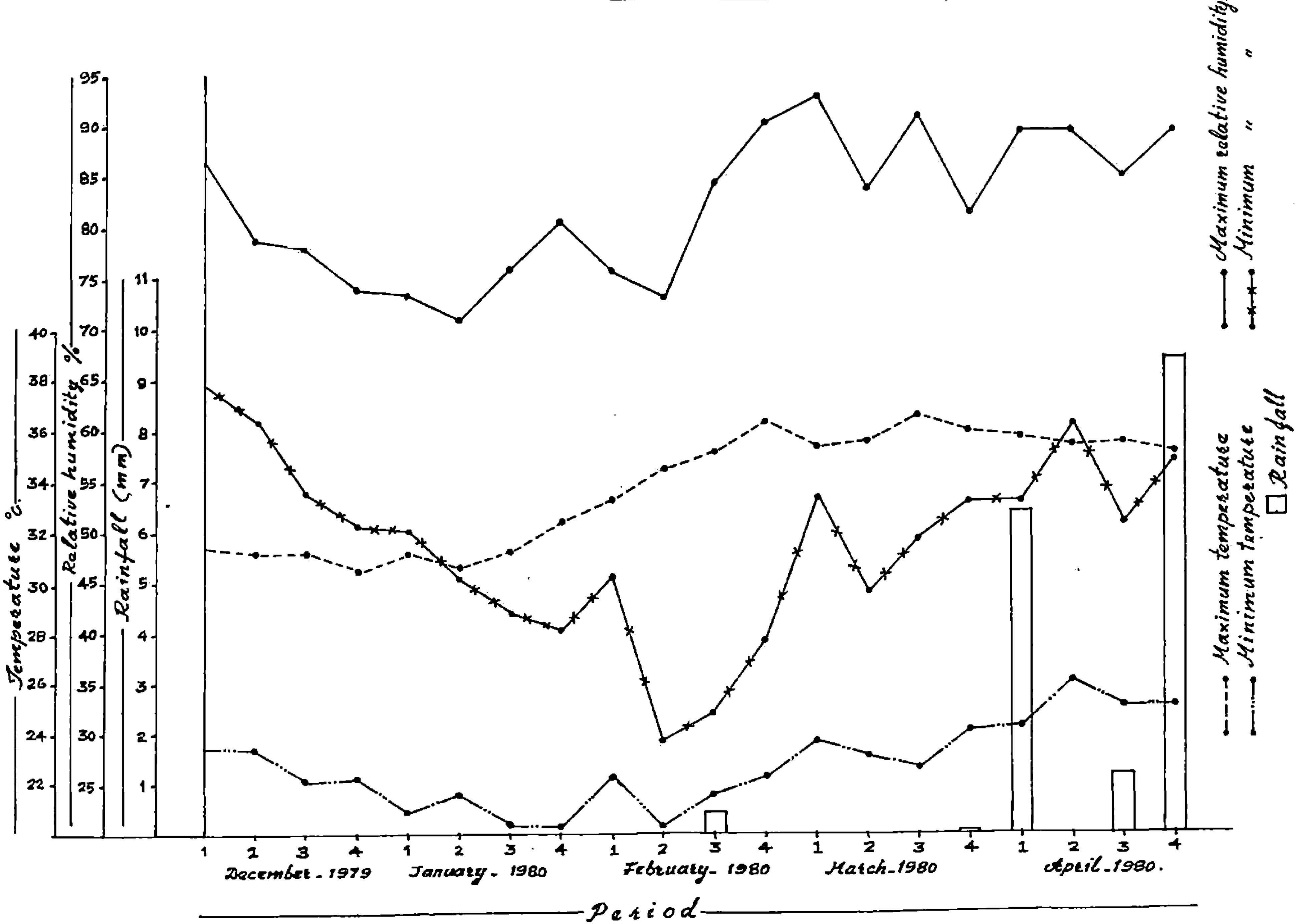
Due to the heavy wind noted during December - February, the plants especially in the open showed symptoms of wind injury (Breakage of leaves at laminar end). A wind break using plaited coconut leaves and wooden poles to the entire length of the experiment plot in North-South direction was provided to prevent this.

3. Observations

3.1. Meteorological observations

The weather data for the experimental period are presented in Appendix I and Fig. 1.

Fig. 1. Weekly averages of weather data for the period from December 1979 to April 1980.



In addition to the usual meteorological data, the following additional observations were also taken.

3.1.1. Solar intensity

Solar intensity was measured and recorded at weekly interval. Measurements were taken with an 'Apalab' lux meter from 6 a.m. to 6 p.m. at hourly intervals. The data are presented in Fig. 2.

3.1.2. Canopy temperature

Canopy temperature at hourly interval once in a week was taken two inches below the tip of the plants and the data are presented in Fig. 3.

3.1.3. Soil temperature

Soil temperatures at two depths of 5 cms and 10 cms were taken once every week at hourly intervals from 6 a.m. to 6 p.m. Soil thermometers were fixed at the above depths and the observations taken from the treatment of 25% moisture depletion from the four shade levels of the first replication only. The data are presented in Fig. 4 and 5.

Over the period of experimentation, the maximum temperature varied between 30.52°C in December and 36.74°C in March. The highest minimum temperature of 26.3°C was

Fig_2. Monthly average of solar radiation (at hourly interval)

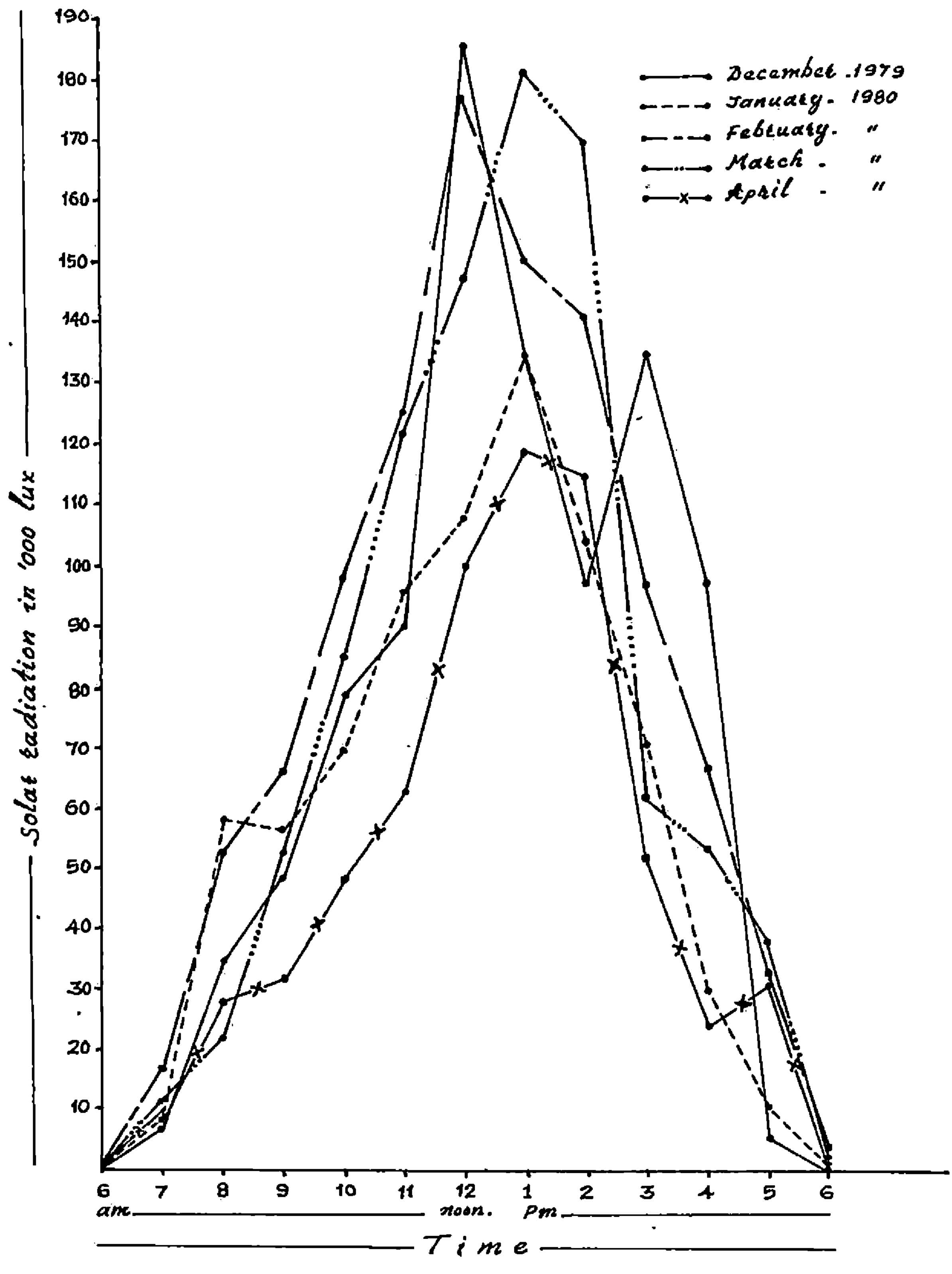


Fig-3. Monthly average canopy temperature.

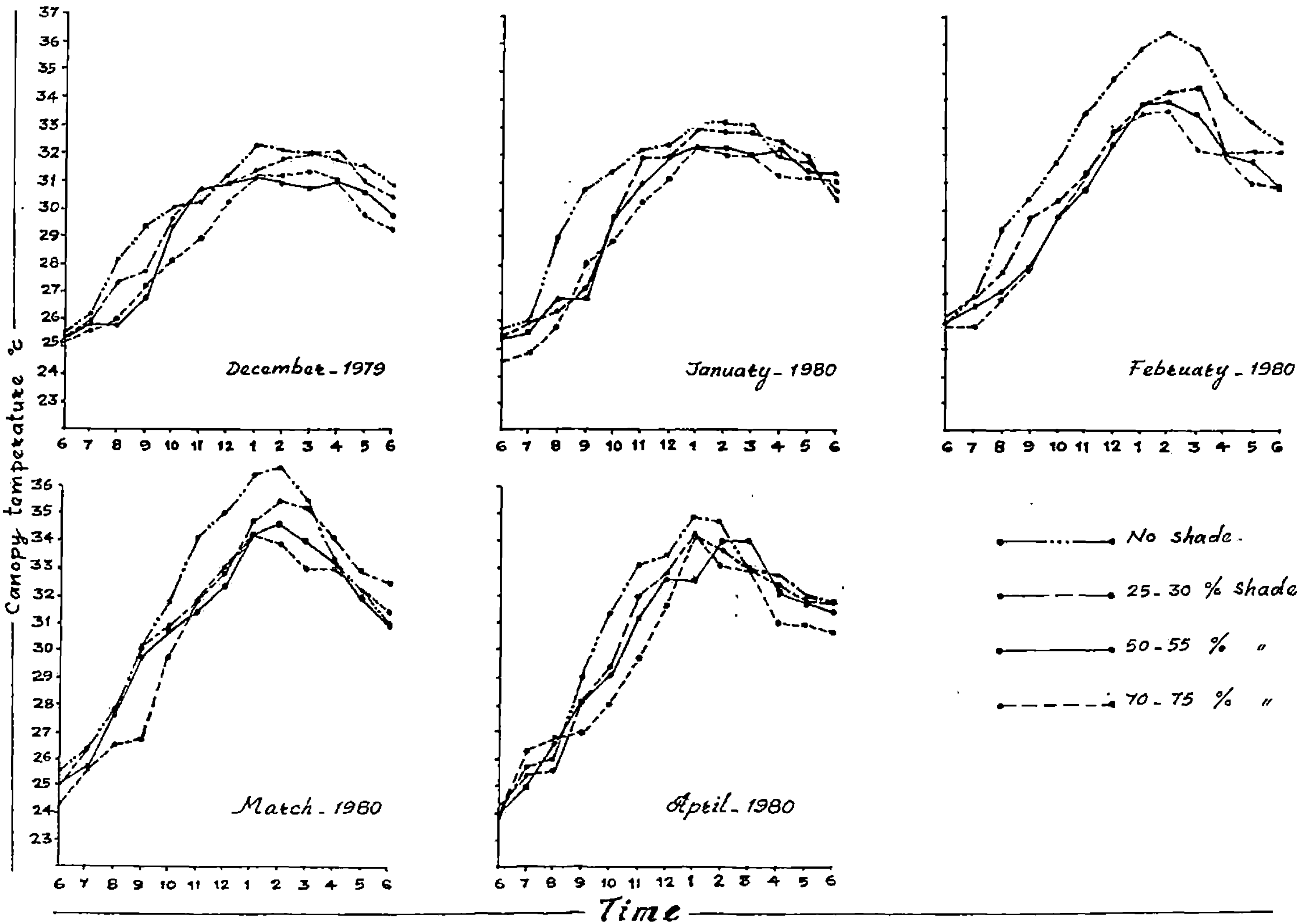


Fig. 4. Monthly average soil temperature at 5 cms. depth.

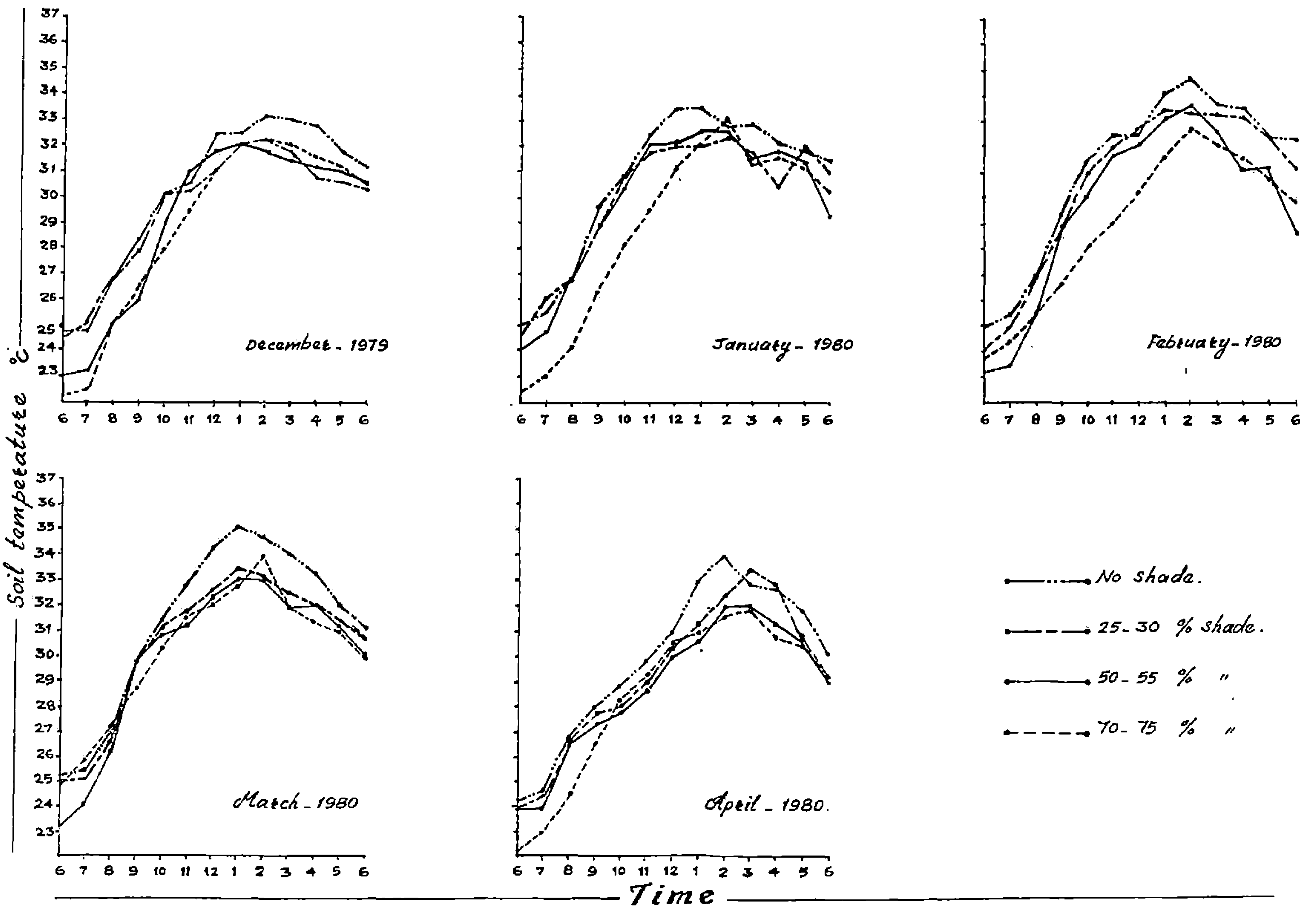
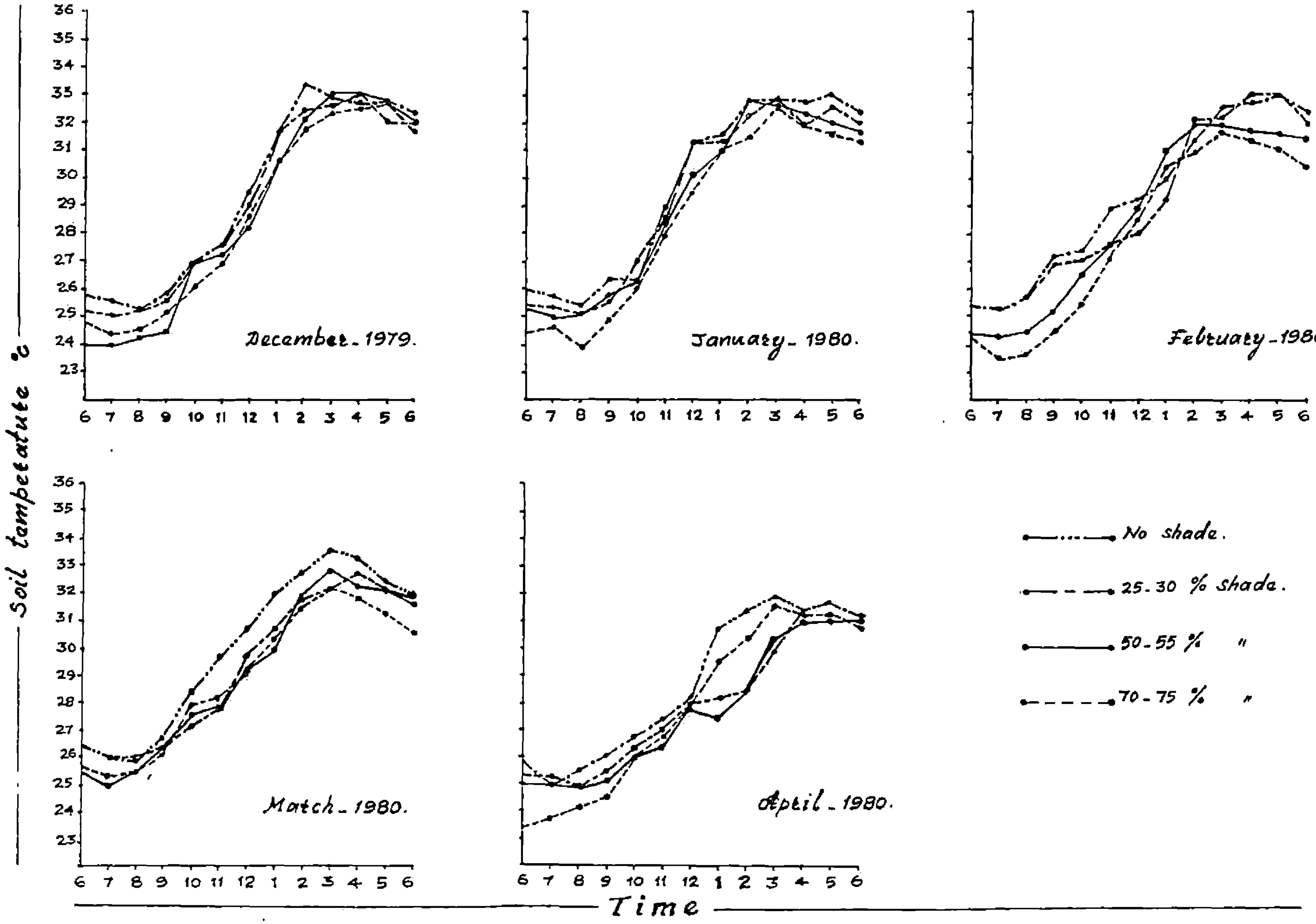


Fig. 5. Monthly average soil temperature at 10 cms depth.



noticed in April while the lowest value, ie. 20.29°C was recorded in January. Relative humidity fell between 71.12% and 93.13% during the period of investigation. Except April all others were practically rain free months. In April a monthly average of 4.2 mm rain was recorded over a period of eight rainy days. The maximum sunshine of 1,85,000 'lux' was recorded in December 1979, closely followed by March 1980. The average sunshine varied between 52,290 lux in April 1980 and 86,091 lux in February 1980. Maximum soil temperature and canopy temperature were always found in the no shade regime. As a general trend with the increase in intensity of shade both soil and canopy temperature also showed a gradual decrease.

3.2. Biometric observations

The following biometric observations were recorded at monthly intervals.

3.2.1. Plant height

Height of all the three observational plants was taken and average worked out. This observation was taken from the soil surface of the bag to the terminal bud.

3.2.2. Stem thickness

Stem thickness was taken by a vernier-calipers at a height of 5 cm above the soil surface. Here also average of three observation plants was worked out to represent the average stem thickness of each plot.

3.2.3. Number of leaves

The total number of leaves of the sample plants harvested for recording other observations was counted and the average per plant was worked out.

3.2.4. Leaf area

A constant (0.6428) was first worked out from the relationship of length x breadth value and actual leaf area of 100 leaves selected randomly from 20 six months - old cocoa seedlings. For recording observation on leaf area, the samples were harvested and their leaves removed. Five leaves from each plot were selected at random and their length and breadth measured. The area of these five leaves were calculated from the factor worked out (between leaf area and length x breadth). These five leaves were dried in an oven seperately. Similarly the remaining leaves of these plots were dried. From the leaf area and dry weight of the five leaf samples of each plot, the area-dry weight relationship was worked out for each plot. The total leaf area of sample plants was calculated from the total leaf dry weight and the above relationship.

3.2.5. Total dry weight

Harvested plants were dried at 80 - 85°C for 2 - 3 days in hot air-oven and dry weight was recorded till two consecutive weights agreed. From the total dry weight of three plants, average dry weight was worked out and recorded in grams per plant.

3.2.6. Leaf area ratio (LAR)

It was calculated by using the leaf area and respective plant dry weight of harvested plant samples.

3.2.7. Net assimilation rate (NAR)

It was calculated using the following equation

$$NAR = \frac{W_2 - W_1 \ (\ln A_2 - \ln A_1)}{(A_2 - A_1)\ 30} \quad \text{Where}$$

W_2 - final plant dry weight in mg, W_1 - initial plant dry weight in mg, A_2 - final leaf area in dm^2, A_1 - initial leaf area in dm^2. NAR was calculated in $mg/dm^2/day$.

4. Chemical analysis

For chemical analysis, the entire plant without root was dried, powdered and sieved. From this required quantity was taken for analysis. Analysis for total nitrogen, phosphorus and potassium was made following the methods of Jackson (1958). Their contents were worked out as percentage on dry weight basis. Uptake of these nutrients was also worked out from the percentage content and dry weight and calculated in mg/plant.

5. Statistical analysis

The data on different parameters were subjected to statistical analysis following the method of Snedacor and Cochron (1967). Mean values were worked out for all different characters. The data were then fed to the computer and analysed.

Results

RESULTS

The results of the experiment as influenced by various levels of shade and moisture, on different characters of cocoa seedlings are presented in the following text with the help of appropriate tables and suitable illustrations. In all the characters studied, the interaction effects were not significant with varying levels of shade and moisture at any stage of observation.

1. Vegetative characters

1.1. Plant height

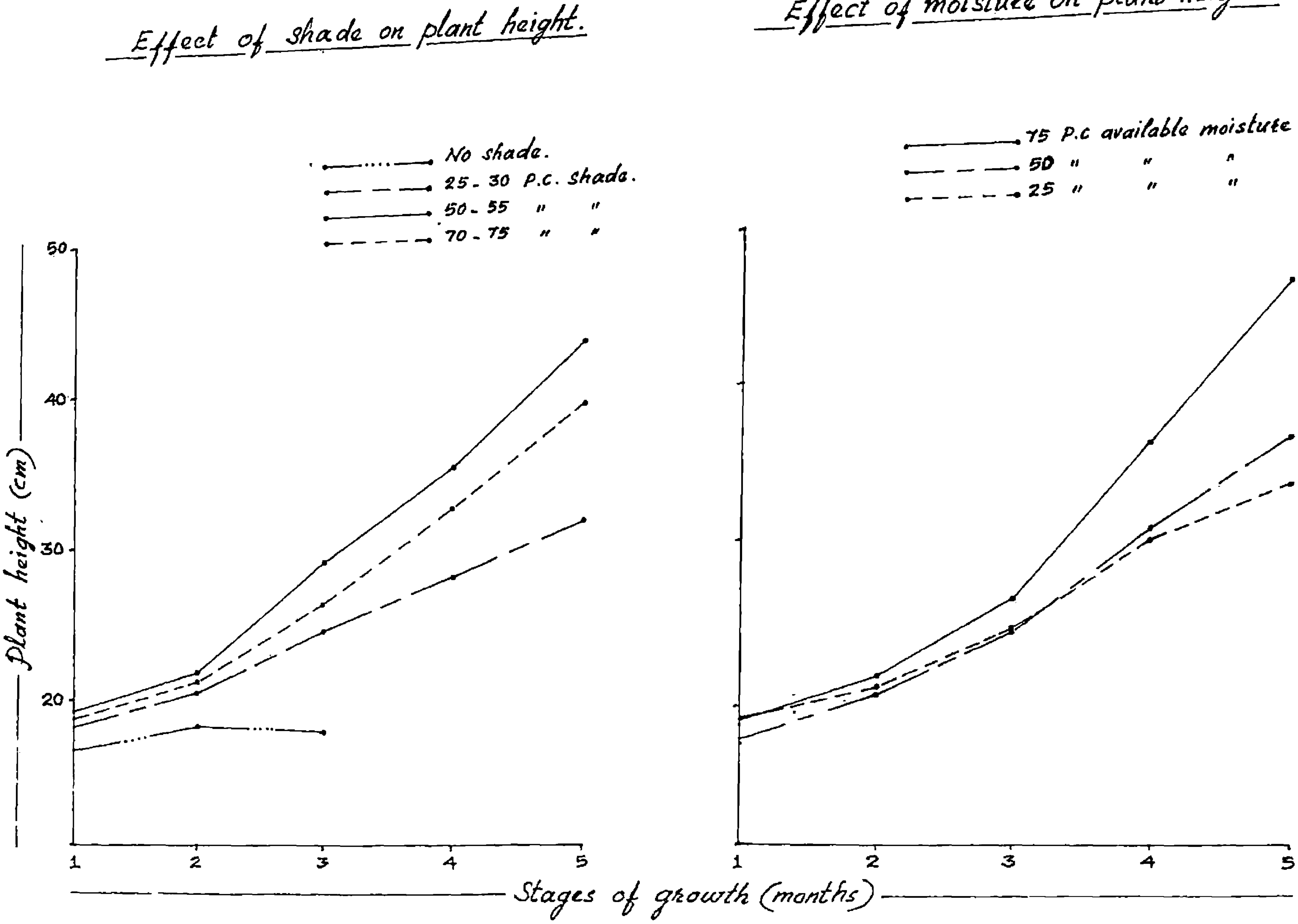
Data on plant height at various stages are presented in Table-1 and Fig. 6.

Effect of shade on plant height was highly perceptible. With increasing intensities of shade, there was increase in plant height upto the intermediate shade level of S_3 (50-55% shade) at all stages. With further increase in shade, there was decrease in plant height, but it was not significant beyond S_3. The treatment differences were significant between S_1 (open) and the rest of the shade levels, at all the stages, but the differences between the treatments receiving shade from 25 to 75 per cent were significant only from the fourth month onwards.

Table-1. Effect of shade and moisture on height (cm) of cocoa seedlings

Treatments	First month	Second month	Third month	Fourth month	Fifth month
<u>Levels of shade</u>					
S_1 (Zero per cent shade)	16.77	17.71	17.51	-	-
S_2 (25 - 30 ")	18.41	20.58	24.47	28.08	31.57
S_3 (50 - 55 ")	19.32	21.83	29.42	35.20	43.32
S_4 (70 - 75 ")	18.73	21.26	26.55	32.85	39.68
F test	Sig	Sig	Sig	Sig	Sig
C.D. at 5%	0.80	0.89	2.12	2.74	3.92
SEm ±	0.278	0.311	0.738	0.943	1.351
<u>Levels of moisture</u>					
M_1 (75 per cent available moisture)	18.51	20.84	25.71	36.20	45.82
M_2 (50 " ")	17.85	19.99	23.88	30.23	35.99
M_3 (25 " ")	18.56	20.20	23.89	29.70	32.77
F test	N.S	N.S	N.S	Sig	Sig
C.D. at 5%	-	-	-	2.74	3.92
SEm ±	0.241	0.269	0.639	0.943	1.351

Fig. 6.



Effect of shade on plant height.
Effect of moisture on plant height.
No shade.
25 - 30 P.C. shade.
50 - 55 " "
70 - 75 " "
75 P.C available moisture
50 " " "
25 " " "
50
40
30
20
Plant height (cm)
1
2
3
4
5
Stages of growth (months)

The effect of moisture levels on plant height was significant only from the third month onwards. However, excepting for the first month, highest mean values were recorded in the treatment receiving irrigation at 75 per cent available moisture followed by M_2 (irrigation at 50% available water). Though the lowest mean plant height was noticed in M_3 (irrigation at 25% available water) the differences between M_2 and M_3 were not statistically significant.

Over the stages there was a steady increase in plant height in all the shade treatments, excepting the plants in the open which practically showed little increase in height. Those receiving shade showed a steady increase in height though the treatment differences were widening with advancing age. The trend in growth at different moisture levels was also similar though the rate of plant height increase was more in plants receiving irrigation at 75% available moisture.

1.2. Stem thickness

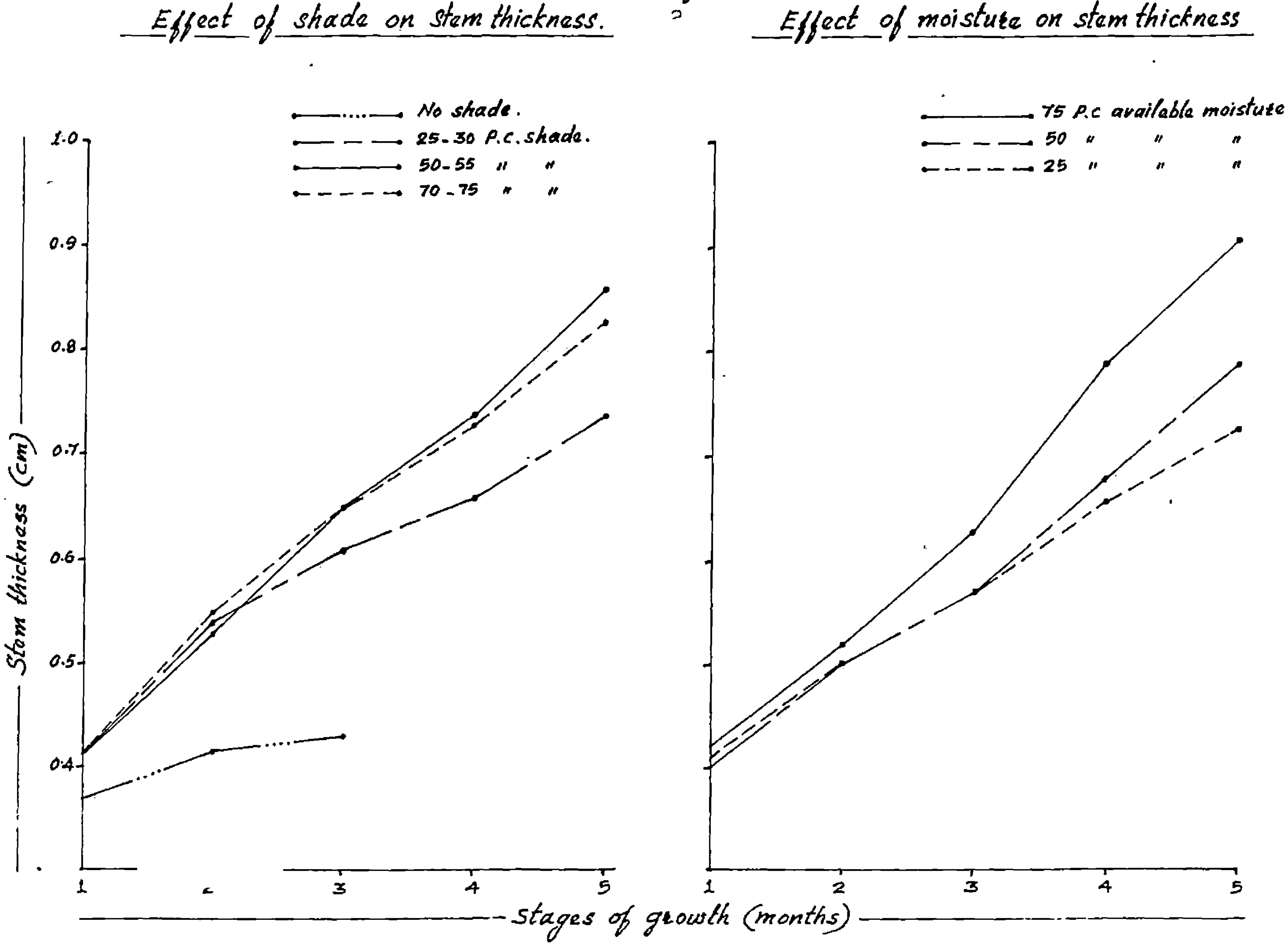
Data on stem thickness are given in Table-2 and Fig.7.

Stem thickness showed a trend almost similar to that

Table-2. Effect of shade and moisture on stem thickness (cm) of cocoa seedlings

Treatments	First month	Second month	Third month	Fourth month	Fifth month
Levels of shade					
S_1 (Zero per cent shade)	0.37	0.42	0.43	-	-
S_2 (25 - 30 ")	0.42	0.54	0.61	0.66	0.74
S_3 (50 - 55 ")	0.42	0.53	0.65	0.74	0.86
S_4 (70 - 75 ")	0.42	0.55	0.65	0.73	0.83
F test	Sig	Sig	Sig	Sig	Sig
C.D. at 5%	0.0158	0.023	0.028	0.036	0.047
SEm ±	0.005	0.008	0.009	0.012	0.016
Levels of moisture					
M_1 (75 per cent available moisture)	0.42	0.52	0.62	0.79	0.91
M_2 (50 " ")	0.40	0.50	0.57	0.68	0.79
M_3 (25 " ")	0.41	0.50	0.57	0.66	0.73
F test	N.S	N.S	Sig	Sig	Sig
CD at 5%	-	-	0.024	0.036	0.047
SEm ±	0.005	0.007	0.008	0.012	0.016

Fig-7.



Effect of shade on stem thickness.
No shade.
25-30 P.C. shade.
50-55 " "
70-75 " "
Effect of moisture on stem thickness
75 P.C available moisture
50 " " "
25 " " "
1.0
0.9
0.8
0.7
0.6
0.5
0.4
Stem thickness (cm)
1
3
4
5
1
2
3
4
5
Stages of growth (months)

of plant height with plants in the open being significantly inferior to all other treatments. The difference in stem thickness between S_3 and S_4 levels of shade was not significant throughout. S_2 was significantly inferior to both S_3 and S_4 from the third month onwards.

M_1 was significantly superior to M_2 and M_3 throughout except for the first and second months, where the treatments did not differ significantly. M_2 and M_3 showed statistical parity till fourth month and at the final stage, M_2 stood superior to M_3.

With increasing age, stem girth showed an increase in all the shaded plants. The difference in girth increment between different shade levels was consistently increasing with increasing age, except for S_3 and S_4 where the difference was very narrow. Similar trend in girth increment was noticed with different levels of moisture.

1.3 <u>Number of leaves</u>

Data on leaf number are given in Table-3 and Fig. 8.

Shade imparted significant effect on the leaf production. In the open, the leaf number was significantly inferior to all levels of shade. Except for the initial

Table-3. Effect of shade and moisture on number of leaves of cocoa seedlings

Treatments	First month	Second month	Third month	Fourth month	Fifth month
Levels of shade					
S_1 (Zero per cent shade)	5.5	3.92	5.5	-	-
S_2 (25 - 30 ")	8.31	10.83	12.22	18.16	17.29
S_3 (50 - 55 ")	8.06	12.89	14.95	23.75	26.83
S_4 (70 - 75 ")	7.70	10.31	13.56	19.42	25.56
F test	Sig	Sig	Sig	Sig	Sig
C.D at 5%	0.807	1.355	1.579	2.667	3.541
S.Em ±	0.281	0.472	0.550	0.919	1.220
Levels of moisture					
M_1 (75 per cent available moisture)	7.92	9.36	12.65	24.05	26.67
M_2 (50 " ")	7.28	9.88	11.23	19.23	22.54
M_3 (25 " ")	6.98	9.32	10.79	17.45	20.53
F test	N.S	N.S	N.S	Sig	Sig
C.D at 5%	-	-	-	2.666	3.541
S.Em ±	0.244	0.409	0.476	0.919	1.220

Effect of shade on no. of leaves.

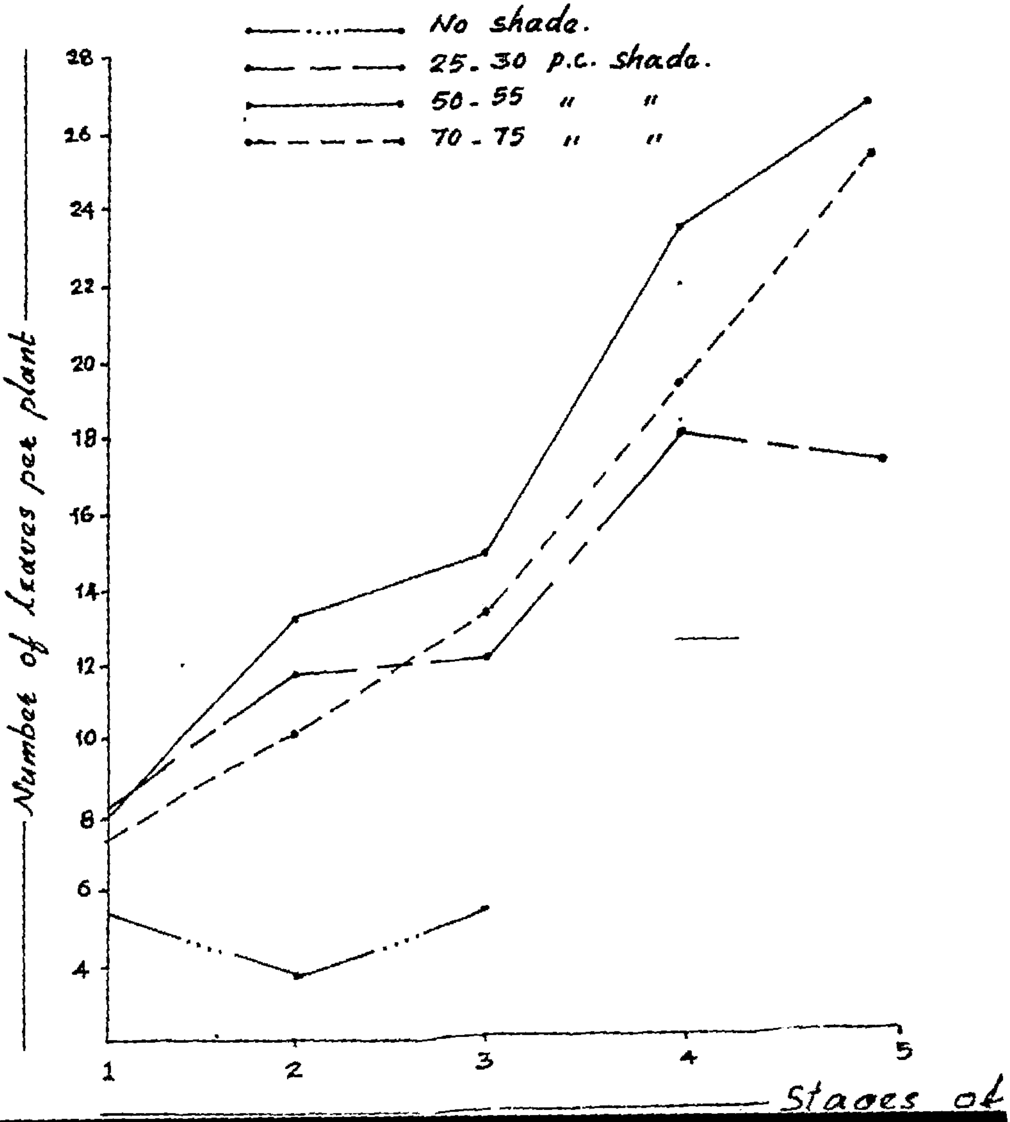
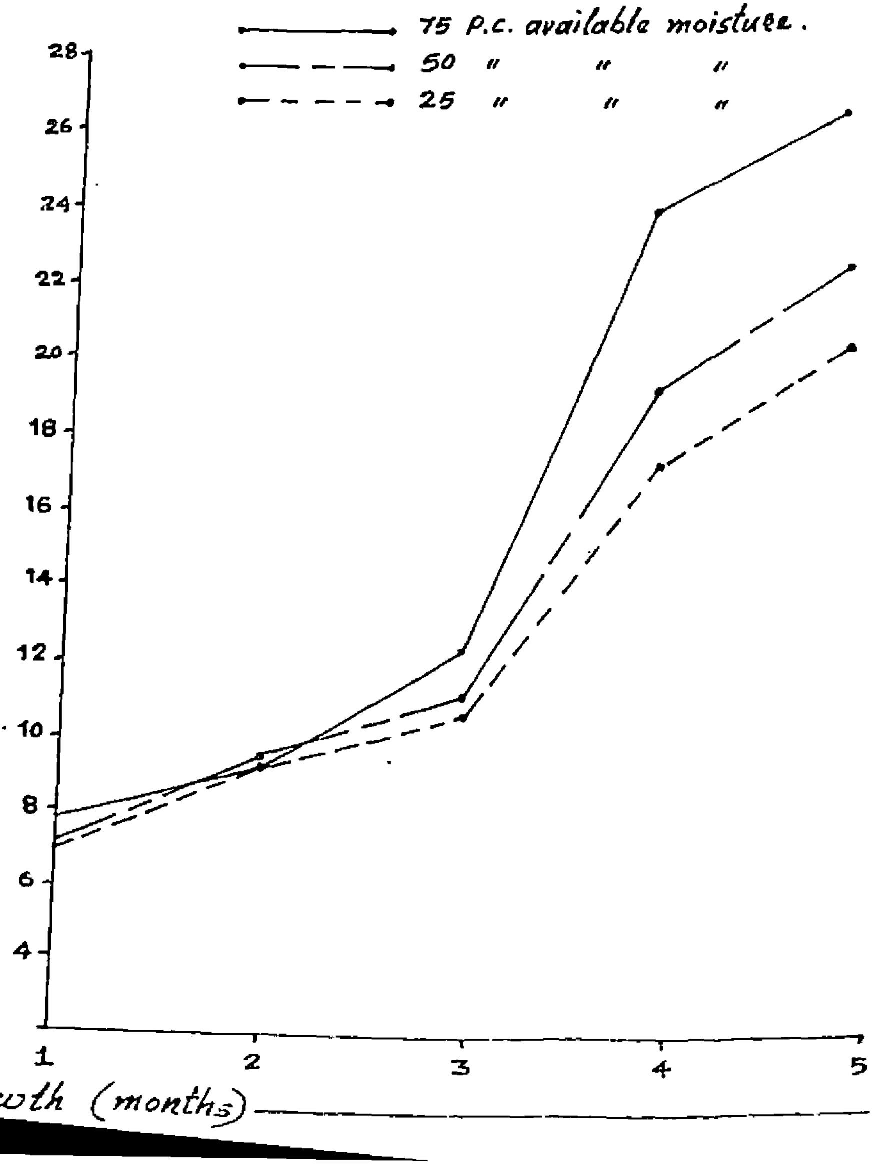


Fig. 8.

Effect of moisture on leaf number.



stage of observation S_3 stood significantly superior to all other shade levels till fourth month, and at the final stage S_3 and S_4 were on par with each other. For the entire period of experimentation, S_2 and S_4 were at par but for the final month where S_4 outnumbered S_2 significantly.

Right from the beginning, except for the second stage of observation, irrigation at 75% available moisture produced higher number of leaves than M_2 and M_3 though the difference was significant only from fourth month onwards. M_2 and M_3 were statistically on par with each other throughout.

Over the stages, the leaf number showed a steep increase in S_3 and S_4. In plants grown under 25% shade, the leaf production was reduced towards the final stage. In the open, leaf number remained nearly static from first to third months.

1.4. <u>Leaf area</u>

Data on leaf area are given in Table 4 and Fig. 9.

Leaf area was markedly influenced by shade and it was increasing with the increasing levels of shade upto the intermediate level. The difference between the shade

Table-4. Effect of shade and moisture on leaf area (cm^2) of cocoa seedlings

Treatments	First month	Second month	Third month	Fourth month	Fifth month
Levels of shade					
S_1 (Zero per cent shade)	77.09	31.70	-	-	-
S_2 (25 - 30 ")	218.34	315.83	418.42	547.01	621.99
S_3 (50 - 55 ")	251.27	359.30	549.73	1147.01	1301.53
S_4 (70 - 75 ")	245.36	365.97	454.42	952.72	1379.57
F test	Sig	Sig	N.S	Sig	Sig
C.D at 5%	21.20	47.79	-	145.32	236.80
S.Em ±	7.385	16.65	32.263	50.078	81.59
Levels of moisture					
M_1 (75 per cent available moisture)	222.51	306.56	640.48	1258.89	1483.54
M_2 (50 " ")	186.07	259.27	477.42	883.74	1102.71
M_3 (25 " ")	185.47	238.76	350.67	504.11	716.84
F test	Sig	Sig	Sig	Sig	Sig
C.D at 5%	18.36	41.38	93.63	145.32	236.80
S.Em ±	6.395	14.415	32.263	50.078	81.59

Effect of Shade on leaf area

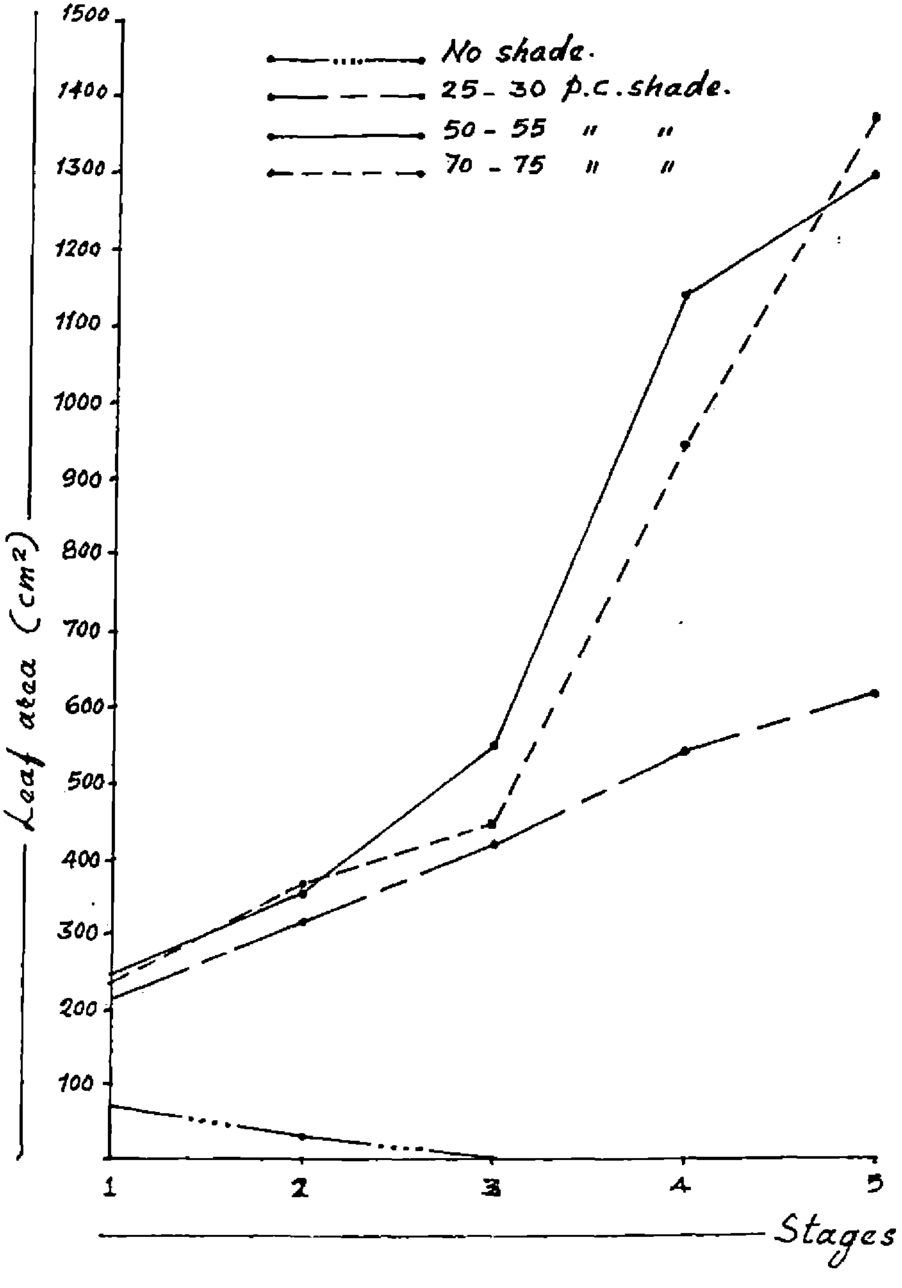
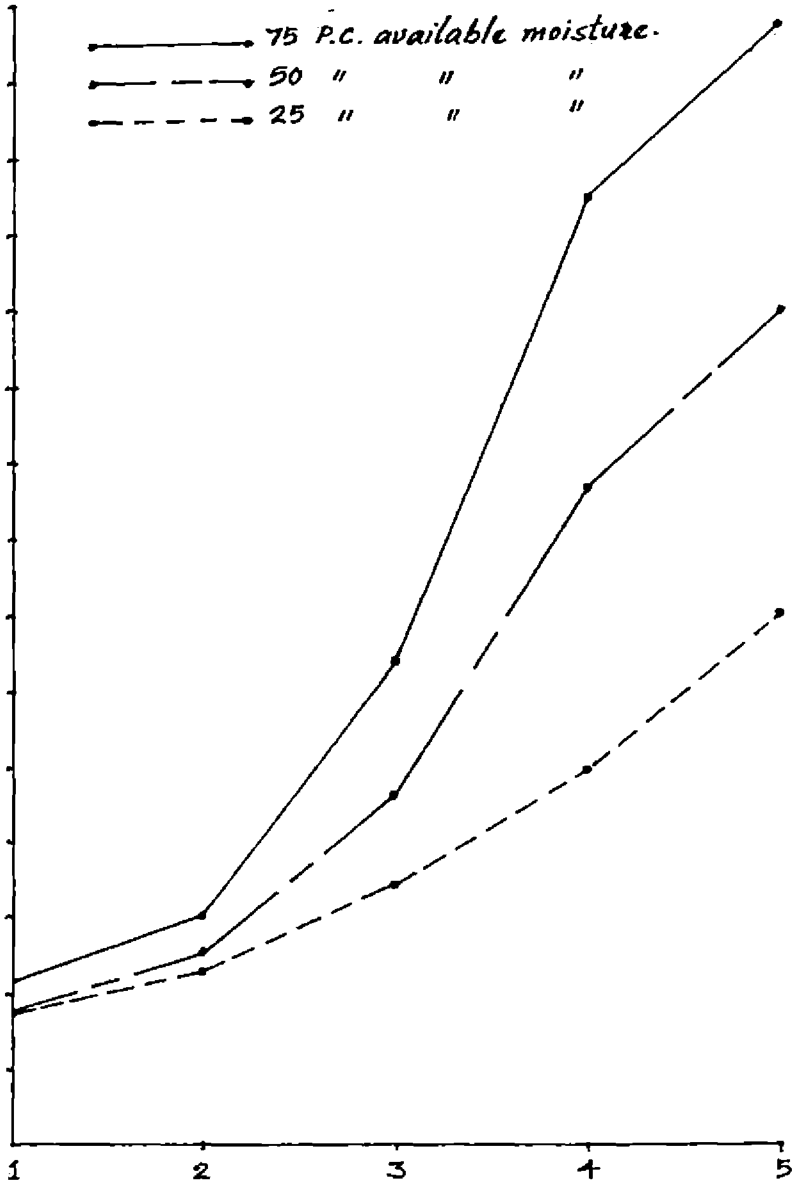


Fig. 9.

Effect of moisture on leaf area.



of growth (months)

levels was significant except for the third month of observation. S_3 and S_4 were on par with each other throughout the experiment, but for the fourth month, S_3 significantly outnumbered S_4 by about 20%. S_2 was always inferior to both S_3 and S_4.

Unlike the shade, irrigation effect was significant on leaf area at all stages. From the start to the final stage, M_1 was significantly superior to both M_2 and M_3. Except for the first two months M_2 showed significant superiority over M_3.

Barring the plants in the open, leaf area was increasing with advancing stages of growth. In the full sunlight leaf area for the second month was about 60% less than the first month and on the third stage it was practically zero though the plants were alive. The difference in leaf area between moisture levels was widening with the stages of plant growth.

1.5. Dry weight

Data on plant dry weight are presented in Table-5 and Fig. 10.

Increase in levels of shade showed a corresponding increase in plant dry weight with the plants grown in open recording the least value. S_2 was on par with S_4 throughout.

Table-5. Effect of shade and moisture on dry weight (g) of cocoa seedlings

Treatments	First month	Second month	Third month	Fourth month	Fifth month
<u>Levels of shade</u>					
S_1 (Zero per cent shade)	0.41	0.45	0.58	-	-
S_2 (25 - 30 ")	1.31	1.80	3.24	4.63	6.35
S_3 (50 - 55 ")	1.39	2.05	3.91	7.68	11.86
S_4 (70 - 75 ")	1.46	2.13	3.88	7.33	10.55
F test	Sig	Sig	Sig	Sig	Sig
C.D.at 5%	0.105	0.259	0.372	0.738	1.609
S.Em ±	0.037	0.090	0.041	0.254	0.555
<u>Levels of moisture</u>					
M_1 (75 per cent available moisture)	1.26	1.8	2.46	8.79	12.60
M_2 (50 " ")	1.14	1.62	2.79	6.25	8.66
M_3 (25 " ")	1.04	1.41	2.46	4.59	6.72
F test	Sig	Sig	Sig	Sig	Sig
C.D at 5%	0.091	0.224	0.323	0.738	1.609
S.Em ±	0.032	0.078	0.036	0.254	0.555

Effect of shade on dry weight.

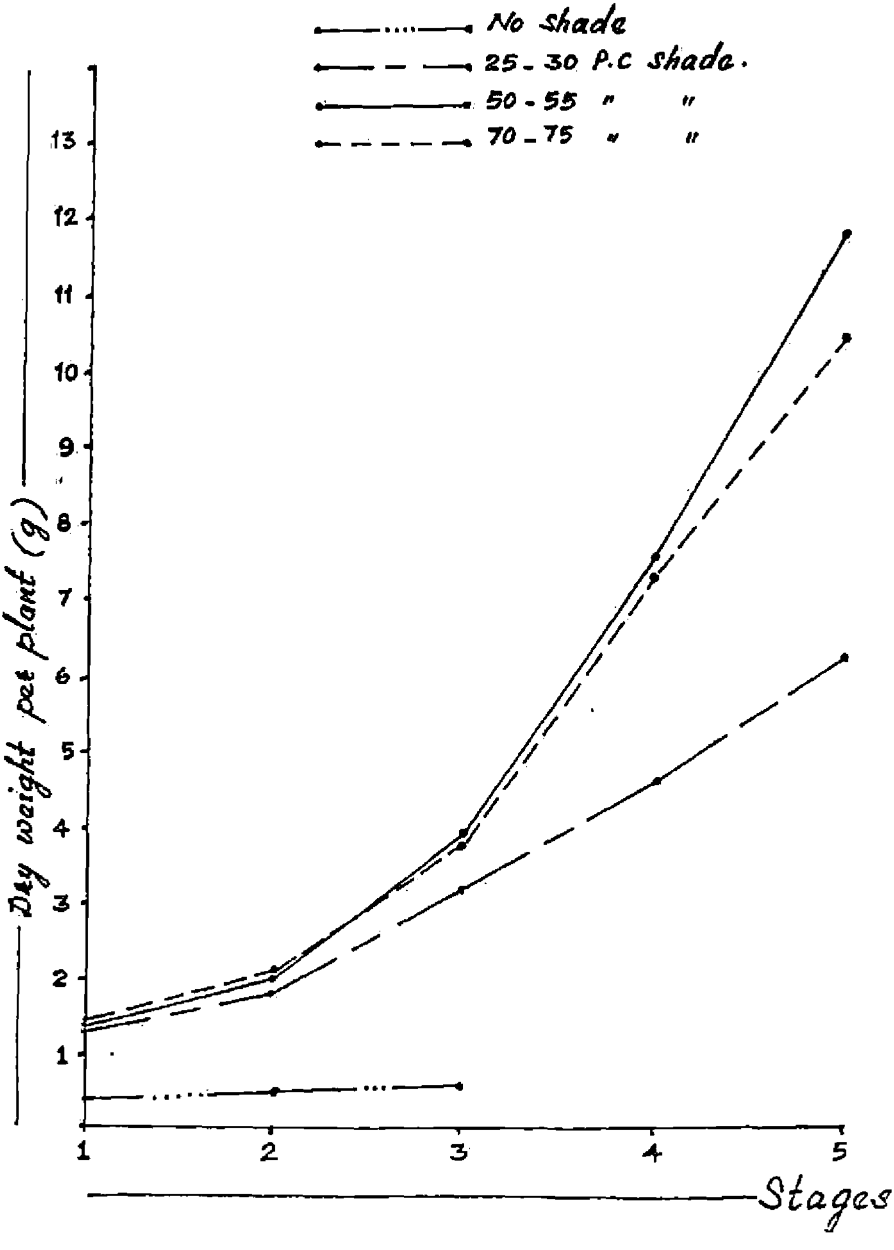
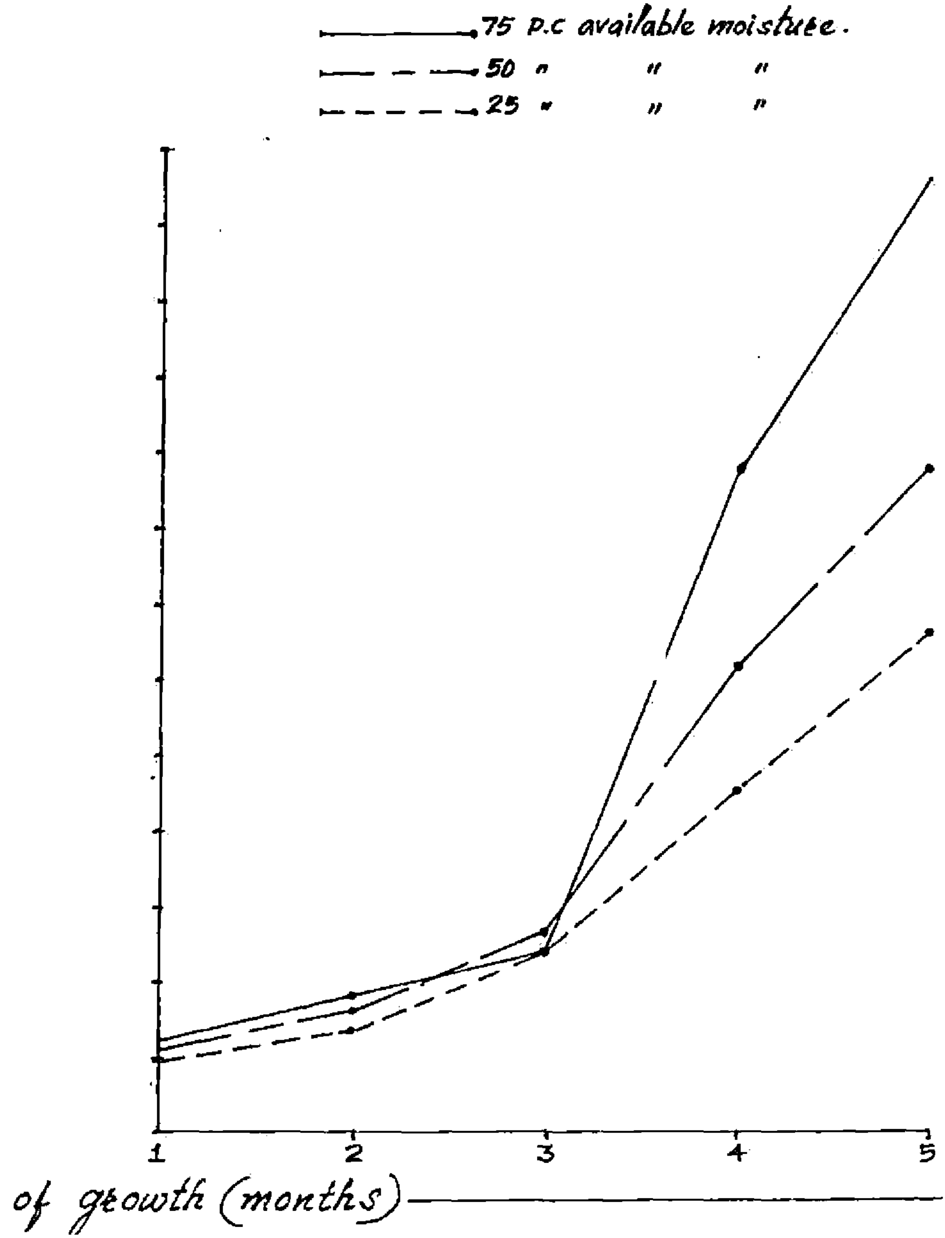


Fig. 10.

Effect of moisture on dry weight.



S_2 was significantly inferior to both S_3 and S_4 except for the first and second stages where it showed parity with S_3.

Irrigation effect, like in all other vegetative characters was almost similar here also. M_1 was significantly superior to the other two levels of moisture except for the second and third stages. At the second stage, it was on par with M_2 while on third month it showed statistical parity with M_3. M_2 was superior to M_3 throughout but for the second stage.

The difference in dry weight between the levels of shade was widening with advancing stages of growth. In the open grown plants dry weight was almost static over the stages of plant growth. The difference in dry weight increase became prominent from the fourth month onwards and thereafter it widened further. Comparing between moisture levels, the rate of increase in dry weight was the most conspicuous from fourth month onwards. The treatment differences tended to widen from this stage onwards.

2. <u>Growth Measures</u>

2.1. <u>Leaf area ratio (LAR)</u>

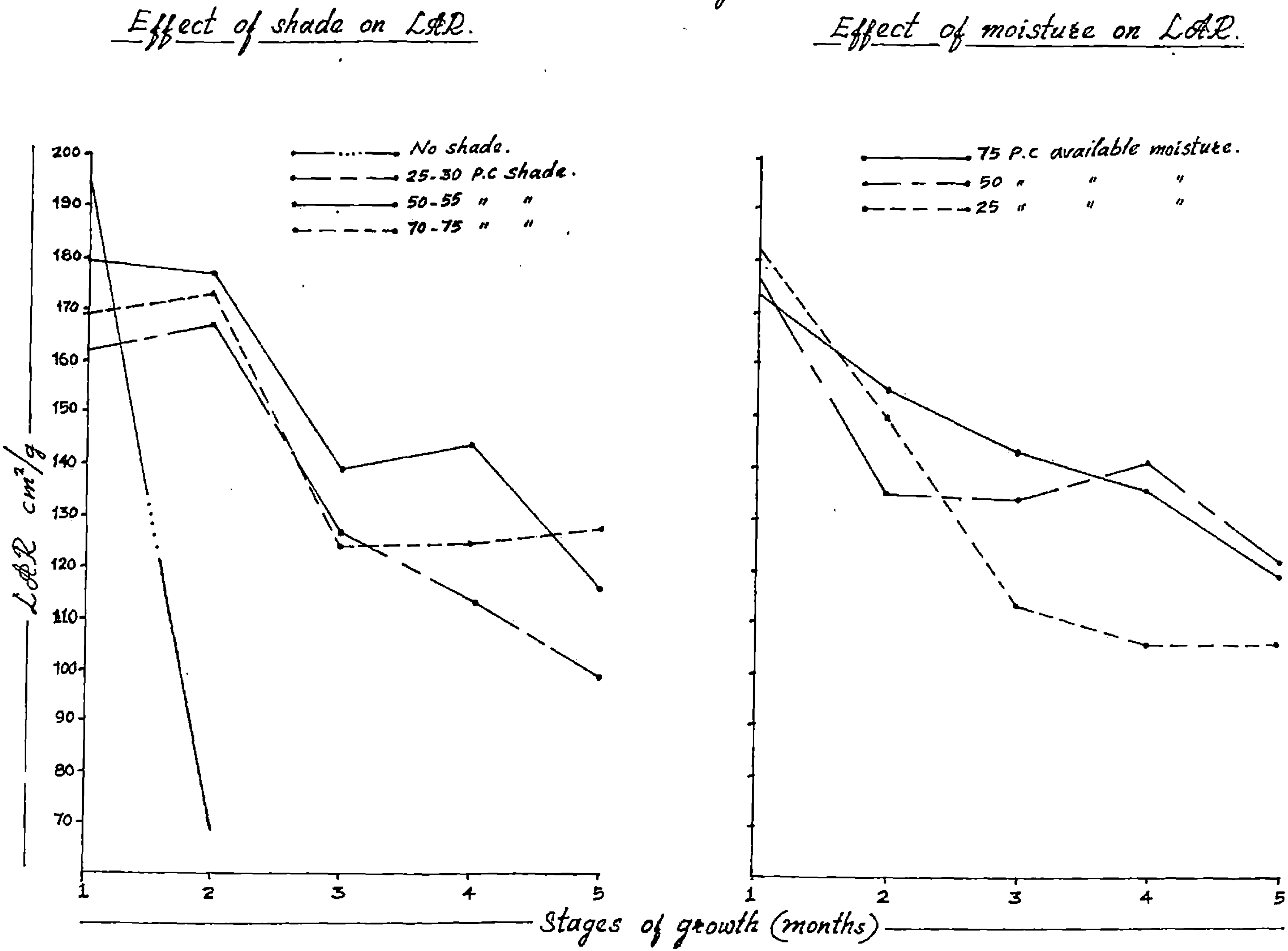
Data are given in Table-6 and Fig. 11.

The effect of shade on leaf area ratio (LAR) was significant only at second and final stage of growth.

Table-6. Effect of shade and moisture on leaf area ratio (LAR) (cm^2/g) of cocoa seedlings

Treatments	First month	Second month	Third month	Fourth month	Fifth month
<u>Levels of shade</u>					
S_1 (Zero per cent shade)	194.69	69.09	-	-	-
S_2 (25 - 30 ")	162.38	167.11	127.63	114.24	98.43
S_3 (50 - 55 ")	179.95	177.30	139.06	144.64	115.160
S_4 (70 - 75 ")	169.03	173.50	124.34	124.82	128.14
F test	N.S.	Sig	NS	N.S	Sig.
C.D at 5%	-	30.876	-	-	12.383
S.Em ±	15.370	10.755	5.481	7.654	4.267
<u>Levels of moisture</u>					
M_1 (75 per cent available moisture)	173.07	154.98	143.54	137.49	114.81
M_2 (50 " ")	176.18	135.41	133.89	140.15	120.29
M_3 (25 " ")	180.29	149.87	113.60	106.05	106.62
F test	N.S	N.S	Sig	Sig	N.S
C.D. at 5%	-	-	15.906	22.212	-
S.Em ±	13.311	9.314	5.481	7.654	4.267

Fig- 11.


Effect of shade on LAR.
Effect of moisture on LAR.
No shade.
25-30 P.C shade.
50-55 " "
70-75 " "
75 P.C available moisture.
50 " " "
25 " " "
LAR cm²/g
200
190
180
170
160
150
140
130
120
110
100
90
80
70
1
2
3
4
5
Stages of growth (months)

Plants receiving 50 - 55% shade, were slightly superior than all others except for the first and last month. Though for the initial stage S_1 was slightly superior to all other levels of shade at the second month it became significantly inferior to them. Towards the final stage S_4 became statistically superior to S_3.

Irrigation effect became significant from the third month onwards. As a general trend, with the increased availability of moisture, except for the initial stage LAR also increased though M_1 and M_2 were always statistically on par with each other. M_3 was significantly inferior to both M_2 and M_1 except for the first two months.

LAR showed a general trend of decrease with advancing stages of growth in all levels of shade except in S_4 which showed a slight increase of about 3% at the final stage as compared to the fourth month. Open grown plants showed the highest initial LAR but during the second month, it dropped by 182% which was much higher than the percentage reduction of LAR in all other cases. With levels of irrigation also LAR showed a general reduction with advancing growth, though the plants irrigated at 50% showed an increase of 5% from fourth to fifth month. The rate of reduction of LAR was higher in M_3 with advancing age of the plant.

2.2. Net assimilation rate (NAR)

Data on net assimilation rate (NAR) are given in Table-7 and Fig.12.

The effect of shade levels on NAR was not significant throughout the experiment, except between the third and fourth months where S_2 was significantly inferior to both S_3 and S_4 which were on statistical parity for the entire period of growth. As a general trend NAR was increasing with increasing levels of shade except for the final stage.

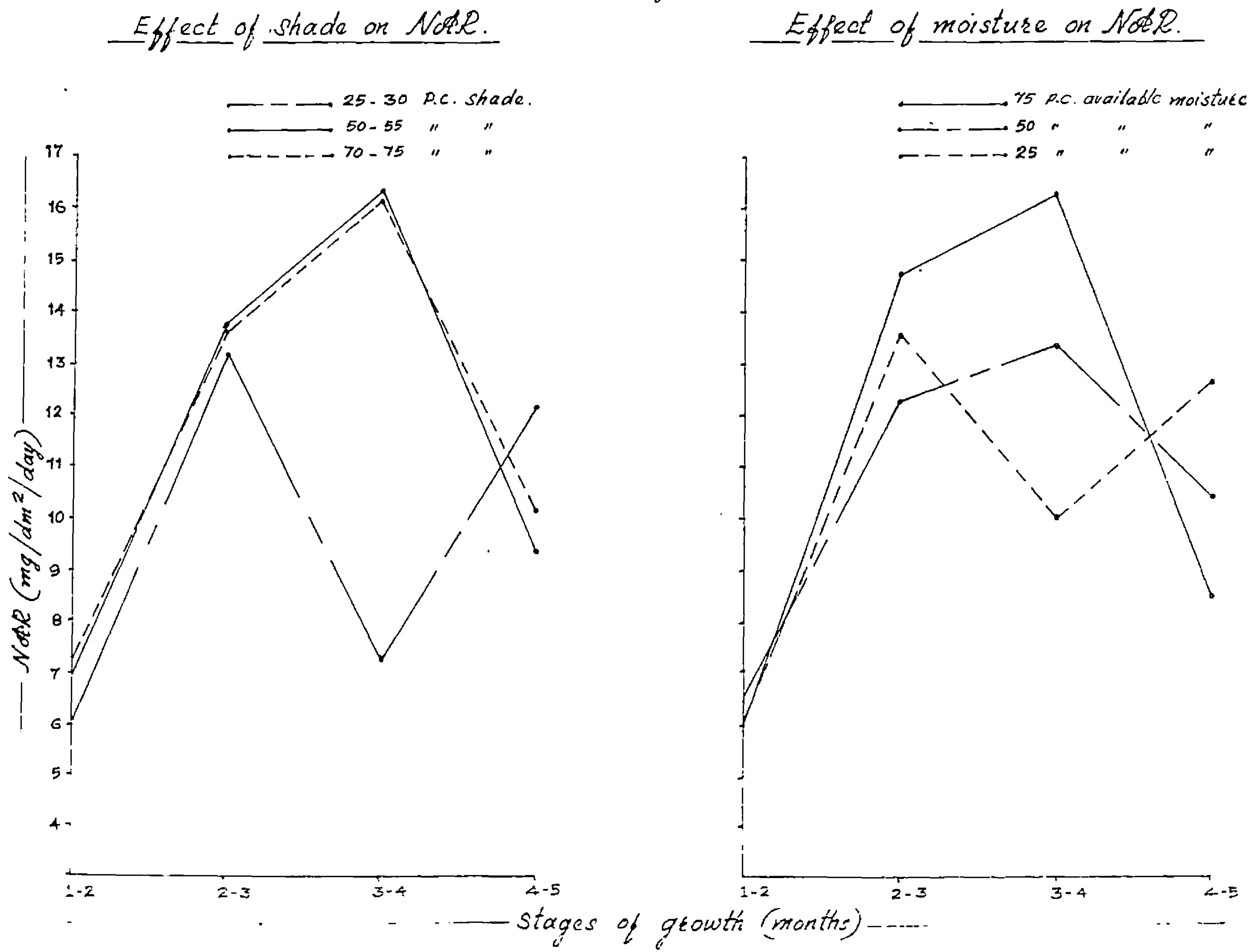
Effect of irrigation on NAR was not significant at any stage of growth except between the third and fourth months when M_1 stood significantly superior to M_3.

With advancing age, NAR also increased upto the fourth month in S_3 and S_4 followed by a decrease afterwards. In the case of S_2 there was a sharp decline in NAR till third month followed by an increase from fourth to fifth month. NAR increased upto fourth month in M_1 and M_2 and then decreased. In M_3, it dropped from third month to fourth month, there being an increase afterwards.

Table-7. Effect of shade and moisture on net assimilation rate (NAR) ($mg/dm^2/day$) of cocoa seedlings

Treatments	First and second month	Second and third month	Third and fourth month	Fourth and fifth month
<u>Levels of shade</u>				
S_1 (Zero per cent shade)	4.42	-	-	-
S_2 (25 - 30 ")	6.08	13.26	7.22	12.13
S_3 (50 - 55 ")	7.03	13.80	16.39	9.44
S_4 (70 - 75 ")	7.34	13.70	16.21	10.14
F test	N.S	N.S	Sig	N.S
C.D at 5%	-	-	5.654	
S.Em ±	0.995	1.210	1.948	2.770
<u>Levels of moisture</u>				
M_1 (75 per cent available moisture)	6.01	14.78	16.36	8.54
M_2 (50 " ")	6.65	12.35	13.43	10.45
M_3 (25 " ")	5.99	13.63	10.03	12.72
F test	N.S	N.S	Sig	N.S
C.D at 5%	-	-	5.654	-
S.Em ±	0.862	1.210	1.948	2.770

Fig-12.


Effect of shade on NAR.
25-30 P.C. shade.
50-55 " "
70-75 " "
NAR (mg/dm²/day)
17
16
15
14
13
12
11
10
9
8
7
6
5
4
1-2
2-3
3-4
4-5
Effect of moisture on NAR.
75 P.C. available moisture.
50 " " "
25 " " "
1-2
2-3
3-4
4-5
Stages of growth (months)

3. Chemical characters

3.1. Nitrogen content

Data are given in Table-8 and Fig. 13.

The effect of shade on nitrogen content was non-significant at all the stages except for the initial two months. Plants in the open showed the highest content of nitrogen, the difference being significant at the first two months. S_2, S_3 and S_4 were statistically on par with each other throughout.

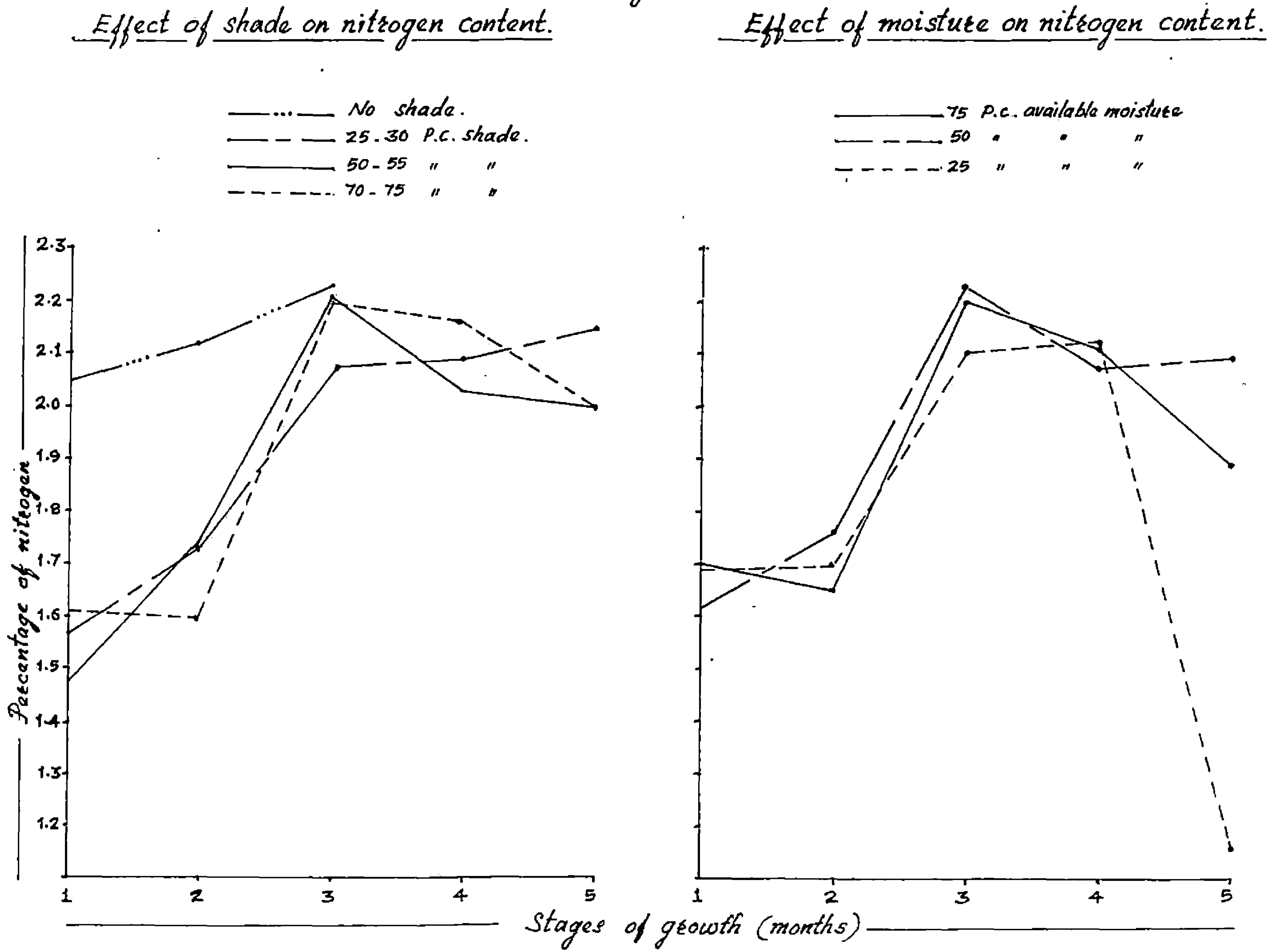
Irrigation effect on nitrogen content was significant only at the final month with M_3 showing the least value. Except for this, all the treatments were on par with each other for the entire period of experimentation.

With all levels of shade nitrogen content exhibited a gradual increase with the stages of plants and decreased towards the final stages in S_3 and S_4. But S_2 showed a continuous increase in nitrogen content with all the stages of growth. With levels of moisture, nitrogen content increased upto the third month of observation, and after which it met with a gradual decrease. In the case of M_3 the percentage of decrease between fourth and fifth month was very conspicuous.

Table-8. Effect of shade and moisture on nitrogen content (%) of cocoa seedlings

Treatments	First month	Second month	Third month	Fourth month	Fifth month
<u>Levels of shade</u>					
S_1 (Zero per cent shade)	2.05	2.12	2.23	-	-
S_2 (25 - 30 ")	1.57	1.73	2.06	2.09	2.15
S_3 (50 - 55 ")	1.48	1.74	2.21	2.03	2.00
S_4 (70 - 75 ")	1.61	1.60	2.20	2.16	2.00
F test	Sig	Sig	N.S	N.S	N.S
C.D at 5%	0.071	0.119	-	-	-
S.Em ±	0.025	0.042	0.044	0.59	0.053
<u>Levels of moisture</u>					
M_1 (75 per cent available moisture)	1.70	1.65	2.20	2.11	1.88
M_2 (50 " ")	1.62	1.76	2.23	2.07	2.09
M_3 (25 " ")	1.69	1.70	2.10	2.12	1.16
F test	N.S	N.S	N.S	N.S	Sig
C.D at 5%	-	-	-	-	0.152
S.Em ±	0.021	0.036	0.038	0.059	0.053

Fig. 13



Effect of shade on nitrogen content.
Effect of moisture on nitrogen content.
No shade.
25-30 P.c. shade.
50-55 " "
70-75 " "
75 P.c. available moisture
50 " " "
25 " " "
Percentage of nitrogen
2.3
2.2
2.1
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1
2
3
4
5
Stages of growth (months)

3.2. Nitrogen uptake

Effect of shade and moisture on nitrogen uptake are presented in Table-9 and Fig. 14.

Effect of different levels of shade on nitrogen uptake was significant throughout. The highest nitrogen uptake was recorded by S_3 closely followed by S_4, throughout except for the initial two months where S_4 had significant superiority over all other shade levels. S_2 was significantly inferior to both S_3 and S_4 from third month onwards, but it reached statistical parity with S_3 for the initial two months. S_1 was highly inferior to all other levels of shade for the entire period.

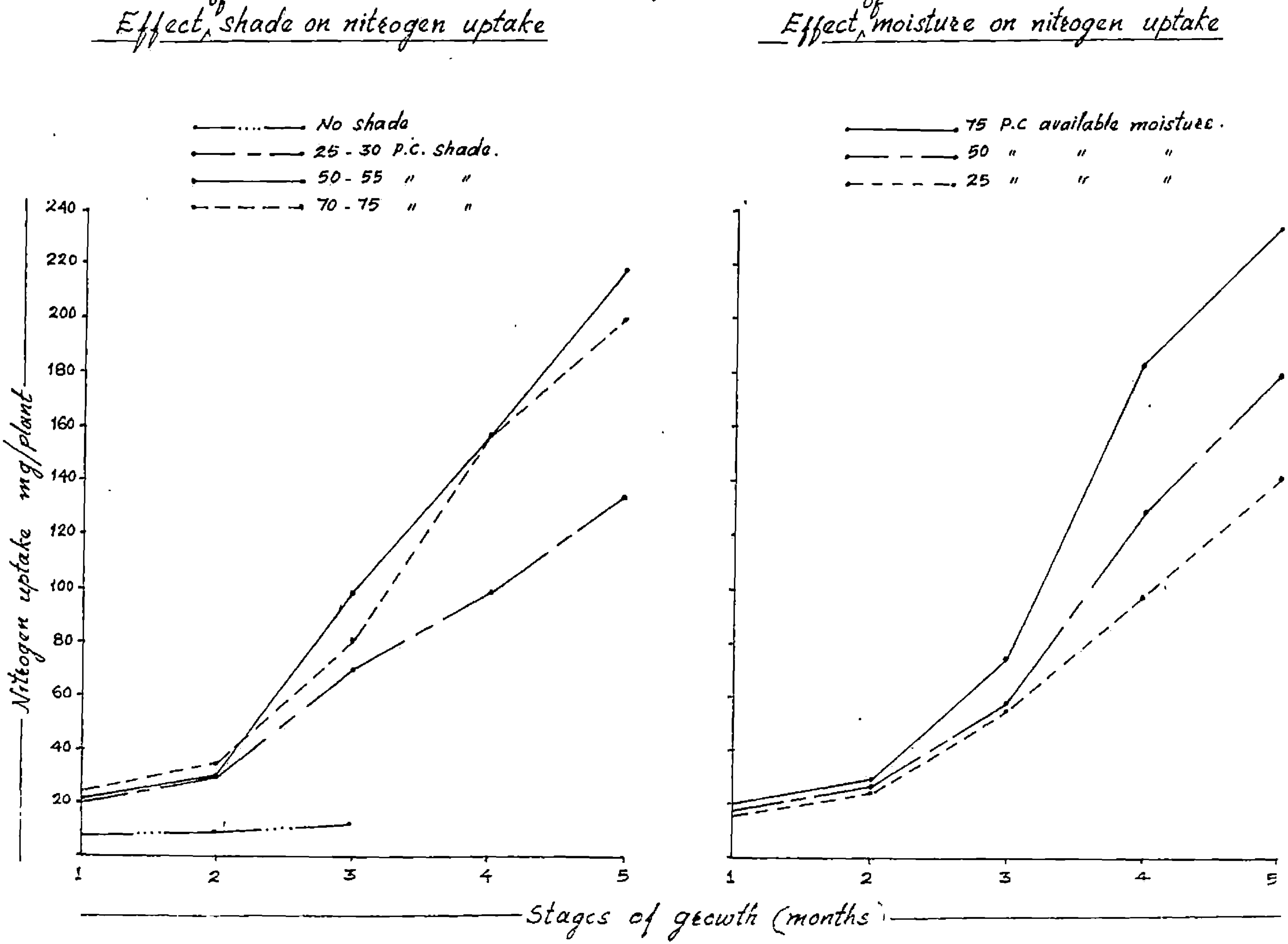
Irrigation also exerted a similar trend on the uptake of nitrogen with the effect being significant at all stages. M_1 was always significantly superior to both M_2 and M_3 except for second month where M_2 recorded similar uptake figures. M_3 was always inferior to M_2 except for the third month, where it was statistically on par with M_2.

Except for the plants grown in open nitrogen content recorded a steady increase over the stages of plar growth. With advancing age the difference in nitrogen uptake was much more conspicuous between the heavily shaded

Table-9. Effect of shade and moisture on nitrogen uptake (mg/plant) of cocoa seedlings

Treatments	First month	Second month	Third month	Fourth month	Fifth month
Levesl of shade					
S_1 (Zero per cent shade)	8.38	9.59	13.00	-	-
S_2 (25 - 30 ")	20.58	31.37	69.93	98.24	134.69
S_3 (50 - 55 ")	20.81	30.81	89.70	156.34	218.04
S_4 (70 - 75 ")	24.07	34.20	80.62	157.48	206.26
F test	Sig	Sig	Sig	Sig	Sig
C.D at 5%	1.729	4.140	13.433	5.529	9.499
S.Em ±	0.602	1.442	4.679	5.529	9.499
Levels of moisture					
M_1 (75 per cent available moisture)	20.55	29.78	74.37	184.45	234.42
M_2 (50 " ")	18.20	27.08	59.27	129.61	180.85
M_3 (25 " ")	16.62	22.62	56.30	98.00	143.73
F test	Sig	Sig	Sig	Sig	Sig
C.D. at 5%	1.497	3.585	11.633	16.046	27.569
S.Em ±	0.522	1.249	4.052	5.529	9.499

Fig. 14



Effect of shade on nitrogen uptake
No shade
25 - 30 P.C. shade.
50 - 55 " "
70 - 75 " "
Effect of moisture on nitrogen uptake
75 P.C available moisture.
50 " " "
25 " " "
Nitrogen uptake mg/plant
240
220
200
180
160
140
120
100
80
60
40
20
1
2
3
4
5
Stages of growth (months)

plants and S_2. In the open grown plants increase in nitrogen uptake over the stages was not perciptible. The trend in nitrogen uptake was similar in the case of moisture levels though the most frequently irrigated plants exhibited higher rate of increase with advancing age.

3.3. Phosphorus content

The data on phosphorus content are given in Table-10 and Fig. 15.

S_1 recorded higher phosphorus content than all other shaded levels at all the stages, though the plants in this treatment died after third month. Only upto the third month, there existed a statistical significance between the shade levels. S_2, S_3 and S_4 were on par with each other throughout, but for the third month where S_2 was inferior to S_4.

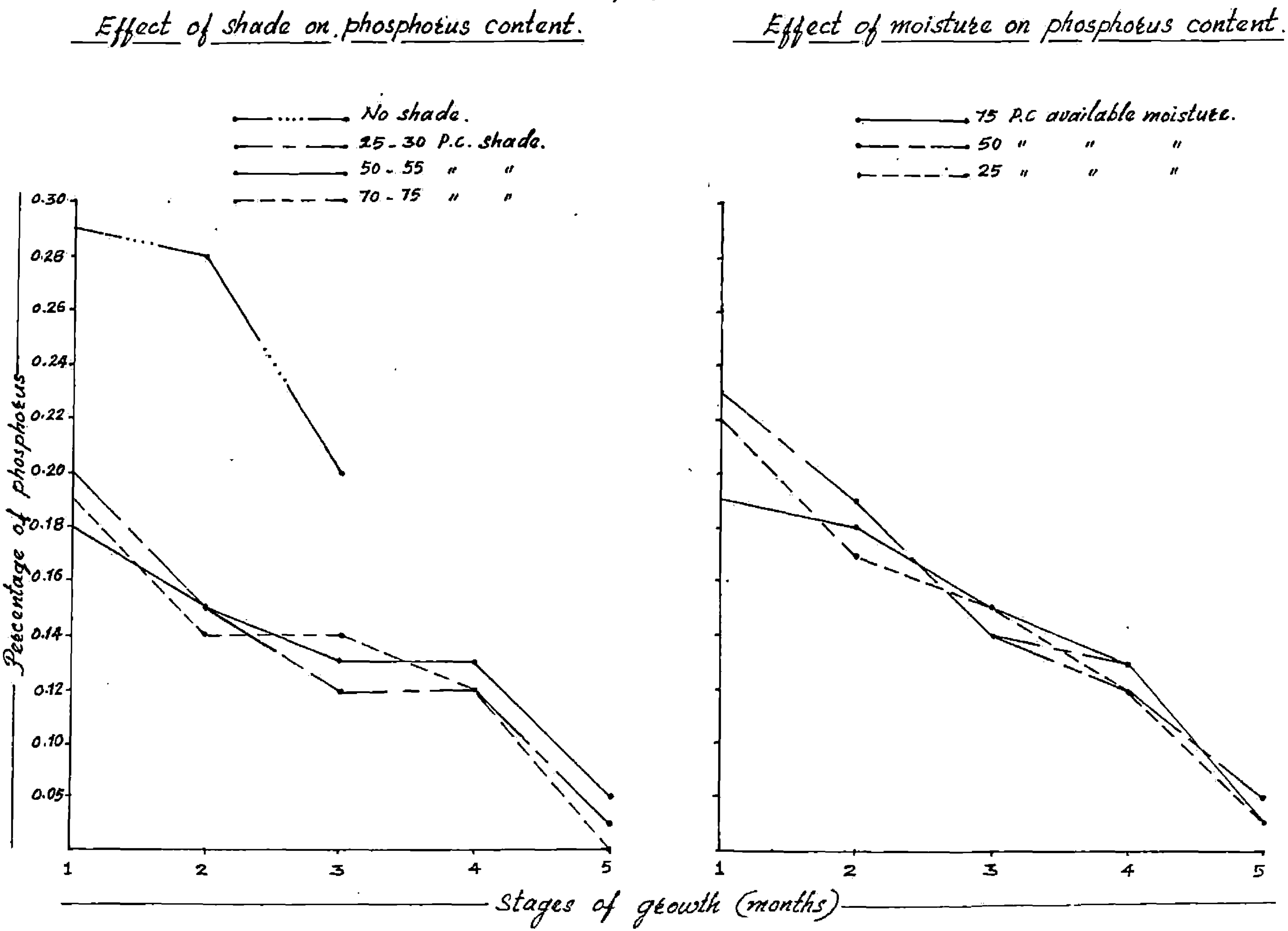
Irrigation affected the phosphorus content significantly only at the initial stage with M_2 and M_3 being superior to M_1. For the rest of the period no significant difference was noticed between the various levels of moisture.

At all the levels, shade exhibited a rapid decrease in the percentage content of phosphorus with the stages of

Table-10. Effect of shade and moisture on phosphorus content (%) of cocoa seedlings

Treatments	First month	Second month	Third month	Fourth month	Fifth month
Levels of shade					
S_1 (Zero per cent shade)	0.29	0.28	0.20	-	-
S_2 (25 - 30 ")	0.20	0.15	0.12	0.12	0.07
S_3 (50 - 55 ")	0.18	0.15	0.13	0.13	0.08
S_4 (70- 75 ")	0.19	0.14	0.14	0.12	0.06
F test	Sig	Sig	Sig	N.S	N.S
C.D. at 5%	0.022	0.022	0.016	-	-
S.Em ±	0.008	0.008	0.005	0.004	0.004
Levels of moisture					
M_1 (75 per cent available moisture)	0.19	0.18	0.15	0.13	0.07
M_2 (50 " ")	0.23	0.19	0.14	0.12	0.08
M_3 (25 " ")	0.22	0.17	0.15	0.12	0.07
F test	Sig	NS	N.S	N.S	N.S
C.D at 5%	0.019	-	-	-	-
S.Em ±	0.007	0.007	0.005	0.005	0.004

Fig-15



Effect of shade on phosphorus content.
No shade.
25-30 P.C. shade.
50-55 " "
70-75 " "
0.30
0.28
0.26
0.24
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.05
Percentage of phosphorus
Effect of moisture on phosphorus content.
75 P.C available moisture.
50 " " "
25 " " "
1
2
3
4
5
Stages of growth (months)

growth, and the percentage reduction at the final stage over the initial stage being 65, 55 and 68 respectively for S_2, S_3 and S_4. In the case of irrigation also phosphorus content showed a rapid decrease with the stages of plant, the percentages of depression with the initial values being 63.13, 65.21 and 68.13 respectively for M_1, M_2 and M_3.

3.4. Phosphorus uptake

Phosphorus uptake data are given in the Table-11 and Fig.16.

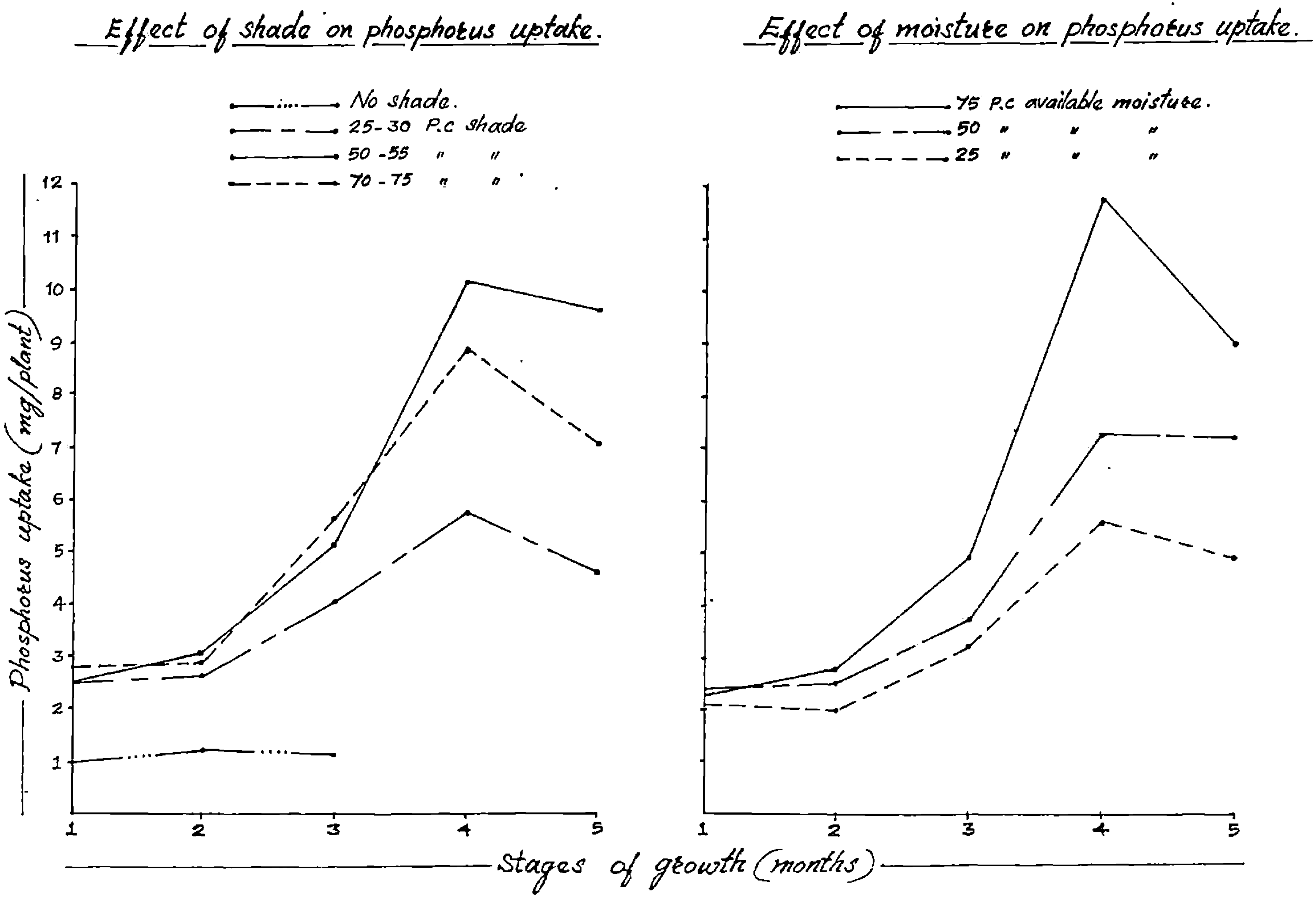
The effect of shade on phosphorus uptake was significant at all stages of plant growth. Upto the third month of observation, S_3 and S_4 were on par with each other and thereafter S_3 was statistically superior to S_4. S_2 was significantly inferior to both S_3 and S_4 except for the initial two months where, S_2, S_3 and S_4 were on par with each other. S_1 was always inferior to all levels of shade.

Increased availability of moisture increased the phosphorus uptake, the effect being significant at all the stages excepting the first month as in the case of shade. M_1 stood superior to both M_2 and M_3, though for the first

Table-11. Effect of shade and moisture on phosphorus uptake (mg/plant) of cocoa seedlings

Treatments	First month	Second month	Third month	Fourth month	Fifth month
Levels of shade					
S_1 (Zero per cent shade)	1.13	1.24	1.15	-	-
S_2 (25 - 30 ")	2.55	2.66	4.08	5.79	4.61
S_3 (50 - 55 ")	2.54	3.06	5.17	10.03	9.60
S_4 (70 - 75 ")	2.79	2.92	5.53	8.95	7.10
F test	Sig	Sig	Sig	Sig	Sig
C.D at 5%	0.257	0.407	0.616	1.004	1.772
S.Em ±	0.0893	0.142	0.214	0.374	0.611
Levels of moisture					
M_1 (75 per cent available moisture)	2.30	2.82	4.98	11.81	9.05
M_2 (50 " ")	2.34	2.52	3.77	7.34	7.29
M_3 (25 " ")	2.10	2.07	3.19	5.61	4.91
F test	N.S	Sig.	Sig.	Sig.	Sig.
C.D. at 5%	-	0.353	0.533	1.084	1.773
S.Em ±	0.077	0.123	0.186	0.374	0.611

Fig. 16.



Effect of shade on phosphorus uptake.
No shade.
25-30 P.c shade
50-55 " "
70-75 " "
Phosphorus uptake (mg/plant)
12
11
10
9
8
7
6
5
4
3
2
1
1
2
3
4
5
Effect of moisture on phosphorus uptake.
75 P.c available moisture.
50 " " "
25 " " "
1
2
3
4
5
Stages of growth (months)

two months M_1 and M_2 did not differ statistically. M_3 was significantly inferior to M_1 throughout excepting the first stage.

Barring the open grown plants, with all levels of shade, phosphorus uptake was increasing with the stages of plant growth except for the final stage at which there was a decrease. In the open grown plants the rate of uptake was rather static with the stages of growth. A similar phosphorus uptake pattern was noticed with different irrigation levels and stages of plant growth. However, in M_1, there was a fall in phosphorus uptake from fourth to fifth month.

3.5. Potassium content

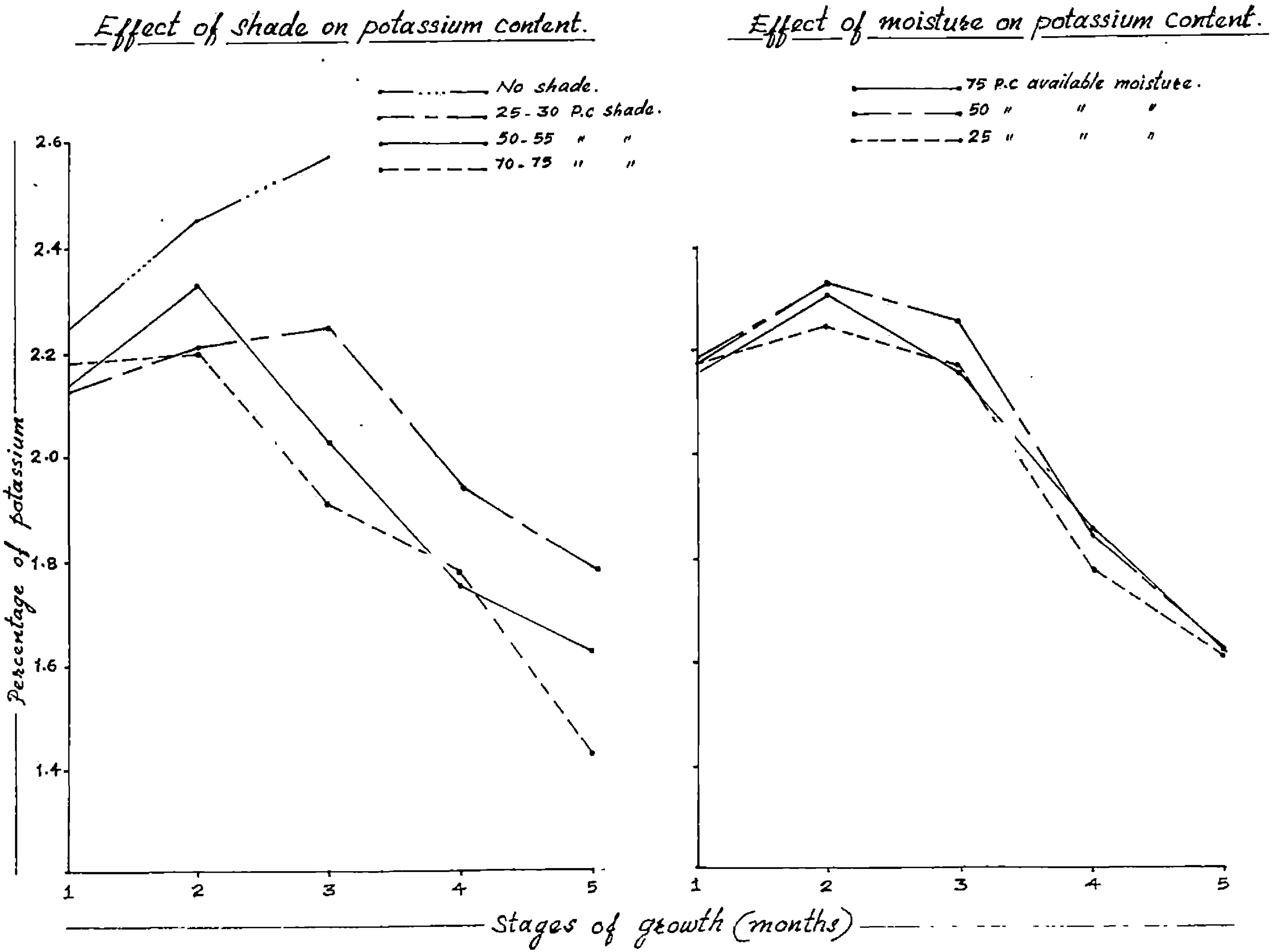
The values are presented in Table-12 and Fig. 17.

As a general trend potassium content was decreasing with the increase in percentage of shade except for the initial month. Effect of shade on potassium content was non-significant only for the initial month and for all other stages it was significant. S_1 showed the highest content of potassium and was significantly superior to all levels of shade, except for the second month when it attained statistical parity with S_3. Till the fourth stage of

Table-12. Effect of shade and moisture on potassium content (%) of cocoa seedlings

Treatments	First month	Second month	Third month	Fourth month	Fifth month
Levels of shade					
S_1 (Zero per cent shade)	2.25	2.45	2.58	-	-
S_2 (25 - 30 ")	2.13	2.21	2.25	1.95	1.79
S_3 (50 - 55 ")	2.14	2.33	2.03	1.76	1.63
S_4 (70 - 75 ")	2.18	2.20	1.91	1.78	1.43
F test	N.S	Sig	Sig	Sig	Sig
C.D at 5%	-	0.143	0.141	0.106	0.108
S.Em ±	0.032	0.049	0.0489	0.037	0.037
Levels of moisture					
M_1 (75 per cent available moisture)	2.16	2.37	2.16	1.06	1.62
M_2 (50 " ")	2.19	2.33	2.26	1.85	1.62
M_3 (25 " ")	2.18	2.25	2.17	1.78	1.61
F test	N.S	N.S	N.S	N.S	N.S
C.D at 5%	-	-	-	-	-
S.Em ±	0.028	0.0431	0.042	0.037	0.037

Fig- 17.



Effect of shade on potassium content.
Effect of moisture on potassium content.
No shade.
25-30 P.c shade.
50-55 " "
70-75 " "
75 P.c available moisture.
50 " " "
25 " " "
2.6
2.4
2.2
2.0
1.8
1.6
1.4
Percentage of potassium
1
2
3
4
5
Stages of growth (months)

observation, S_3 and S_4 did not show any significant difference but on fifth month S_3 was superior to S_4. Though for the first two months, S_2 was on par with S_3 and S_4, from the third month onwards it was significantly higher.

There was no significant effect of moisture levels on the percentage content of potassium. At all stages of growth M_1, M_2 and M_3 were statistically on par with each other.

Only in the open grown plants there was a marked increased content of potassium with the increase in age of the plant. In all the shaded plants it was generally decreasing over the stages of plant growth though during the second month, a slight increase was noticed. While S_4 showed a percentage decrease of 34.4 over the initial stage, it was 23.8 and 15.96 respectively for S_3 and S_2 at the final stage. But S_1 recorded an increase of 14.6% over the initial month at the third month.

3.6 Potassium uptake

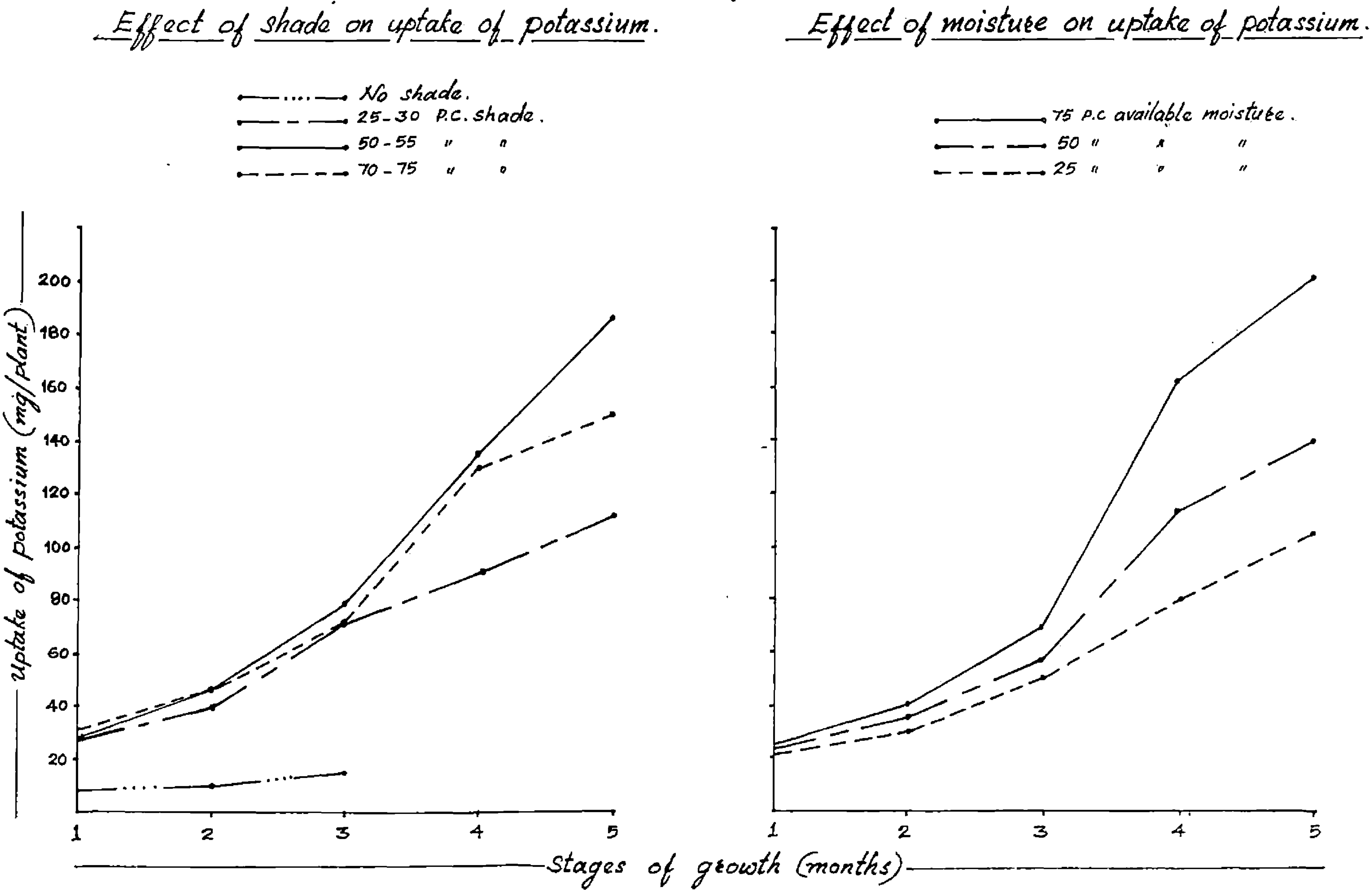
Data on the potassium uptake are given in Table-13 and Fig. 18.

Effect of shade on potassium uptake was statistically

Table-13. Effect of shade and moisture on potassium uptake (mg/plant) of cocoa seedlings

Treatments	First month	Second month	Third month	Fourth month	Fifth month
<u>Levels of shade</u>					
S_1 (Zero per cent shade)	9.12	10.10	15.15	-	-
S_2 (25 - 30 ")	28.01	40.04	72.94	89.96	112.01
S_3 (50 - 55 ")	29.00	46.73	79.50	135.81	184.96
S_4 (70 - 75 ")	32.57	47.02	73.18	131.05	150.61
F test	Sig	Sig	Sig	Sig	Sig
C.D at 5%	2.455	6.077	15.459	13.097	24.005
S.Em ±	0.855	2.116	3.037	4.513	8.270
<u>Levels of moisture</u>					
M_1 (75 per cent available moisture)	27.39	41.07	70.06	162.89	201.84
M_2 (50 " ")	24.42	36.90	59.40	114.01	140.09
M_3 (25 " ")	22.22	30.62	51.12	79.93	105.65
F test	Sig	Sig	Sig	Sig	Sig
C.D at 5%	2.126	5.262	13.388	13.097	24.000
S.Em ±	0.741	1.633	2.629	4.513	8.270

Fig. 18.



Effect of shade on uptake of potassium.
No shade.
25-30 P.C. shade.
50-55 " "
70-75 " "
Uptake of potassium (mg/plant)
200
180
160
140
120
100
80
60
40
20
1
2
3
4
5
Effect of moisture on uptake of potassium.
75 P.C available moisture.
50 " " "
25 " " "
1
2
3
4
5
Stages of growth (months)

significant throughout the investigation period. From the second month onwards S_3 and S_4 continued to be on statistical parity with each other but for the final stage S_3 was significantly superior to S_4. S_2 was highly inferior to both S_3 and S_4 except for the first and third months. During these stages, it was on par with S_3. S_1 was significantly inferior to all other shade levels.

On the uptake of potassium, different levels of moisture also exerted significant difference. Always M_1 stood highly superior to the other two levels of moisture except for the second month, when M_1 and M_2 were on par. M_2 showed statistical superiority over M_3 but for the third month when M_2 and M_3 were on par. As a general trend increase in available moisture increased the potassium uptake also.

With the increase in age of the plant, potassium uptake recorded a steady increase at all the levels of shade, the difference in increase getting wider towards the final stages. In contrast to the shaded plants S_1 plants showed almost static potassium uptake. In the case of moisture levels also, increased potassium uptake was noticed over the stages of plant growth, with the highest value being always recorded by M_1 followed by M_2 and M_3.

Discussion

DISCUSSION

The present investigation was taken up with a view to study the effect of different levels of shade and moisture on the growth of cocoa seedlings. Growth characters, nutrient content, and uptake of nutrients under four levels of shade and three levels of moisture were studied.

From the results of the present investigation, it can be seen that shade and moisture imparted significant effects on the growth of cocoa seedlings. Medium shading and irrigation at 75% available moisture produced most vigrous seedlings. The interaction effect of the treatments was not significant in any of the characters.

Shade effect on seedling growth was highly perceptible in almost all the growth characters studied. Plant height was significantly increasing with the increase in level of shade up to 50 - 55%, and thereafter it decreased slightly with the increase in shade. Cambial activity as measured in terms of girth also showed an exactly similar trend with the levels of shade. Leaf number and size was remarkably influenced by different levels of shade. Plants in the full sunlight produced small, pale and crinkled leaves with short internodes. Similar effect of full sunlight was also reported by Clark (1905) and Frederick Hardy

(1958). Leaf number was also considerably inferior to all other shaded plants with the medium shade producing the largest number of leaves. Increase in leaf area of plants is also reported to be the immediate perceptible morphological adaptation generally associated with low intensities of light both in shade tolerant and shade intolerant species. In the present study, significant increase in leaf area was noticed with the increase in shade up to the intermediate level after which it decreased. In the plants grown in the open, leaf number and size were drastically reduced resulting in low leaf area. Similar results were reported by Frederick Hardy (1958). It was also reported that leaves produced under heavy shade are much larger and often attain a length of 20 - 24 inches because of loosened mesophylls, and elongated epidermal cells (Gourley, 1920). In the case of dry matter accumulation, which is the net result of active vegetative growth and optimum resource utilization, similar results were obtained with increasing levels of shade. Plants in the open met with the least dry matter accumulation. The percentage increase in dry matter accumulation with advancing stages of growth was also very meagre in this case. On the contrary, dry weight was increasing substantially with the levels of shade and stages of growth except for the heavy shade. Similar results were reported by Silveria and Maestri (1973) in coffee. Leaf area ratio (LAR) was also higher in medium shaded plants, though it was on par with the heavily shaded plants except for the final month, where heavily shaded plants became superior to the former. In support to this, Frederic Hardy (1958), and Okali and Owusu (1975) reported that for cocoa mean leaf area ratio (MLAR) was greater for plants in deep shade and lowest for plants in open. With the increase in age all the shade levels showed notable reduction in LAR eventhough leaf area showed an increase. Goodall (1950), Frederick Hardy (1958), Baker and Hardwick (1973) and Okali and Owusu (1975) all noted increased net assimilation rate (NAR) with the increased intensity of illumination. By contrast to the above observations, in the present study NAR was affected significantly, but positively by increasing shade levels. It may thus be concluded that excepting in the case of NAR, the results agreed, in general, with the general trend reported in literature with nearly all growth parameters being improved by increasing shade intensities upto the medium level of 50 - 55 per cent shade.

As early as 1896 Watt stressed the importance of shade and moisture for the better growth of cocoa seedlings by stating that young cocoa plants must be shaded and well watered (Holland, 1931). Evans and Murray (1953) reported that optimum intensity of light for young cocoa lies between 25 - 60%. Goodall (1950) observed 20% light intensity as best for seedling cocoa. Frederidc Hardy (1958) reported 25% full sunlight as the most favourable light intensity for cocoa seedlings.

It has been established that the rate of photosynthesis by cocoa as evidenced by continued stomatal opening with increasing illumination is the highest in full light (Hardy, 1958). However the vegetative growth of the crop is reported to be better under a certain degree of shade than in the open (Humphries, 1944; Greenwood and Posnettee, 1950; Cunningham, 1963; Streitberry and Hoffman, 1973; Boyer, 1974 and Mainstone, 1976). Such a crop performance is in marked contrast to other shade loving plants like coffee where both growth and yield have been found best under shade than in the open (Weaver and Clements, 1929; Anon. 1932; Elgueta and Bonilla, 1951). Again, in such crops, the mechanism of shade affinity has been attributed to stomatal behaviour. Hardy (1958) reported that in coffee, stomata begin to close at light intensities beyond 8000 - 8500 ft. cndles. According to Hardy (1958) the better growth performance and leaf production of cocoa under shade than in the open is because of regulation of leaf production by certain auxins. The auxins concentration, according to him at full direct sunlight decreases because of photo-destruction. If this could be the reason for the reported better vegetative growth and leaf production of cocoa under shade, it would then explain why the shade response of this crop is different for early establishment in contrast to production. In the early stages when the canopy development is inadequate, probably leaf area for photosynthesis is more critical in deciding the rate of photosynthesis, and hence the increased rate of dry-matter accumulation. At later stages when canopy deve-lopment is full and when it is optimal or superoptimal more of light would be benefitial as the limiting factor for the rate of photosynthesis per unit of leaf area.

The results of the present study also agree with the generally observed shade response of cocoa. Being in the early stages when the leaf area per plant was only upto 245.36cm^2 and when leaf number was below a maximum of 8.831 per plant the dominant limiting factor was probably leaf area. With advancing age and hence larger leaf area, there was a tendency towards a superiority of lower shade levels.

Even then, the above reasons do not explain why the seedlings in the open failed to survive beyond a period of three months even with most frequent irrigations (75% available water). There are however, indications in the reported literature that many leaves on top of the canopy even in established cocoa dry up in the open. Still this is not reported to cause death of the plant as the top most leaves, though gradually scorched, provide shade for lower layers which put out new flushes. In the early stages when the leaf number itself was suboptimal, such an auto-shading was probably not effective. Moreover the continued, comparatively high canopy temperature and soil temperature, might have also contributed to the early death of the plants in the open by way of suppressing further flushing and root development (Humphries, 1944; Greenwood and Posnetee, 1950 and Smith, 1964). Though leaf area was increasing with advancing age in all shade levels, LAR showed a decrease. This may be explained because of the increased production of photosynthates and its accumulation as dry matter. The open grown plants faced ~~with~~ a drastic reduction of about 182% LAR which was uncomparable with the trend in reduction of other treatments. Substantial reduction in leaf area and static dry matter accumulation with the stages of plant growth resulted in this drastic reduction of LAR in the open grown plants. (Okali and Owusu, 1975).

It may also be worthwhile arriving at a clue to the illumination intensity requirements of the crop for hormonal induction for leaf development. It may be noted that in early stages (upto two months) of growth, there were indications of parity between 25 and 50 p.c. shade and even superiority of the intense shade (75 p.c.) in some characters. With advancing age (from third month onwards) the medium shade of 50 - 55 p.c. proved to be consistently superior. This gives a vague indication that light intensity optimum for hormonal induction of leaf production is less than 50 p.c. full light.

The above explanation for the response of cocoa to varying shade intensities is suppported by the results of the present study in terms of all growth components excepting net assimilation rate. In the case of net assimilation rate (NAR) which is a measure of dry matter accumulation per unit of leaf area, the expected trend was that of a markedly higher NAR with increasing light intensities it being highest in the open. The reported results also support this (Hardy, 1958 and Baker and Hardwick, 1973). However, in the present study, the differences in NAR between shade intensities were not significant at any of the stages except between 3rd and 4th months. Even when it was significant, the results followed a reverse trend with the lowest shade level recording lowest values. Such an unusual trend contrary to the expected pattern and also contradicting the general trend reported in literature can be attributed to experimental error. Even so, the constant lack ofsuperiority of low shade intensities remains unjustified. If such a trend is real, it would then be against the validity of the hormonal inhibition theory of leaf production by Hardy (1958). It would then mean that there may be some other mechanisms that control vegetative and reproductive growth of cocoa differentially.

Canopy temperature and soil temperature may also have affected the seedling growth. Maximum monthly average canopy temperature (32.36°C) was recorded in the open. The monthly average was always higher than 30°C both in the open and at 25% shade level, while in the medium and heavy shaded treatment it varied between 28°C and 30°C. The soil temperature, both at 5 cm and 10 cm depths also increased with the increasing intensity of light with the maximum values being recorded in the open. This increased canopy temperature and soil temperature might have decreased the flushing and growth rate in the open and low shade level which resulted in the poor growth of seedlings. It has been reported (Wood, 1975) that constant temperatures beyond 30°C may lead to loss of apical dominance and result in production of smaller leaves.

Increased nitrogen content was noticed in plants grown under direct sunlight than in the shaded plants (Leach, 1969). Between the shaded plants, nitrogen content showed no significant difference at any stage of growth. Nitrogen content was increasing upto the third month and afterwards it showed a decrease in all the treatments except for the 25 - 30% shade level. Phosphorus and potassium contents were decreasing with stages of plant growth. As far as the total uptake of nutrients was concerned, medium shaded plants showed the maximum value and the open grown plants the least.

Decrease in nutrients content with the advancing age and increased growth is a usual trend in almost all the plants. This is due to dilution effect, a consequence of the differences in rates of nutrient uptake and carbohydrate synthesis. Hence the increased nitrogen content in the open grown plants can be explained to be the result of lower dry matter accumulation following poor growth when compared to the shaded plants. Even in the shaded plants nitrogen content was increasing upto the third month because of less dry matter accumulation, insufficient to project the dilution effect. Highest total uptake of all nutrients with 50 - 55% shaded plants can be attributed to the increased dry weight as a result of higher vegetative growth as previously explained, the percentage content of nutrients being almost the same. Though the percentage content of nutrients was more with the open grown plants, total uptake of all nutrients always stood remarkably lower than all other shaded plants because of the lower dry weight.

Like shade, irrigation also imparted significant influence on almost all the growth characters of cocoa seedlings. Irrigating at 75% available mosture (Wettest treatment) was always found better in all the growth characters studied and thereby producing the most vigrous and healthy seedlings. The other two levels behaved in succession though they were on par statistically in many of the characters. Many of the reported results also agree with the finding of the present investigation (Clore, 1937; Khachaturyan and Tokhadze, 1937; Alvim, 1960 and Ahenkorah and Akrofi, 1968). LAR showed an increase with the increase in availability of moisture but it was decreasing with the stages of growth. Irrigation effect on NAR was significant only between the third and fourth month although wetter treatments always showed slight increase except for the final stage of growth, where it showed a drastic reduction.

Increased growth rate, always associated with the wettest treatments can mainly be attributed to the increased water supply and nutrient uptake. It can, still more clearly be explained by quotting the work of Alvim (1960). He showed that the stomata of container grown cocoa plants started to close when the available moisture fell to 75 p.c. and closed rapidly as available moisture fell from 50 - 25 p.c. and thereby restricted the supply of carbondioxide for photosynthesis. So the increased growth rate associated with wettest treatment must be mainly because of the increased rate of photosynthesis and accumulation of photosynthetes. The validity of this theory becomes still more appreciable from the proportionately reduced growth rate and dry matter accumulation met with, as the availability of water falls from 50 p.c. to 25 p.c. Maximum dry weight was met within the wettest treatment with significant increase over the others except for the third month when the least and most frequently irrigated plants showed statistical parity. If the above explanation is true, this can only be an accidental deviation from the general trend. Though not statistically significant, the increased NAR with the increase in availability of moisture can also be well explained by the above theory. But towards the final stages of growth plants receiving irrigation at 75% and 50% available moisture met with a decrease in NAR, the least frequently irrigated plants showed an increase in NAR.

Effect of irrigation on the percentage content of nitrogen, phosphorus and potassium was not significant, presumably indicating that the supply of these nutrients was not limiting. Plants receiving the wettest treatment, ie. irrigation at 75% available moisture showed the highest total uptake of all the three nutrients always, followed by the other two treatment in succession presumably because of the reasons already explained.

Summary

SUMMARY

An experiment was conducted at the College of Horticulture, Vellanikkara to study the effect of shade and moisture levels on the growth of cocoa seedlings.

The growth characters, nutrient content and total uptake were studied and subjected to statistical analysis. Results of the experiments are summarised below:

1. Intermediate shade (50 - 55%) was found best for the better growth of cocoa seedlings With the advancing age of the plant the intense shade (75%), which appeared to be superior in the very early stages (upto two months), proved inferior to the intermediate shade level.

2. Death of all seedlings in the open was observed by the third month of investigation irrespective of the frequency of irrigation.

3. All the growth characters studied were improving with the increasing levels of shade upto the intermediate level of shade. Though for the initial two months 75% shade was superior to the medium level of shade in some aspects, towards the final stages, 50% shade was always

superior in all growth characters studied. This indicates that both intense as well as low shade levels are equally inefficient in producing healthy seedlings.

4. Leaf area ratio (LAR) was decreasing with the stages of growth in all levels of shade. Plants in the open faced with a drastic reduction of 182% in LAR which was uncomparable with the trend in reduction of other treatments.

5. Net assimilation rate (NAR) was decreasing with increase in illumination intensity as a contradiction to the expected trend and reported results.

6. Increased contents of nitrogen, phosphorus and potassium was noticed in plants grown under direct sunlight than in the shaded plants. Between the shaded plants the nutrient contents showed no significant differences. Towards the final stages of growth it showed a decrease in all the treatments because of dilution effect, a consequence of the differences in rates of nutrient uptake and carbohydrate synthesis.

7. Highest total uptake of all the nutrients was noticed in the plants shaded to 50 - 55% level.

8. Irrigation at 75% available water was always

found superior to the other two moisture regimes. Treatments with irrigation at 50 and 25 per cent available water were statistically at par.

9. All the growth characters except NAR showed an almost similar trend, with the wettest treatment being the best at all stages of growth.

10. Irrigation effect on NAR was significant only between the third and fourth months. But the wettest treatment always recorded slight superiority over others, except for the final stage.

11. Effect of irrigation on the percentage contents of nitrogen, phosphorus and potassium was not remarkable, presumably indicating that the supply of these nutrients was not limiting. Plants in the wettest treatment always showed the highest total uptake of the three nutrients.

12. Shading has influenced both the soil and canopy temperature the maximum values always being recorded in the open.

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*Original not referred

APPENDIX - I

Weather data (weekly averages) from December 1979 to April 1980

Month	Week	Temperature °C		Relative humidity (%)		Rainfall (mm)
		Maximum	Minimum	Maximum	Minimum	
December 1979	1st week	31.50	23.50	86.88	64.63	Nil
	2nd week	31.12	23.40	79.05	61.25	Nil
	3rd week	31.21	22.05	78.38	54.25	Nil
	4th week	30.52	22.20	74.71	51.00	Nil
January 1980	1st week	31.20	20.84	73.50	50.25	Nil
	2nd week	30.68	21.61	71.13	45.50	Nil
	3rd week	31.35	20.35	76.00	42.25	Nil
	4th week	32.04	20.29	81.29	40.29	Nil
February 1980	1st week	33.29	22.19	76.43	45.57	Nil
	2nd week	34.37	20.77	73.57	29.29	Nil
	3rd week	35.2	21.69	84.86	32.57	0.40
	4th week	36.44	22.24	90.13	30.88	Nil
March 1980	1st week	35.56	23.78	93.13	53.00	Nil
	2nd week	35.60	23.10	84.25	44.50	Nil
	3rd week	36.74	22.88	91.13	49.43	Nil
	4th week	36.00	24.23	81.57	53.00	0.045
April 1980	1st week	35.93	24.40	89.29	53.00	6.40
	2nd week	35.54	26.30	89.50	61.50	Nil
	3rd week	35.70	25.21	85.29	51.00	1.23
	4th week	35.10	25.19	89.63	57.26	9.38

APPENDIX - II

Mean interval between irrigations (days)

Treatments	December 1979	January 1980	February 1980	March 1980	April 1980
S_4 M_1	1.88	1.63	1.56	1.43	1.61
S_4 M_2	2.64	2.82	2.23	2.58	3.11
S_4 M_3	4.33	4.43	3.63	3.88	4.43
S_3 M_1	2.17	1.94	1.58	1.35	1.33
S_3 M_2	3.00	2.73	2.64	2.21	3.22
S_3 M_3	4.14	4.43	3.75	3.88	4.57
S_2 M_1	2.21	2.00	1.53	1.82	2.21
S_2 M_2	3.63	3.20	2.73	2.82	3.38
S_2 M_3	3.83	4.57	3.63	4.00	4.83
S_1 M_1	2.31	1.94	2.36	-	-
S_1 M_2	3.86	3.20	3.80	-	-
S_1 M_3	4.43	4.83	5.6	-	-

APPENDIX - III

Analysis of variance for plant height (cm)

Source	First month		Second month		Third month		Fourth month		Fifth month	
	D.F.	M.S.	D.F.	M.S.	D.F.	M.S.	D.F.	M.S.	D.F.	M.S.
Shade (S)	3	14.412*	3	40.225*	3	309.764*	2	157.718*	2	434.279*
Moisture (M)	2	2.554	2	3.150	2	17.588	2	156.144*	2	554.883*
S x M	6	1.285	6	1.580	6	4.512	4	19.002	4	27.027
Error	36	0.927	36	1.159	36	6.533	27	10.670	27	21.893

*Significant at 5 per cent level

APPENDIX - IV

Analysis of variance for stem thickness (cm)

Source	First month		Second month		Third month		Fourth month		Fifth month	
	D.F.	M.S.	D.F.	M.S.	D.F.	M.S.	D.F.	M.S.	D.F.	M.S.
Shade (S)	3	0.007*	3	0.045*	3	0.1369*	2	0.0211*	2	0.0517*
Moisture (M)	2	0.001	2	0.0014	2	0.0133*	2	0.0537*	2	0.1020*
S x M	6	0.0008	6	0.0008	6	0.0012	4	0.0015	4	0.0058
Error	36	0.0004	36	0.0007	36	0.0011	27	0.0018	27	0.0031

*Significant at 5 per cent level

APPENDIX - V

Analysis of variance for number of leaves

Source	First month D.F.	First month M.S.	Second month D.F.	Second month M.S.	Third month D.F.	Third month M.S.	Fourth month D.F.	Fourth month M.S.	Fifth month D.F.	Fifth month M.S.
Shade (S)	3	19.805*	3	180.322*	3	210.497*	2	103.028*	2	324.581*
Moisture (M)	2	3.682	2	1.875	2	15.008	2	134.414*	2	117.845*
S x M	6	1.535	6	0.989	6	3.939	4	3.569	4	11.954
Error	36	0.949	36	2.672	36	3.631	27	10,127	27	17.863

*Significant at 5 per cent level

APPENDIX - VI

Analysis of variance of leaf area (cm^2)

Source	First month D.F.	First month M.S.	Second month D.F.	Second month M.S.	Third month D.F.	Third month M.S.	Fourth month D.F.	Fourth month M.S.	Fifth month D.F.	Fifth month M.S.
Shade (S)	3	80453.45*	3	304239.00*	2	52155.30	2	1124703.88*	2	2083605.0*
Moisture (M)	2	7198.46*	2	19347.03*	2	254305.94*	2	1709109.98*	2	1763512.02*
S x M	6	985.15	6	4025.04	4	13837.03	4	52667.52	4	160077.80
Error	36	654.42	36	3324.77	27	12490.69	27	30093.47	27	79901.99

*Significant at 5 per cent level

APPENDIX - VII

Analysis of variance for dry weight (g)

Source	First month		Second month		Third month		Fourth month		Fifth month	
	D.F.	M.S.	D.F.	M.S.	D.F.	M.S.	D.F.	M.S.	D.F.	M.S.
Shade (S)	3	2.914*	3	7.371*	3	29.830*	2	33.443*	2	85.087*
Moisture (M)	2	0.186*	2	0.621*	2	4.189*	2	53.854*	2	106.347*
S x M	6	0.020	6	0.055	6	0.518	4	4.0376	4	3.881
Error	36	0.016	36	0.097	36	0.202	27	0.776	27	3.691

*Significant at 5 per cent level

APPENDIX - VIII

Analysis of variance for leaf area ratio (LAR) (cm^2/g)

Source	First month		Second month		Third month		Fourth month		Fifth month	
	D.F.	M.S.	D.F.	M.S.	D.F.	M.S.	D.F.	M.S.	D.F.	M.S.
Shade (S)	3	2382.356	3	32371.278*	2	716.529	2	2857.752	2	2661.880*
Moisture (M)	2	210.198	2	1648.244	2	2803.857*	2	4317.741*	2	567.723*
S x M	6	1865.399	6	897.695	4	328.870	4	705.864	4	341.120
Error	36	2334.973	36	1388.048	27	360.532	27	703.048	27	218.487

*Significant at 5 per cent level

APPENDIX - IX

Analysis of variance for net assimilation rate (NAR) (mg/dm^2/day)

Source	First and second month		Second and third month		Third and fourth month		Fourth and fifth month	
	D.F.	M.S.	D.F.	M.S.	D.F.	M.S.	D.F.	M.S.
Shade (S)	3	20.673	2	0.972	2	329.971*	2	23.341
Moisture (M)	2	2.261	2	17.723	2	120.388*	2	52.621
S x M	6	7.485	4	5.723	4	110.558	4	90.013
Error	36	11.889	27	17.573	27	45.549	27	92.102

*Significant at 5 per cent level

APPENDIX - X

Analysis of variance for nitrogen content (%)

Source	First month		Second month		Third month		Fourth month		Fifth month	
	D.F.	M.S.	D.F.	M.S.	D.F.	M.S.	D.F.	M.S.	D.F.	M.S.
Shade (S)	3	0.773*	3	0.083*	3	0.072	2	0.048	2	0.099
Moisture (M)	2	0.028	2	0.083	2	0.072	2	0.008	2	0.239*
S x M	6	0.013	6	0.008	6	0.059	4	0.015	4	0.031
Error	36	0.007	36	0.008	36	0.024	27	0.042	27	0.033

*Significant at 5 per cent level

APPENDIX - XI

Analysis of variance for nitrogen uptake (mg/plant)

Source	First month		Second month		Third month		Fourth month		Fifth month	
	D.F.	M.S.	D.F.	M.S.	D.F.	M.S.	D.F.	M.S.	D.F.	M.S.
Shade (S)	3	572.182*	3	1550.367*	3	14282.888*	2	13771.435*	2	24415.361*
Moisture (M)	2	62.639*	2	208.730*	2	1502.476*	2	22957.299*	2	24949.220*
S x M	6	9.754	6	17.734	6	209.166	4	306.857	4	474.273
Error	36	4.352	36	24.957	36	262.731	27	366.898	27	1082.993

*Significant at 5 per cent level

APPENDIX - XII

Analysis of variance for phosphorus content (%)

Source	First month		Second month		Third month		Fourth month		Fifth month	
	D.F.	M.S.	D.F.	M.S.	D.F.	M.S.	D.F.	M.S.	D.F.	M.S.
Shade (S)	3	0.029*	3	0.053*	3	0.013*	2	0.0004	2	0.0007
Moisture (M)	2	0.005*	2	0.0008	2	0.0005	2	0.0008	2	0.0003
S x M	6	0.001	6	0.0009	6	0.001	4	0.0002	4	0.00005
Error	36	0.0007	36	0.0007	36	0.0004	27	0.0003	27	0.0002

*Significant at 5 per cent level

APPENDIX - XIII

Analysis of variance for phosphorus uptake (mg/plant)

Source	First month		Second month		Third month		Fourth month		Fifth month	
	D.F.	M.S.	D.S.	M.S.	D.S.	M.S.	D.S.	M.S.	D.S.	M.S.
Shade (S)	3	6.889*	3	8.474*	3	47.425*	2	58.369*	2	74.576*
Moisture (M)	2	0.272	2	2.326*	2	13.409*	2	122.961*	2	50.585*
S x M	6	0.133	6	0.138	6	1.647	4	1.917	4	2.969
Error	36	0.096	36	0.242	36	0.552	27	1.675	27	4.479

*Significant at 5 per cent level

APPENDIX - XIV

Analysis of variance for potassium content (%)

Source	First month		Second month		Third month		Fourth month		Fifth month	
	D.F.	M.S.	D.F.	M.S.	D.F.	M.S.	D.F.	M.S.	D.S.	M.S.
Shade (S)	3	0.035	3	0.170*	3	1.065*	2	0.139*	2	0.389*
Moisture (M)	2	0.004	2	0.026	2	0.574	2	0.020	2	0.0006
S x M	6	0.040	6	0.007	6	0.047	4	0.013	4	0.009
Error	36	0.018	36	0.030	36	0.029	27	0.016	27	0.167

*Significant at 5 per cent level

APPENDIX - XV

Analysis of variance for potassium uptake (mg/plant)

Source	First month		Second month		Third month		Fourth month		Fifth month	
	D.F.	M.S.	D.F.	M.S.	D.F.	M.S.	D.F.	M.S.	D.F.	M.S.
Shade (S)	3	1337.045*	3	3510.499*	3	10930.691*	2	7625.018*	2	15981.626*
Moisture (M)	2	107.956*	2	442.739*	2	1442.202*	2	20862.955*	2	28501.259*
S x M	6	9.188	6	38.534	6	150.400	4	148.012	4	702.943
Error	36	8.778	36	53.761	36	110.645	27	244.427	27	820.785

*Significant at 5 per cent level

EFFECT OF SHADE AND MOISTURE REGIMES ON THE GROWTH OF COCOA (*Theobroma cacao* L.) SEEDLINGS

BY
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ABSTRACT OF A THES

Submitted in partial fulfilment of the
requirement for the degree

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Department of Agronomy
COLLEGE OF HORTICULTURE
VELLANIKKARA - TRICHUR

1981

ABSTRACT

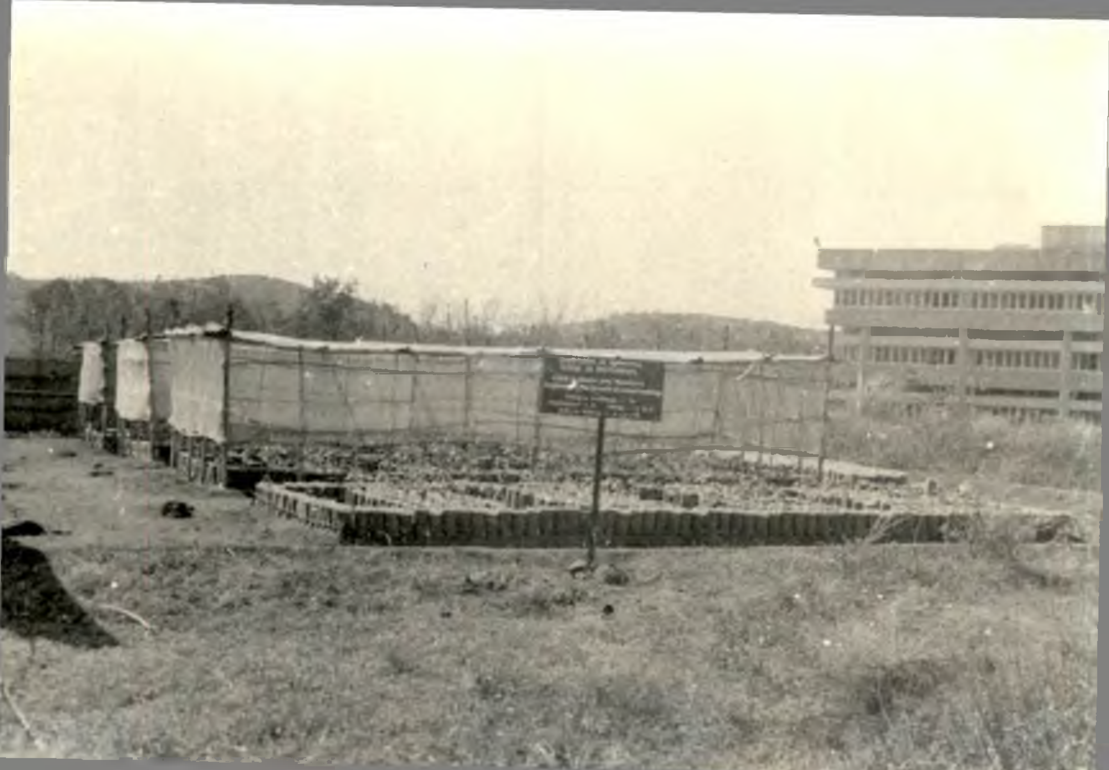
An experiment was conducted at the College of Horticulture, Vellanikkara during 1979-80 on the effect of shade and moisture regimes on the growth of cocoa (Theobroma cacao L.) seedlings.

The investigations were carried out to arrive at the optimum shade and moisture requirement for the growth of cocoa seedlings.

The experiment was laid out in a completely randomised design with four levels of shade and three levels of moisture with four replications.

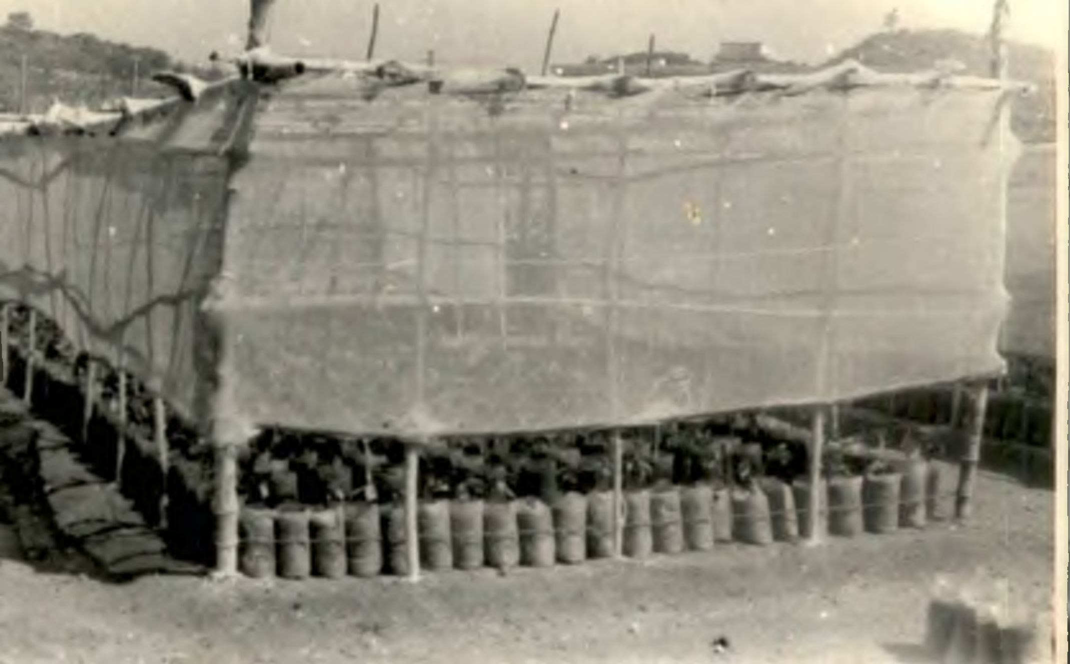
The study revealed that cocoa seedlings must be shaded and well watered for their better growth. 50 - 55% shade and irrigation at 75% available moisture was found best. Death of all the seedlings in the open by the third month of observation stresses that, cocoa seedlings cannot be grown without any shade irrespective of the frequency of irrigation. Except net assimilation rate (NAR) and leaf area ratio (LAR) all the growth characters were increasing with increasing shade (upto 50 - 55%) and increasing frequencies of irrigation.

A general view of the site



Plants with no shade

25 - 30% shade being provided by 'calicloth' mosquito net



50 - 55% shade being provided by a type of handloom cloth