SHADE RESPONSE OF COMMON RAINFED INTERCROPS OF COCONUT

BY

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THESIS

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DECLARATION

I hereby declare that this thesis entitled the "Shade response of common rainfed intercrops of coconut" is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award of to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

Vellanikkara,
3rd October 1981.

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Certified that this thesis entitled the "Shade response of common rainfed intercrops of coconut" is a record of research work done independently by Kum. Lalitha Bai, E.K. under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to her.

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CERTIFICATE

We, the undersigned, members of the Advisory Committee of Kum. Lalitha Bai, E.K., a candidate for the degree of Master of Science in Agriculture with major in Agronomy, agree that the thesis entitled the "Shade response of common rainfed intercrops of coconut" may be submitted by Kum. Lalitha Bai, E.K. in partial fulfilment of the requirement for the degree.

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INTRODUCTION

Research on multiple cropping in coconut garden was taken up only since 1970, though the practice of cultivating crops in the interspaces of coconut had been a common practice in Kerala. Early studies conducted mainly at the Central Plantation Crops Research Institute, Kasaragode, have indicated that there is enough scope for intensifying cropping in coconut gardens especially as the coconut roots actively exploit only about 20 per cent of the land area. However, success of this sort of inter and mixed cropping had been highly variable. It has been discerned that such differences in the success of crop combination arise mainly out of differences in the competition between crops for the three basic inputs of production viz. light, water and nutrients. The competition for these factors is reflected both in terms of a decrease in yield of the main crop because of competition for water and nutrient and also in terms of poor performance of associated crop mainly due to competition for light.

Preliminary studies conducted at the Central Plantation Crops Research Institute have indicated that the amount of light that filters through the coconut canopy is markedly affected by the age of coconut palm. It has been estimated that the light infiltration can range from as low as 10 per cent to as much as 70 per cent depending upon age of the palm in a space - planted coconut plantation. Based on this indication, the general recommendation had been that multiple cropping in coconut garden can be taken up before the 10th year and after 20th year of planting. Even so, the illumination intensity in the interspace of coconut still shows wide variations from about 20 to 70 per cent. With the idea of getting reasonable and profitable returns from the associated crop, the general recommendation again can be to grow shade-loving and shade-tolerant plants in situations of higher shade intensity. It was in this context of selecting crops that would be suitable for intercropping in various shade situations that the present study was taken up. Though such studies on the shade response of some crops have been reported, no work on these lines has been done in tropical crops that could be cultivated along with coconut.

The primary objectives of the present study were:

1) To study the yield response of common rainfed intercrops of coconut under varying intensities of shade.

ii) To select crops suitable for different intensities of shade and to predict their yields under varying shade situations.

iii) To categorise crops as shade-loving, shade-tolerant, shade-intolerant and shade-sensitive.

iv) To study the nutrient removal of crops under shade so that it could be used as a tool for tentatively arriving at fertilizer schedules for these crops under shade.

REVIEW OF LITERATURE

Research work on the response of crops to varying intensities of shade is relatively scanty especially in the case of tropical crops that are commonly cultivated as intercrops of perennial crops. The literature available on this aspect on the common agriculturally important crops is reviewed in this chapter. The shade levels tried in each of these experiments apparently had been highly variable and these had not been mentioned in many of the reports. Wherever the shade levels are mentioned, these are included in the review. Where these are not available, the overall effects of shade (irrespective of its intensity) are only presented.

The review is given classifying the effect of shade on the following characters with a brief summary of the general trend of reported results under each.

1. Plant height

The reported results indicate that the response to shade on plant height may be positive as in tobacco, ginger and cowpea or negative as in grain sorghum or positive, negative or neutral as in tomato.

Panikar et al. (1969) noticed that in tobacco plant height increased by 35.2 per cent under shade as compared to unshaded plants. Aclan and Quisumbing (1976) observed that in the case of ginger, plants grown under the full sunlight were shorter than those in the shade. Tarila et al. (1977) reported that in cowpea, higher light intensity reduced plant height.

The height of grain sorghum plants was found to decrease with increasing levels of shade from 0 to 50 per cent (Palis and Bustrillos, 1976).

Cooper (1969) observed in the case of tomato that shading either decreased or had no effect on mean stem extension rate. It was also noticed that the effect of shade on plant height was either positive, negative or neutral depending on the time of year and age of the plant.

2. Number of branches

The response to shade on number of branches produced per plant is negative as reported in peaches, clover, cowpea and many other plants.

Duggar (1903) elucidated that plants under shaded conditions exhibited reduced number of branches. Under shade, the peach plants produced only lesser number of branches which were willowy and slender (Gourley, 1920). Beinhart (1963) concluded that increased light intensity resulted in increased branching in white clover. Tarila et al. (1977) reported that in cowpea, higher light intensity increased branching of the plants.

3. Nodulation in legumes

Effect of shade on nodulation in legumes is generally adverse. However, increases in nodulation consequent to increased illumination had been reported to adversely affect nodule activity and size.

Light intensity had been shown to affect growth, nodulation and symbiotic nitrogen fixation in legumes (Gibson, 1971; Bethlenfalvay and Phillips, 1977; Wahua and Miller, 1978) and this was related to the photosynthate supply to nodules (Allison, 1935; Wilson, 1935; Hardy and Havelka, 1975 and Latimore et al., 1977). Nodulation of alfalfa had been observed essentially to stop at light intensities of less than 257 foot candles (Pritchett and Nelson, 1951). Rabie and Kumazawa (1979) reported that in soybeans, size and number of nodules decreased by shading. However, in natural light, the highest values of nodule size corresponded to lower nodule numbers. Effect of shade on soybean was studied by Trang and Giddens (1980) at four shade intensities (0, 18, 40 and 62 per cent) and they reported that the plants with no shade produced higher nodule mass and number than those under shade. However, total nodule activity (acetylene reduction assay) was greatest at 18 per cent shading. Wong and Wilson (1980) observed reduced nodulation of Macroptilium atropurpureum cv. Siratro under shade.

4. Leaf development

The reported results on the response to shade on leaf development generally indicated increased leaf expansion and decreased leaf thickness with shading. In the case of total leaf area, there were decreases in some plants whereas in apple and tomato, there were increases because of shading. The results on vegetative growth were variable, it generally decreasing with shading. In the case of tomato, the reports indicate enhanced vegetative growth because of shading.

Rolfs (1903) reported that citrus plants which were grown under 50 per cent shade developed thinner leaves with a greater leaf area; however, the total leaf area per plant was less. 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 in smaller and thicker leaves. Gourley (1920) reported that in apples, shading resulted in the production of loosely packed mesophyll tissues and thinner epidermal cells in leaves and in increased leaf area. Increased leaf area consequent to shading had also been reported by Porter (1937) in tomato plants. Hardy (1958) studied the nature of leaves of cocoa seedlings under varying intensities of shade and observed that leaves produced under heavy shade were much larger, often attained a length of 20 to 24 inches and were thinner, heavier and contained higher proportion of water. In general, the leaves of shaded plants were thinner showing poor development of palisade tissue and spongy-mesophyll cell (Boardman, 1977).

Citrus plants grown under 50 per cent shade developed considerably less total leaf area per plant (Rolfs, 1903). Beinhart (1963) reported that increased light intensity resulted in greater leaf area in clover though the mean number of leaves produced per plant remained non-significant. Panikar et al. (1969) observed that in tobacco, length and breadth of leaves were increased by 15.1 and 17.6 per cent, respectively, under shade as compared to unshaded plants. From the trial on the effects of shade on the growth and photosynthetic capacity of the exotic noxious weed itchgrass (Rottboellia exaltata L.f.) Patterson (1979) stated that leaf area production was not severely retarded by shading; the plants grown at 2, 25 and 60 per cent sunlight had respectively, 1.7, 42 and 99 per cent of the leaf area of the plants grown at 100 per cent sunlight. In another experiment with three ecotypes of cogon grass (Imperata cylindrica) grown under three light intensities, viz., 100, 56 and 11 per cent of full sunlight, Patterson (1980) reported that after 89 days, the plants of all the ecotypes produced, on an average, three times as much leaf area in full sunlight as in 56 per cent full light and 20 times as much as in 11 per cent full light. In a 30-year old Trinitario cocoa plantation, Boyer (1970) observed that the flushing intensity, leaf number and total foliar surface per tree were greater in unshaded trees than those under light or moderate shade. Tarila et al. (1977) reported that in cowpea, higher light intensity improved leaf area and plant size. Radha (1979) observed that number of leaves in pineapple was not influenced by shading.

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 and observed that with decrease in light intensity, there was increased vegetative growth as measured by both fresh and dry weight.

5. Chlorophyll content

Most of the reported evidences show that the concentration of chlorophyll per unit weight of leaf increases with shading as reported in the case of plants like cocoa, tea, strawberry, bean, alfalfa, birdsfoot trefoil, etc. But the chloroplast content per unit leaf surface has been found to decrease with shading as in alfalfa, birdsfoot trefoil and in some other plants. In crops like cowpea, wheat etc., increasing shade intensities have been found to decrease the chlorophyll content per unit leaf weight. Changes in the position of chloroplast according to the differences in light intensity have also been reported.

Clark (1905) observed that in the case of strawberry, direct sunlight of high intensity resulted in the destruction of chlorophyll. Increased chlorophyll content was noticed in the leaves of shaded cocoa plants (Evans and Murray, 1953; Guers, 1971). Similar observations were made by Ramaswami (1960) and Venkatamani (1961) in the case of tea. Khossien (1970) noticed reduction in the leaf pigment at high intensity of light in the case of bean plants. Radha (1979) observed that chlorophyll 'a', 'b' and total chlorophyll contents of leaves were found to increase as the intensity of shade increased in pineapple. Okali and Owusu (1975) noticed that, in cocoa plants, the chlorophyll content per unit leaf fresh weight was significantly greater in deep shade. Chlorophyll content per unit weight of leaf was found to increase in the case of plants grown at lower light intensities, but the chlorophyll content per unit area of leaf surface was very often lower than the plants grown in open (Bjorkman and Holmgren, 1963). Similar observations were obtained by Cooper and Qualls (1967) in the case of alfalfa and birdsfoot trefoil.

Contrary to the above reports, in the case of cowpea, Higazy et al. (1975) observed that the concentration of total chlorophyll as well as its components 'a' and 'b' decreased by increasing shade intensity. In wheat, Moursi et al. (1976a) observed that all pigments decreased significantly with increasing shade intensities viz., 100, 60, 40 or 20 per cent full sunlight; but the ratio of chlorophyll a:b remained constant at all shade intensities.

While discussing the biology of living chloroplast, Priestly (1929) stated that the chloroplasts in leaves would undergo changes in position according to the differences in light intensity. It was 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.

6. Stomatal frequency and stomatal opening

In plants like cocoa, alfalfa, birdsfoot trefoil etc. response to shade on the number of stomata per unit area of leaf has been reported to be negative. It has also been observed that the light intensity at which stomata starts to open and close in plants is something which is highly variable between crops; there are specific threshold values of light intensity, for each of the crops at which stomata start to open and close. For example, in the case of cocoa, the stomata start closing whenever light intensity falls below 500 to 700 foot candles and remain fully open at intense and direct illumination, whereas in coffee, the stomata remain partially close whenever the light intensity exceeded 8000 to 8500 foot candles.

Hardy (1953) observed that in the case of cocoa, the leaves produced under shade had less number of stomata per unit area, as the epidermal cells in the leaves were longer. Cooper and Qualls (1967) observed that alfalfa (Medicago sativa L.) and 'Tana' birdsfoot trefoil (Lotus corniculatus L.) had more stomata per unit area of leaf when grown in the shade. Number of palisade and mesophyll cells and the cell volume appeared greatest in leaves exposed to sun and palisade layer was more clearly differentiated. 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.

Hardy (1958) differed on the possibility of cocoa being a shade-loving plant and reported the following results. 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 water supply was plentiful. As against this, the stomata of coffee leaves were reported to partially close whenever the intensity of illumination exceeded 8,000 to 8,500 foot 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 to 700 foot candles, which was about 5 per cent of the full sunlight. It was also observed that under ordinary circumstances, the stomata began to open at about 6 AM and maintained their maximum size between 8 AM and 4 or 5 PM, after which time it started closing because of diminishing light intensity.

7. Photosynthesis and dry matter accumulation

Photosynthesis and dry matter accumulation have been reported to be adversely affected by shading in many of the plants, while in the case of ginger positive influence was reported. The extent of decline in dry matter accumulation was however, varying between plants. In the case of pineapple, there was no appreciable decrease in dry matter accumulation even upto 75 per cent shading.

Singh (1967) reported that exposure of ginger to intense light is detrimental to photosynthesis. According to Minoru and Hori (1969) Zingiber mioga, Rosc. requires a saturating light intensity of 200 kilolux. In the trial on potted arabica coffee seedlings shaded to provide 25, 50 or 75 per cent light, Silveira and Maestri (1973) found that the best growth (as measured by dry matter production) was with 50 per cent light. Radha (1979) noticed comparable dry matter accumulation in the leaves of pineapple both in shade and in the open upto flowering stage. It was also seen that the reduction in total dry matter accumulation was not considerable in spite of shading upto 75 per cent. Wong and Wilson (1980), from the studies on the effect of shading to 100, 60 and 40 per cent of full sunlight on the growth of green-panic grass and siratro in pure and mixed swards defoliated at 4 weeks and 8 weeks stage reported that individual leaves of shaded green-panic had greater photosynthetic activity than those from full sunlight.

It was reported by Duggar (1903) that shading either partially or completely reduced the carbondioxide assimilation and thereby the available constructive materials for plants. In tomato plants, Porter (1937) observed that total amount of photosynthates decreased with decrease in light intensity. Benedict (1941) reported that plants of Agropyron cristatum, A. smithii and Bouteloua gracilis grown in shade had smaller dry weight. Myhr and Saebo (1969) from the trial on the effects of shade on growth, development and chemical composition in some grass species observed that shading greatly reduced dry matter yields particularly in Festuca rubra, Lolium perenne and Phleum pratense. Agrostis tenuis, Poa palustris and Poa trivialis were the least affected. It was also observed that heading was retarded and decreased by shading particularly in Phleum pratense. At high light intensities, photosynthetic rate per unit chlorophyll in the case of cocoa was found to be highest for leaves in the open which suggested that photosynthetic efficiency was increased by growth in full day light (Baker and Hardwick, 1973). Mourai et al. (1976b) found that the efficiency of solar energy conversion in wheat decreased with increasing shade (100 to 20 per cent full sunlight) from 1.44 to 0.37. In the case of grain sorghum plants subjected to 0, 25 or 50 per cent shade, it was found that total dry matter decreased with increase in shade (Palis and Bustrillos, 1976). The effects of shade on the growth and photosynthetic capacity of the exotic noxious weed itchgrass was studied by Patterson (1979). It was found that shading markedly reduced dry matter production and that at 40 days after planting, plants grown in 2, 25 and 60 per cent sunlight had 0.3, 16 and 55 per cent, respectively, of the dry weight of the plants grown at 100 per cent sunlight. In shade experiments with cogon grass, Patterson (1980) observed that after 89 days, the plants of three ecotypes produced on an average three times as much total dry weight in full available sunlight as in 56 per cent full light and 20 times as much as in 11 per cent full light. The plants from the shaded and exposed habitats generally did not differ significantly in their responses to shading. Wong and Wilson (1980) reported that leaves of shade-grown Siratro had a lower photosynthetic potential than in the full sunlight treatment.

8. Growth analysis

Review of work done indicates that effect of shade on leaf area index (LAI) of plants varied widely. In the case of green-panic, the response was positive, while in siratro, it was negative. In cocoa, net assimilation rate (NAR) was not influenced by shade in one of the experiments whereas in another, decrease in NAR with increasing shade was reported. Also, a negative response to shade on NAR in wheat had been reported. In cocoa, relative growth rate (RGR) has been positively influenced by shading, while leaf area ratio (LAR) showed a negative relationship.

Wong and Wilson (1980) observed an increased LAI in shaded green-panic swards and a decreased LAI in shaded siratro. When a crop of grain sorghum was subjected to 0, 25 or 50 per cent shade, the LAI was found to decrease with increase in shade (Palis and Bustrillos, 1976).

Hardy (1958) observed lowest NAR at highest shade level and vice-versa in cocoa. In the case of cocoa seedlings, Gopinathan (1981) observed that, NAR was not influenced by increase in shade intensity ranging from 25 to 75 per cent. Moursi et al. (1976b) found that the NAR of wheat decreased with increasing shade intensities from 5.7 to 3.2 and from 11.9 to 0.8 g m^{-2} day^{-1} at 80 to 95 and 95 to 100 days respectively when the light intensity was brought down from 100 to 20 per cent full sunlight.

From the studies on light and fertilizer requirements of cocoa, Evans and Murray (1953) recorded greatest RGR at a light intensity between 30 to 60 per cent of full day light. Okali and Owusu (1975) observed that RGR was maximal for cocoa plants grown under medium shade.

Cooper and Qualls (1967) noticed that the increase in the ratio of leaf area to leaf weight which occurs due to shading of legume (alfalfa and birdsfoot trefoil) was associated with changes in leaf morphology.

9. Yield and yield attributes

The general effect of shade on final yield of crops was that of a decrease in the case of apple, peaches, sorghum, soybean, cowpea and cocoa. Reports of increases in yield consequent to shading were noted in cocoa, tomato, tea and green-panic. In the case of ginger, reduction in yield was reported only at very intense shades.

Edmond et al. (1964) conducted shade experiments in tomatoes and maximum yield was obtained from plants receiving only 45 per cent of full sunlight. Joseph (1979) reported that the tea clones under shade gave much higher yield than in exposed plots. Wong and Wilson (1980) from the studies on the effect of illumination at 100, 60 and 40 per cent of sunlight on the growth of siratro and green-panic in pure and 50:50 mixture swards, defoliated every

4 (D_4) or 8 (D_8) weeks, observed that shading to 60 and 40 per cent of full sunlight increased the shoot yield of green-panic in pure sward by 30 and 27 per cent, respectively in the D_8, but reduced it in the D_4 treatment by three and 14 per cent.

Kraybill (1922) observed decreased fruit bud formation in apple and peaches under shade. Freeman (1929) in the earliest recorded field experiment to determine the optimum degree of shade for cocoa reported that lightly shaded cocoa gave higher yield than those under intence shade. The number of flowers per tree was found to be 60 to 70 per cent more in cocoa under moderately shaded trees than in unshaded trees (Boyer, 1974). In the case of tomato, Porter (1937) observed a decrease in fruit production with the decrease in light intensity. In shading experiments with tomato in which the light intensity was lowered to 50 or 25 per cent of that of the controls, Sakiyama (1968) noticed that the greater the shading, the lower was the fruit weight. Boneta Garcia and Bosque Lugo (1973) observed that more yield was obtained when coffee was grown in full sunlight than when grown in partial shade (40 per cent). Buttrose (1974) observed a decrease in the number of flower bud initiated in shaded cocoa compared to unshaded cocoa. Gramen (1974) observed that decreasing the amount of photosynthetically active radiation by 40 to 60 per cent by shading in bean (Vicia faba) plants resulted in decreased production of flowers, though it decreased the shedding of young pods. Experiments with wheat at shade intensities ranging from 20 to 100 per cent full light showed that increase in shade intensity decreased the number of tillers and spikes, dry weight, fruiting efficiency, grain weight per plant and yield of grain and straw (Moursi et al., 1976c). Aono et al. (1976) observed that shading tea bushes to about 45 per cent light intensity with cloth screen about 60 cm above the plucking table depressed new shoot growth and yield. It was also found that the shade intensity was inversely related to yield and this decrease in yield was highest during the first plucking season. Palis and Bustrillos (1976) found that, in sorghum, grain yield and grain-straw ratio decreased with increase in shading ranging from 0 to 50 per cent. Huang (1977) in a trial in which rice plants were grown with or without 90 per cent shading observed that shading decreased spikelet number per panicle by 54 per cent giving a higher proportion of degenerated spikelets. Tarila et al. (1977) reported that in cowpea high light intensity delayed flowering, but increased blossom and pod numbers and improved seed yield. Wahua and Miller (1978) observed that seed yields of soybean plants shaded to reduce sunlight by 20, 47, 63, 80 and 93 per cent were 90, 75,48, 18 and 2 per cent, respectively, of that obtained from unshaded plants. They also found that number of pods per plant and seed yield were highly and negatively correlated with shade. Venkateswarlu and Srinivasan (1978) conducted a trial to study the influence of low light intensities on rice and observed that yield loss was greatest with continual shading at 40 to 50 per cent of natural light.

In the case of wheat, reduction in grain yield due to increasing shade was curvilinearly related to radiation such that small reduction had little effect on yield at any developmental stage (Fisher, 1975). Aclan and Quisumbing (1976) reported that yield of ginger under full sunlight was just as high as those obtained under 25 and 50 per cent light attenuation. When light attenuation was over 50 per cent, the yield decreased. Radha (1979) observed that the fruit weight of pineapple with crown was not influenced by shading. But the contribution of crowns to the fruit weight increased as the intensity of shade increased. Consequently, there was a reduction in fruit weight without crown. It was also observed that shading above 25 per cent was beneficial to the extent of reducing peel and core weight of the fruits.

10. Quality of produce

The response to shade on the quality of produce varies widely. In general, protein content increases and carbohydrate content decreases with shading.

Myhr and Saebo (1969) observed that in some grass species, the crude ash and protein contents were approximately doubled by shading to 10 to 15 per cent of the intensity of natural light whereas the sugar contents approximately halved; and serious lodging occurred as a result of reduction in fibre content. Shading was found to increase the concentration of total soluble and protein nitrogen in the grain tissue when 20 to 100 per cent full light was tried on wheat (Moursi et al., 1976c). Palis and Bustrillos (1976) observed in the case of grain sorghum plants subjected to 0, 25 or 50 per cent shade that protein increased while carbohydrate decreased with decrease in light. Aclan and Quisumbing (1976), in the case of ginger recorded lowest starch content in rhizomes from the plants grown under 75 per cent shade. In an experiment where soybean plants were shaded at the four-trifoliate leaf stage to reduce sunlight by 20, 47, 63, 80 and 93 per cent, it was seen that shade had little effect on oil and protein contents of seed except that protein content was highest and oil content lowest at 93 per cent shade (Wahua and Miller, 1978).

Hwang (1968) reported that shading pineapple after flowering gave higher grade fruits than unshaded; the unshaded fruit suffered from sunburn and gave lower canning ratios than the shaded treatment due to sun scorch. Radha (1979) observed that quality of fruits in general decreased in pineapple under shaded conditions. While the acidity of fruits increased, there was a general reduction in sugar and ascorbic acid contents.

Aono et al. (1976) found that shading tea bushes to about 45 per cent light intensity with cloth screens about 60 cm above the plucking table, improved the green tea quality. It was noticed that the quality was directly related to the shade intensity and this increase in quality was the greatest in the first plucking season.

11. Nutrient content

In general, the mineral nutrient status of plants has been found to improve under shading as in the case of apple, cocoa, spinach and tea. In the case of soybean, on the contrary, nitrogen content was found to be positively related to illumination levels. Also, adverse effect of shade on nutrient content has been reported in siratro. cocoa seedlings and pineapple.

Myhr and Saebo (1969) found that potassium contents were approximately doubled by shading some grass species to 10 to 15 per cent of the intensity of natural light. Phosphorus, calcium and magnesium contents also increased under shading. Kraybill (1922) observed higher contents of moisture and nitrogen in shaded apple leaves. Guers (1971) reported that cocoa leaves exposed to direct sunlight contained less moisture and nitrogen than shaded leaves. American Holly plant exhibited higher amounts of potassium and magnesium in leaf tissues when the plants were grown at 92 per cent shade (Fretz and Dunham, 1971). Cantliffe (1972) observed in spinach that the concentration of potassium in the tissue increased with reduction in the light intensity. Dracaena sanderiana plants grown at five shade intensities were analysed for foliar nitrogen, phosphorus, potassium, calcium and magnesium and it was found that the different shades had little effect on the leaf nutrient content except that high shade intensity increased potassium and magnesium especially in young leaves (Rodrigues et al., 1973). Radha (1979) observed that the uptake pattern of major nutrients in pineapple was not greatly influenced by shading. It was also noticed that shading increased the magnesium content of leaves at all stages of growth and nitrogen content at later stages of growth. Oladokun (1980) reported that in the case of coffee, shade significantly affected plant nitrogen, phosphorus and potassium contents. According to, Wong and Wilson (1980), nitrogen accumulation in all the plant components of green-panic was markedly improved by shading.

Wahua and Miller (1978) in their trial on soybean with shade levels of 20, 47, 63, 80 or 93 per cent observed that total leaf and stem nitrogen contents were highly and negatively correlated with shade. Wong and Wilson (1980) observed that the nitrogen yield of siratro in pure sward declined with shading. Trang and Giddens (1980) concluded from their shade experiment that soybean plants without shade had higher nitrogen content. In the case of cocoa seedlings, Gopinathan (1981) noticed higher percentage of nitrogen, phosphorus and potassium in plants grown under direct sunlight than in the shaded plants. However, between the plants exposed to different shade intensities, the nutrient contents showed no significant differences.

12. General growth of plants

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 as general effects of shading on plant growth.

Evans (1951) described a shade experiment in which cocoa was grown under different artificial shade levels, viz. 15, 25, 50, 75 and 100 per cent day light. Results during the first year showed that cocoa made the best growth at 25 to 50 per cent sunlight but plants receiving 50 per cent light 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 of nitrogen fertilizer became more apparent. The result of a shade and fertilizer experiment on cocoa conducted in Trinidad showed that 50 per cent shade gave the greatest early growth and highest initial yields of cocoa (Murray, 1953). 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 appeared to be between 25 and 60 per cent and intensities above 75 per cent retarded the growth. There was some indication that the optimum light intensity increased with size of the plant and consequent self-shading. Optimum growth of cocoa seedlings was attained in shade rather than in full day light (Goodall, 1955; Hurd and Cunningham, 1961; Asomaning and Kwakwa, 1965). The most favourable light intensity for cocoa seedlings had been stated to be about 25 per cent of full sunlight (Hardy, 1958). It was also stated that the amount of light may gradually be 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.

Contrary to the above reports, Cunningham and Burridge (1960) stressed that high rates of growth may be attained by cocoa seedlings in full day light provided fertilizer is applied to the soil, precautions are taken to maintain a favourable water balance and to minimise damage by wind and insect pests. It was also observed that in particular circumstances, shade may be beneficial in limiting insect pest damage, and suppressing weed growth. Fisher (1975) found that shading always reduced growth of wheat plants approximately in direct proportion to the reduction in radiation. Gopinathan (1981) observed that intermediate shade (50 to 55 per cent) was best for the better growth of cocoa seedlings; with the advancing age of the plant, the intense shade (75 per cent) which appeared to be superior in the very early stages (upto two months) proved inferior to the intermediate shade level of 50 to 55 per cent.

MATERIALS AND METHODS

MATERIALS AND METHODS

A field experiment was conducted to investigate the shade response of common rainfed intercrops of coconut *viz.* sweet potato (*Ipomoea batatas* (L.) Lam.), coleus (*Coleus parviflorus* Benth.), colocasia (*Colocasia esculenta* (L.) Schott), turmeric (*Curcuma longa* L.) and ginger (*Zingiber officinale* Rosc.) under different intensities of shade, during the year 1980-81.

The experiment was carried out at the College of Horticulture, Vellanikkara, Trichur, Kerala, India, which is situated at 10° 32'N latitude and 76° 10'E longitude at an altitude of 22.25 meters above mean sea level.

Cropping history of the field

The area was left fallow during the previous four to five years and was under rubber prior to it.

Soil

The soil of the experimental site was deep well-drained sandy clay loam. The data on the physical and chemical properties of the soil are given in Table 1.

Season and climate

The experiment was conducted during the period

Table 1. Mechanical composition and chemical properties of the soil

A. Mechanical composition

Coarse sand	: 26.00 per cent
Fine sand	: 23.10 per cent
Silt	: 21.20 per cent
Clay	: 29.70 per cent

B. Chemical properties

Constituent	Content	Rating	Method used for estimation
Total nitrogen	0.072 per cent	medium	MicroKjeldahl (Jackson, 1958)
Available phosphorus (Bray-I extract)	1.827 ppm	low	Chlorostannous reduced molybdo-phosphoric blue colour method (Jackson, 1958)
Available potassium (Neutral normal ammonium acetate extract)	143.60 ppm	high	Flame Photometric (Jackson, 1958)
pH (1:2.5 soil:water ratio)	4.5		pH meter (Jackson, 1958)

May 1980 to January 1981. Among the five crops grown, turmeric, colocasia and ginger were planted on 27th, 28th and 30th of May 1980. Sweet potato and coleus were planted on 21st and 23rd June 1980. Individual crops were harvested at the end of the maturity periods of the respective crops. Thus sweet potato, coleus, colocasia, turmeric and ginger were harvested 110, 125, 180, 220 and 225 days after planting or sprouting, respectively.

The meteorological data for the crop periods are presented in Appendix 1. The area has a humid tropical climate. The weekly average daily range in meteorological parameters relating to individual crops are given in Appendix 2. Turmeric and ginger crops underwent a drought period of about two and a half months at the later stages of growth. Coleus and colocasia had a short period of drought for about 15 and 25 days, respectively, at the later period of the crop growth, which was congenial for the proper maturity of the crops.

The climate as a whole was suitable for the normal growth of all the crops tried.

Materials

Seeds

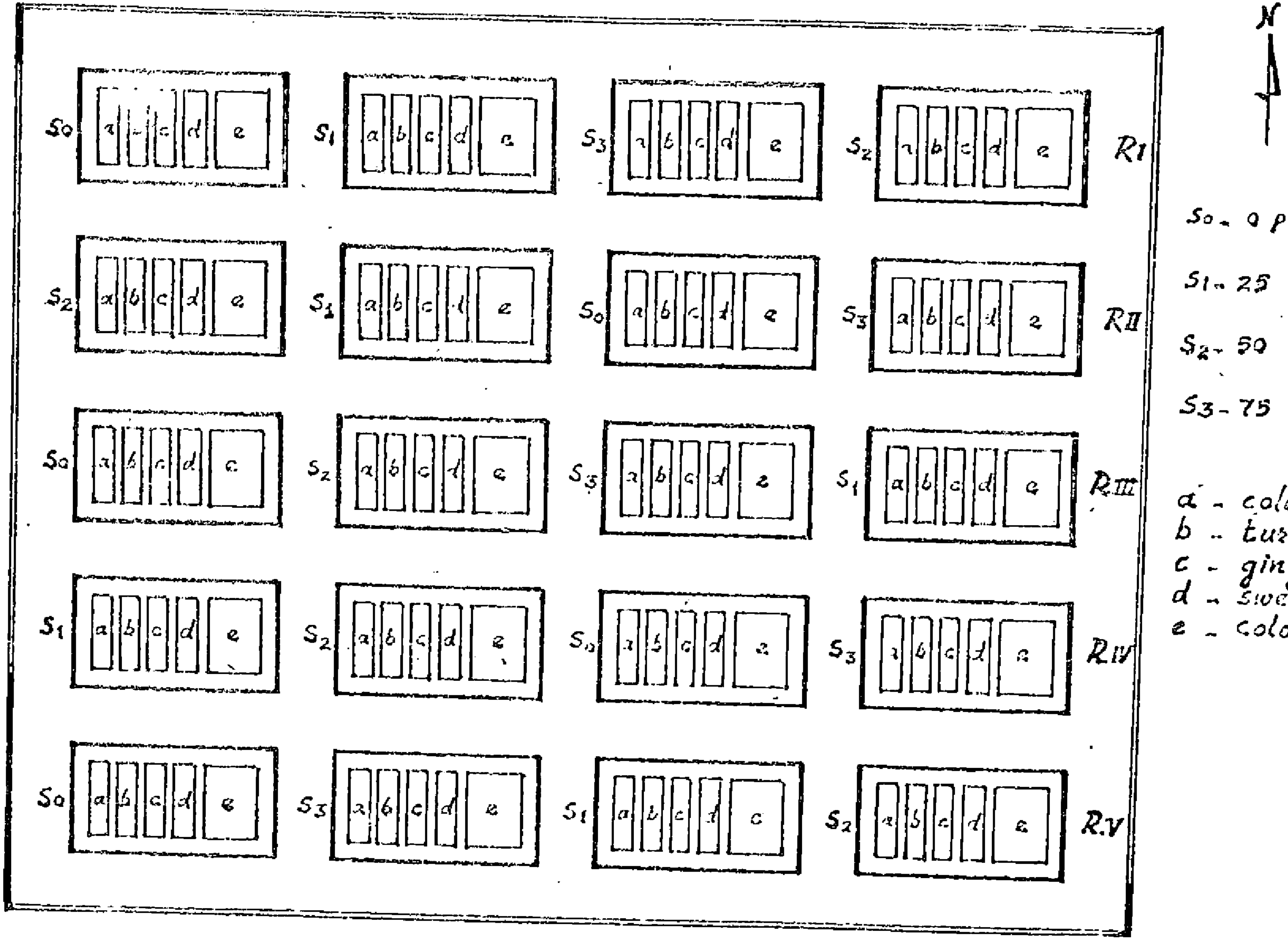
Local varieties of sweet potato, coleus and colocasia, 'Kasthuri thanak' variety of turmeric and 'Juggijan' variety of ginger were used for the trial.

In the case of sweet potato, 45 days old 20 to 25 cm long vine cuttings were planted on ridges 60 cm apart, at a distance of 20 cm between cuttings in 4 m x 1.2 m area. One month old coleus slips (10 to 12 cm long) were planted on raised beds of size 4 m x 1 m at a spacing of 15 cm x 15 cm. Colocasia side tubers, each weighing 40 to 45 g were planted on the ridges 60 cm apart at a spacing of 45 cm on the ridges in 3 m x 4 m area. Finger rhizomes of turmeric each weighing 20 to 25 g were planted in small pits taken at a spacing of 15 cm x 30 cm on raised beds of size 4 m x 1 m. In the case of ginger, bits of rhizomes of size 15 g collected from healthy, disease free plants were planted in small pits taken on raised beds of size 4 m x 1 m at a spacing of 25 cm x 25 cm.

Fertilizers

Each of the crops received the respective cultural and manurial practices as per the package of practices recommendations of the Kerala Agricultural University (KAU, 1978). Nitrogen, phosphorus and potassium were supplied through ammonium sulphate, superphosphate and muriate of potash, respectively.

Fig. 1. Lay-out plan - Randomised block design.



S_0 - 0 percent shade.

S_1 - 25 " "

S_2 - 50 " "

S_3 - 75 " "

a - coleus.
b - turmeric.
c - ginger.
d - sweet potato.
e - colocasia.

Shading

Unplaited coconut leaves were used for providing shade to the desired level.

Methods

Lay out of the experiment

The experiment was laid out in a randomised block design with five replications. The shades were common for all the five crops tested and thus five different crops were tested together in a contiguous area. The lay out plan of the experiment is given in Fig. 1.

Treatments

The treatments consisted of four intensities of shade as given below.

S_0 - 0 per cent shade (no shade)
S_1 - 25 per cent shade (low shade)
S_2 - 50 per cent shade (medium shade)
S_3 - 75 per cent shade (high shade)

Provision of shade

Artificial shading to the desired level was obtained by placing unplaited coconut leaves on erected pandals.

Pandals of size 11 m x 6 m were individually erected for each shade level by fixing wooden reapers on posts. Sufficient space (3 m) was provided between the treatments so that mutual shading of shade levels were minimised to the extent possible. Each pandal was covered on all the sides with unplaited coconut leaves except for 60 cm from the ground level to avoid the direct entry of slant rays. Raised beds were taken leaving a border area of 1 m within the shade levels to avoid the border effect considerably. An Aplab luxmeter was used for adjusting the shade intensities. Frequent checks were made throughout the course of experiment to maintain the shade intensities to the desired levels.

General growth of the crops

In general, the growth of the crops was satisfactory. However, the growth and development of colocasia plants were highly retarded during the early phase due to colocasia blight (Phytophthora palmivora (Butler) Butler) in spite of the prophylactic and control measures taken.

Observations

I. Plant characters

A. Biometric observations

The following growth characters were recorded at monthly intervals in sweet potato, coleus and colocasia. In the case of ginger and turmeric, observations were taken at bimonthly intervals.

1. Plant height

The height of ten randomly selected plants in each of the crops was measured from the base to the tip of the longest vine or tallest tiller or branch as the case may be, and the average worked out.

2. Girth at collar

This observation was taken only in colocasia where the circumference at the collar of the most vigorous tiller of 10 randomly selected plants was taken and the mean value computed.

3. Number of branches or tillers

The number of aerial shoots arising around a single plant was noted in 10 randomly selected plants and the average worked out. In the case of coleus and sweet potato, the number of branches in plants were recorded for calculating the mean number of branches per plant.

4. Leaf area index (LAI)

Leaf area index of each of the crops was worked out following the gravimetric method (Ruck and Bolas, 1956). Destructive sampling was followed and three plants in each of the crops were uprooted at different growth stages and their leaves separated. Five leaves were chosen at random in the case of colocasia and turmeric and 10 leaves in sweet potato, coleus and ginger and the leaf impressions were traced accurately on quality bond paper of known area per unit weight. The traced portions of paper were then cut out and weighed. From this, the area of the sample leaf was calculated from the weight to area relationship.

The leaves were then dried, in a hot air oven at 70 to 80° C to constant weight and the dry weight of these leaves and the rest of the leaves were recorded separately. Total leaf area for three plants was then calculated using the weight to area relationship and total dry weight of leaves. Thus LAI for each of the crops was calculated at different stages using the following equation.

$$\text{LAI} = \frac{\text{Total leaf area of three plants}}{\text{Land area occupied by three plants}}$$

5. Chlorophyll content of leaves

Chlorophyll 'a', 'b' and total chlorophyll content of each of the crops were estimated periodically by spectrophotometric method as described by Starnes and Hadley (1965).

Fully mature leaves were used for the estimation and second terminal leaf was used in each of the crop, except in sweet potato where the second green leaf from the tip was used, since the terminal leaves were tender and purple.

One gram of the representative sample, collected from five plants chosen at random, was taken in a mortar in the presence of excess acetone. A pinch of calcium carbonate was added to prevent pheophytin formation and the contents were then ground well and filtered through a Buchner funnel. The brei was washed repeatedly with fresh acetone (80 per cent) until the washing was colourless. The extract and washings were then made upto 250 ml. The optical density (A) of an aliquot was measured using a spectrophotometer (Spectronic-20) at wavelength of 645 nm and 663 nm. The contents of chlorophyll 'a', 'b' and total chlorophyll (mg g^{-} fresh weight) were then estimated using the following relationships.

$$\text{Chlorophyll a} = 12.72\, A_{663} - 2.58\, A_{645}$$

$$\text{Chlorophyll b} = 22.87\, A_{645} - 4.67\, A_{663}$$

$$\text{Total chlorophyll} = 8.05\, A_{663} + 20.29\, A_{645}$$

[Chlorophyll (a+b)]

6. Total dry weight

Leaves, stem + petiole (or pseudostem), and tubers or rhizomes, of the uprooted plants were separated and dried to constant weights at 70 to 80°C in hot air oven. From the dry weight of component parts for three plants, average dry weight per plant for these parts was worked out. The sum of dry weight of components gave the total dry matter yield, expressed as g^{-1}plant.

7. Net assimilation rate (NAR)

The procedure given by Watson (1958) as modified by Buttery (1970) was followed for calculating the NAR. The following formula was used to arrive at the NAR expressed as g m^{-2} day^{-1}.

$$NAR = \frac{w_2 - w_1}{(t_2 - t_1)\left(\frac{A_1 + A_2}{2}\right)}$$, where,

w_2 = total dry weight of plant g m^{-2} at time t_2

w_1 = total dry weight of plant g m^{-2} at time t_1

$(t_2 - t_1)$ = time interval in days

A_2 = leaf area m^{-2} at time t_2

A_1 = leaf area m^{-2} at time t_1

8. Yield (yield of rhizomes or tubers)

The yield of rhizomes or tubers in respective crops was recorded from the net area marked for recording the yield. The net plot areas were 2.40, 1.33, 6.00, 3.33 and 3.25 sq.m. respectively, in the case of sweet potato, coleus, colocasia, turmeric and ginger and the yield was expressed as t ha^{-1} of fresh weight.

9. Yield of haulm (top)

The yield of top (vegetative parts) in individual crops was recorded from the net area and expressed as t ha^{-1} of dry weight.

10. Harvest Index (HI)

Harvest index values for the different crops were calculated as follows.

$$HI = \frac{Y\ econ.}{Y\ biol.}, \text{ where,}$$

Y econ. = dry weight of rhizomes or tubers

Y biol. = total dry weight of plants (excluding roots)

B. Chemical studies

1. Content of fertilizer nutrients

Samples of plant components collected for recording the dry weight were used for chemical analysis. The nitrogen, phosphorus and potassium contents of leaf, stem + petiole (or pseudostem) and tubers (or rhizomes) at different stages of growth were determined by using Autoanalyzer (Technicon-II), colorimetrically (Vanadomolybdophosphoric yellow colour method) and Flame Photometrically, respectively (Jackson, 1958).

2. Uptake of fertilizer nutrients

The total uptake of nitrogen, phosphorus and potassium by the plant and individual plant parts were calculated, at different stages of growth, from the nutrient contents and dry weights of plant parts at different stages of growth and expressed as kg ha^{-1}.

II. Soil characters

Content of fertilizer nutrients in soil

Composite soil samples were taken replicationwise before the start of the experiment. After the experiment, individual samples were collected from the area occupied by each crop. The total nitrogen, available phosphorus and available potassium contents in these samples were estimated using microKjeldahl method, Colorimetrically (Chlorostannous reduced molybdophosphoric blue colour method) and Flame Photometrically, respectively (Jackson, 1958).

Statistical analyses

The data on different characters were subjected to statistical analysis following the method of Snedecor and Cochran (1967).

RESULTS AND DISCUSSION

RESULTS AND DISCUSSION

As there are five crops involved in the present study and as the responses of these crops to varying shade intensities were vastly different, the results are furnished and discussed separately for individual crops. A brief summary of the major conclusions drawn out of the study succeeds each discussion.

Sweet potato

Sweet potato
(*Ipomoea batatas* (L.) Lam.)

RESULTS

I. Plant characters

A. Biometric observations

1. Length of vine

The data are presented in Table 2 and the analysis of variance in Appendix 3.

The effect of shade on the length of vine in sweet potato was significant only in the intermediate stages of growth *viz.* 60 and 90 days after planting. No general trend with increasing levels of shade was observed except at 90 days after planting when the length of vine increased with increasing shade intensities.

Over the stages, the vine length was found to increase with advancing age. The extent of increase in vine length between stages was much greater at the intense shade of 75 per cent.

2. Number of branches

The data are presented in Table 2 and the analysis of variance in Appendix 3.

The effect of shade on number of branches produced by a plant was highly perceptible and significant at all stages of plant growth. The number of branches decreased tremendously with increasing intensities of shade. At all stages, the difference between the different shade levels and the plants in the open was highly perceptible.

With advancing age, the number of branches increased at all shade levels.

3. Leaf area index

The data are presented in Table 2 and the analysis of variance in Appendix 3.

There was significant effect of shade on LAI at all stages of growth with plots without shade and highest shade levels recording the maximum and minimum values, respectively, at all stages. The LAI values decreased with increasing shade levels at all stages.

Between stages, the leaf area index showed an increasing trend with advancing age at all shade levels but the extent of increase is much higher in the plot without shade.

4. Chlorophyll content of leaves

The data on the content of chlorophyll 'a', 'b',

Table 2. Effect of shade on length of vine, number of branches and leaf area index of sweet potato at different growth stages

Shade intensity (per cent)	Length of vine (cm) (days after planting)			Number of branches $plant^{-1}$ (days after planting)				Leaf area index (days after planting)			
	30	60	90	30	60	90	Harvest (110)	30	60	90	Harvest (110)
0 (no shade)	78.3	185.3	276.2	8.5	20.7	21.3	22.7	2.72	8.01	7.55	11.09
25 (low shade)	98.5	246.0	356.3	3.0	8.9	14.6	12.9	1.58	4.84	6.37	6.74
50 (medium shade)	89.0	271.6	391.7	2.9	6.1	10.1	15.8	1.20	2.68	4.58	6.60
75 (high shade)	78.6	222.4	400.2	2.3	5.9	7.1	8.8	1.18	2.45	3.03	2.74
SEm ±	7.9	16.4	17.8	0.8	1.0	1.4	1.7	0.32	0.69	0.59	0.90
CD (0.05)	NS	50.6	54.8	2.3	3.0	4.3	5.3	0.97	2.11	1.81	2.78

Table 3. Effect of shade on contents (mg g^{-1} fresh weight) of chlorophyll 'a', 'b' and total chlorophyll; chlorophyll a-b ratio of sweet potato leaves at different growth stages

Shade intensity (per cent)	Chlorophyll 'a' (days after planting)			Chlorophyll 'b' (days after planting)			Total chlorophyll (days after planting)			Chlorophyll a:b (days after planting)		
	80	95	Harvest (110)	80	95	Harvest (110)	80	95	Harvest (110)	80	95	Harvest (110)
0 (no shade)	1.54	1.62	1.65	1.90	1.84	1.95	3.44	3.46	3.59	0.81	0.88	0.85
25 (low shade)	1.53	1.58	1.50	1.87	1.82	1.70	3.40	3.40	3.21	0.82	0.87	0.89
50 (medium shade)	1.59	1.65	1.70	1.97	1.87	2.00	3.58	3.52	3.71	0.81	0.88	0.85
75 (high shade)	1.62	1.52	1.66	2.00	1.79	1.94	3.62	3.31	3.60	0.81	0.85	0.86
SEm ±	0.05	0.07	0.04	0.07	0.08	0.08	0.11	0.14	0.12	0.01	0.02	0.01
CD (0.05)	NS	NS	0.13	NS	NS	NS	NS	NS	NS	NS	NS	NS

total chlorophyll and ratio of chlorophyll a-b are presented in Table 3 and the analyses of variance in Appendix 4.

In general, the effect of shade on total chlorophyll and its components was not significant, at any of the stages of growth considered. The content ranged from 1.50 to 1.70, 1.70 to 2.00 and 3.21 to 3.71 mg g^{-1} fresh weight, in the case of chlorophyll 'a', 'b' and total chlorophyll, respectively. The content of these factors showed high variability and no general trend could be noticed with increasing shade levels.

The ratio of chlorophyll a-b remained almost constant in different shade densities at all growth stages.

5. Total dry weight

The data are presented in Table 4 and Fig. 2. The analysis of variance is given in Appendix 5.

Shading had a significant effect on plant dry weight at all growth stages. The total plant dry weight exhibited a steep decrease with increasing shade levels. The dry weight in the plot without shade was significantly higher than at all shade levels.

Table 4. Effect of shade on total dry matter production, net assimilation rate, tuber yield, haulm yield and harvest index of sweet potato

Shade intensity (per cent)	Total dry weight (g plant^{-1}) (days after planting) 30	60	90	Harvest (110)	Net assimilation rate (g m^{-2} day^{-1}) Between 30 & 60 days	Between 60 & 90 days	Tuber yield (t ha^{-1} fresh weight)	Haulm yield (t ha^{-1} dry weight)	Harvest index
0 (no shade)	18.64	86.92	145.28	149.55	3.48	2.68	7.654 (0.9377)	16.00	0.263 (0.1012)
25 (low shade)	7.10	38.54	74.46	73.00	2.79	2.25	1.631 (0.4201)	10.38	0.094 (0.0390)
50 (medium shade)	5.61	18.62	48.48	66.76	1.84	1.78	0.137 (0.0557)	5.95	0.012 (0.0050)
75 (high shade)	4.61	12.88	24.36	18.70	1.24	1.25	0.000 (0.0000)	5.94	0.000 (0.0000)
SEm ±	2.04	4.09	8.76	11.35	0.26	0.82	0.17	0.40	0.032
CD (0.05)	6.28	12.61	26.98	34.98	0.81	NS	0.53	1.24	0.097

NS = Not significant

(Figures in parenthesis represent $\log_{10}(y+1)$ transformed values)

Fig. 2. Effect of shade on dry matter accumulation of sweet potato at different stages of growth.

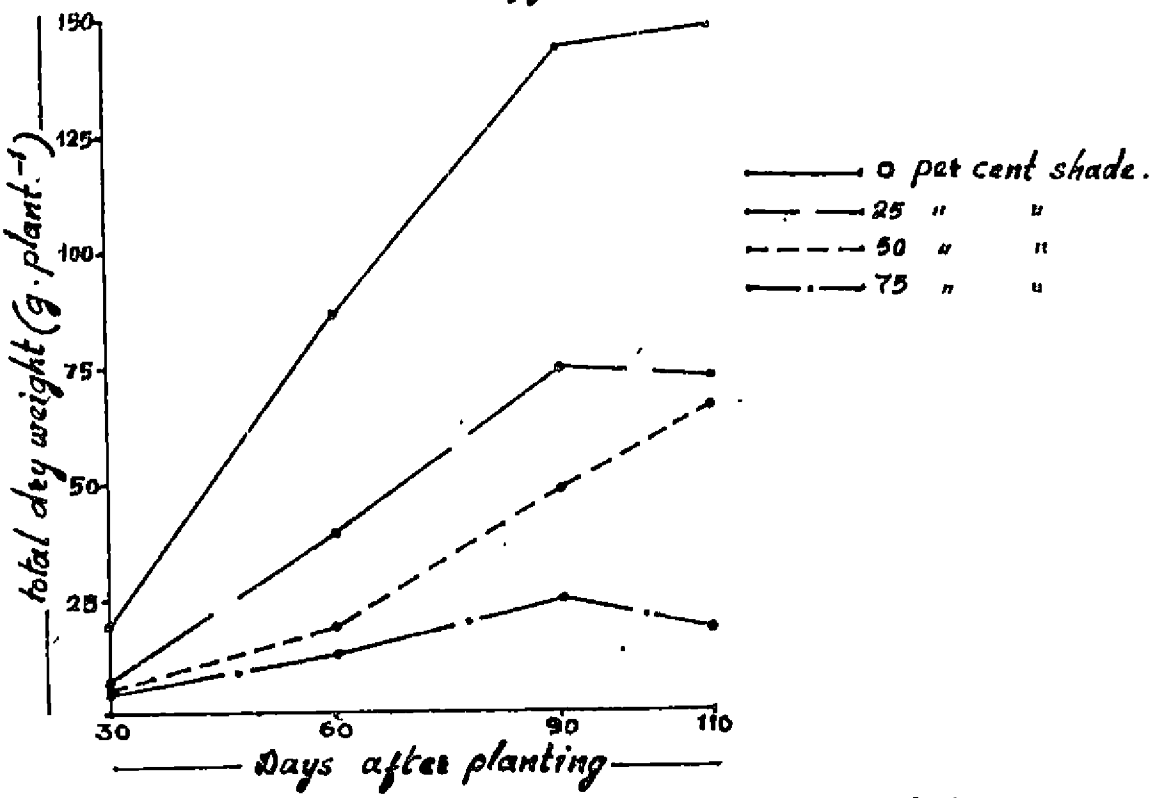
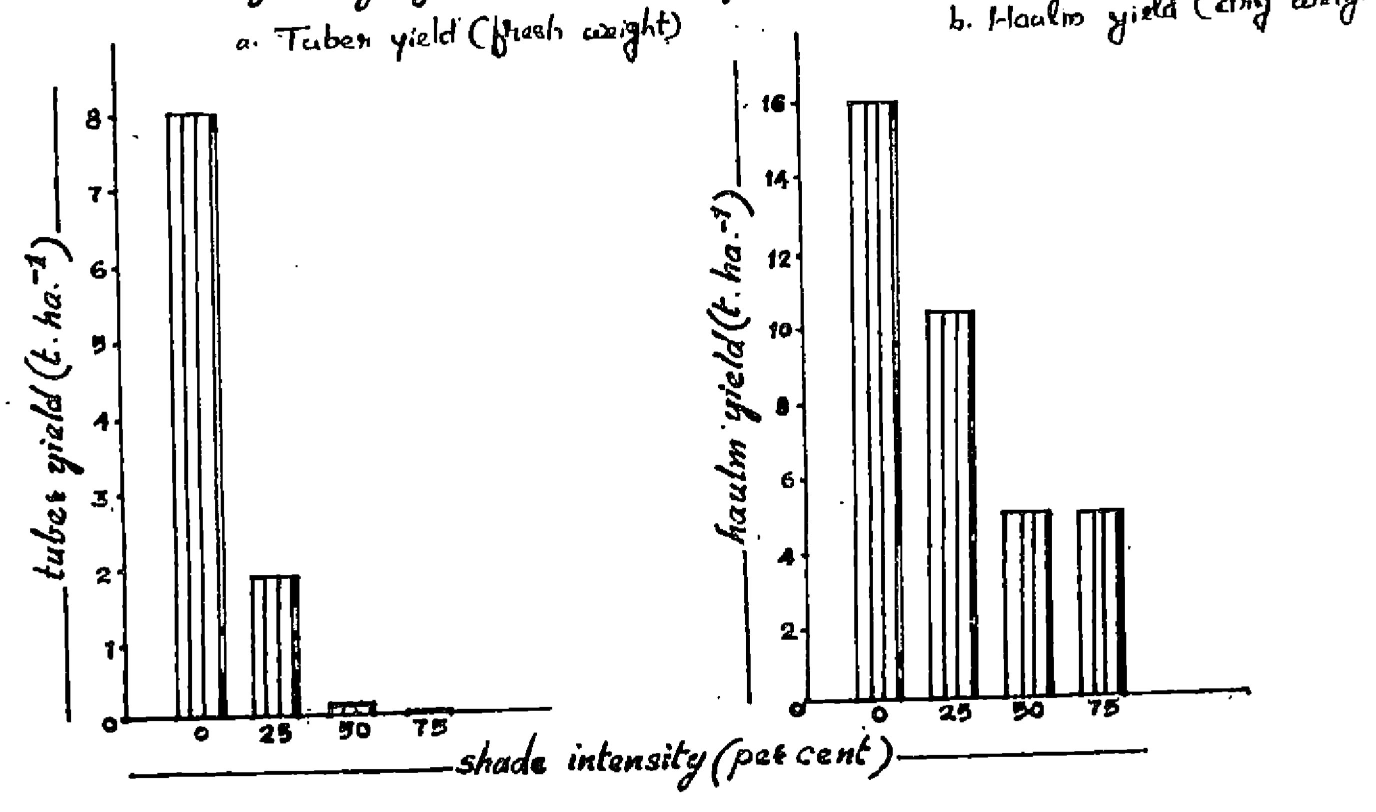


Fig. 3. Tuber and haulm yield of sweet potato as affected by varying intensities of shade.



The plant dry weight increased with advancing age at all the shade levels. The extent of increase was most marked during the period between 30 and 60 days after planting.

6. Net assimilation rate

The data are presented in Table 4 and the analysis of variance in Appendix 5.

There was significant effect of shade on NAR in sweet potato only between 30 and 60 days after planting. The NAR went on increasing with decrease in shade intensities. Though an identical trend was noticed between 60 and 90 days after planting, the differences fell short of statistical significance.

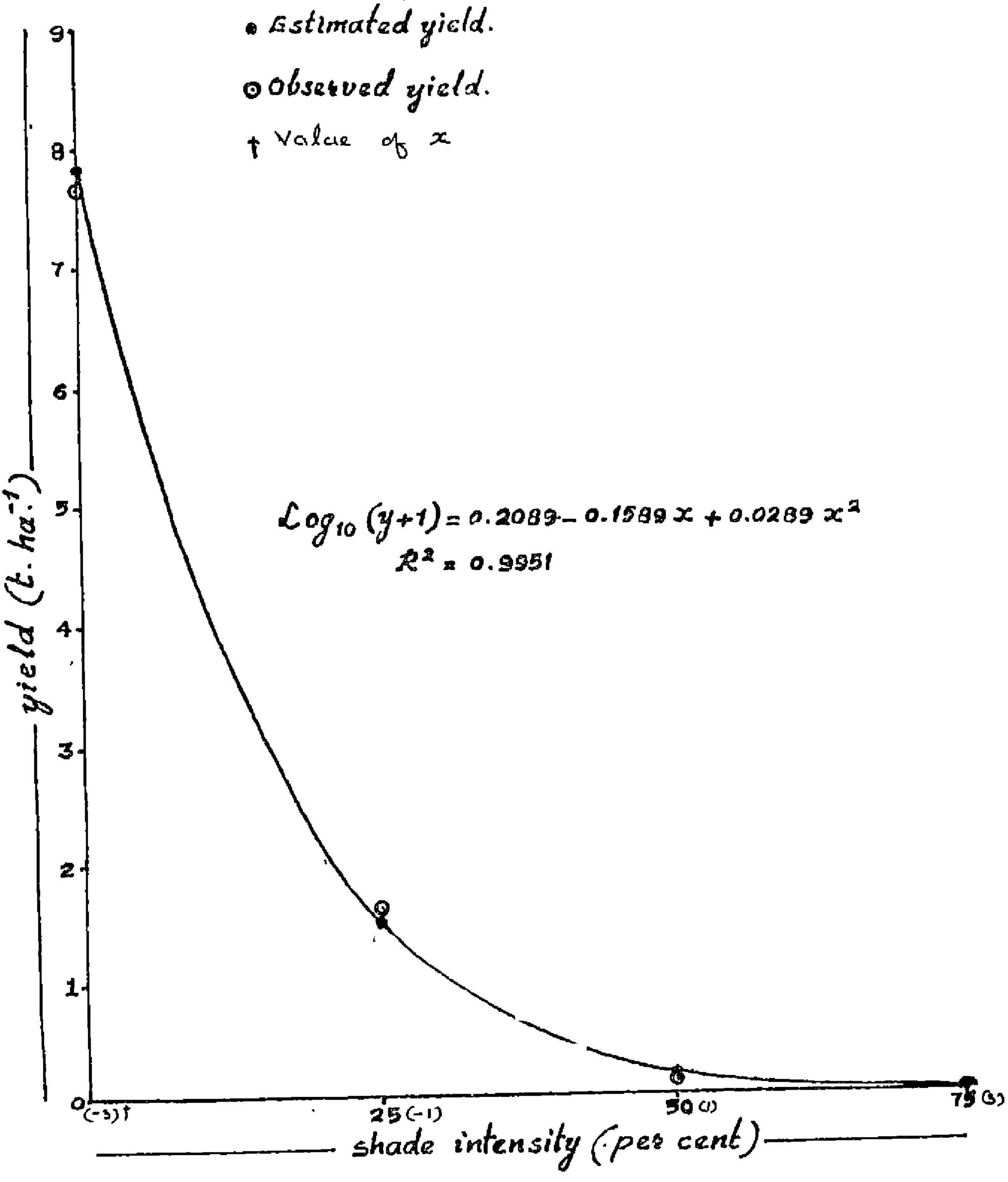
Over the stages, the NAR was found to decrease at all shade levels. The decrease was more conspicuous in the plots without shade.

7. Tuber yield

The data are presented in Table 4 and Fig. 3. The analysis of variance is given in Appendix 5.

The yield of tuber was significantly influenced by shade. The yield declined rapidly with increasing shade intensities and the intense shade (75 per cent) level

Fig. 4. Yield response of sweet potato to different intensities of shade.



resulted in no harvestable produce. The plants without shade gave the highest yield of 7.65 t ha^{-1} which was significantly higher than that at low (25 per cent) and medium (50 per cent) shade levels. Calculated as percentages of the yield in the open, the yields at low, medium and high shade intensities were 21.3, 1.8 and 0.0 per cent, respectively.

Response curve

The yield data were transformed to logarithms using the log (y+1) transformation. A quadratic polynomial was found to give a better fit to the transformed data (Fig.4 and the analysis of variance in Appendix 4B). The equation of the curve is given below.

$$\text{Log}_{10}\ (y+1) = 0.2089-0.1589x + 0.0289x^2$$

The co-efficient of determination was found to be 0.9951 which showed that 99.51 per cent of the total variation in the response can be explained by the fitted polynomial.

8. Yield of haulm

The data are presented in Table 4 and Fig.3. The analysis of variance is given in Appendix 5.

As in the case of tuber yield, there was significant effect of shade on haulm yield in sweet potato. The maximum yield was recorded in the open and minimum yield at high shade levels. The yield of haulm in low, medium and high shade levels were found to be 64.9, 37.3 and 37.0 per cent of that in the open.

9. Harvest index

The data are presented in Table 4 and the analysis of variance in Appendix 5.

The response due to shade on harvest index of sweet potato was highly perceptible and significant. The maximum and minimum values were in plots without shade and medium to high shade levels, respectively.

B. Chemical studies

1. Content and uptake of nitrogen

The data on the content of nitrogen in leaf, stem + petiole and tubers along with the total uptake of nitrogen are presented in Table 5 to 6 and Fig.5. The analyses of variance are given in Appendix 6.

In general, shade had a significant effect on these characters at all growth stages. The content varied from 3.54 to 4.34, 1.29 to 1.89 and 0.36 to 0.6b per cent in

Table 5. Effect of shade on nitrogen content of leaf and stem + petiole of sweet potato at different growth stages

Shade intensity (per cent)	Leaf nitrogen content (per cent) (days after planting)				Stem + petiole nitrogen content (per cent) (days after planting)			
	30	60	90	110 (harvest)	30	60	90	110 (harvest)
0 (no shade)	3.97	3.78	3.54	4.13	1.44	1.43	1.29	1.43
25 (low shade)	4.10	4.16	3.99	4.35	1.77	1.62	1.45	1.56
50 (medium shade)	3.88	4.28	3.84	4.05	1.82	1.76	1.40	1.57
75 (high shade)	4.15	4.01	4.34	4.18	1.84	1.89	1.49	1.62
SEm ±	0.11	0.03	0.12	0.05	0.03	0.03	0.06	0.01
CD (0.05)	NS	0.08	0.36	0.17	0.08	0.08	NS	0.04

NS = Not significant

Table 6. Effect of shade on the nitrogen content of tuber and on the total uptake of nitrogen by sweet potato at different growth stages.

Shade intensity (per cent)	Tuber nitrogen content (per cent) (days after planting)				Total uptake of nitrogen (kg ha^{-1}) (days after planting)			
	30	60	90	110 (harvest)	30	60	90	110 (harvest)
0 (no shade)		0.62	0.36	0.70	39.73	153.11	186.43	244.57
25 (low shade)		0.81	0.56	0.80	17.29	82.74	135.79	146.97
50 (medium shade)				0.80	13.29	42.45	86.34	126.44
75 (high shade)					11.27	30.13	48.45	38.53
SEm ±					4.22	8.58	10.80	22.37
CD (0.05)					13.00	26.45	33.29	68.92

NS = Not significant

the case of leaf, stem + petiole and tubers, respectively, at the different stages. The variation in the content was wide and it is difficult to derive a general trend. It was also noted that the nitrogen content of leaves was found to be 2.0 to 5.0 times more than that of stem + petiole.

The uptake of nitrogen by leaf, stem + petiole and tubers were also calculated separately and all these were found to be significantly influenced by shading at all the growth stages. The total uptake of nitrogen closely followed the total dry weight, at all the growth stages. The plants without shade and with high shade recorded the maximum and minimum uptake values, respectively. The uptake showed a drastic decline with increasing shade intensities.

Over the stages, the uptake went on increasing with advancing age; while the content remained almost at the same level.

2. Content and uptake of phosphorus

The data on the content of phosphorus in leaf, stem + petiole and tubers along with the total uptake of phosphorus are presented in Table 7 to 8 and Fig.5. The analyses of variance are given in Appendix 7.

Table 7. Effect of shade on phosphorus content of leaf and stem + petiole of sweet potato at different growth stages

Shade intensity (per cent)	Leaf phosphorus content (per cent) (days after planting)				Stem + petiole phosphorus content (per cent) (days after planting)			
	30	60	90	110 (harvest)	30	60	90	110 (harvest)
0 (no shade)	0.35	0.33	0.30	0.38	0.21	0.24	0.20	0.22
25 (low shade)	0.43	0.36	0.29	0.37	0.31	0.23	0.19	0.21
50 (medium shade)	0.37	0.38	0.32	0.41	0.25	0.21	0.19	0.25
75 (high shade)	0.40	0.29	0.37	0.40	0.29	0.26	0.19	0.21
SEm ±	0.01	0.02	0.01	0.01	0.01	0.02	0.01	0.01
CD (0.05)	0.02	NS	0.02	0.04	0.02	NS	NS	0.02

NS = Not significant

Table 8. Effect of shade on phosphorus content of tuber and total uptake of phosphorus by sweet potato at different growth stages

Shade intensity (per cent)	Tuber phosphorus content (per cent) (days after planting)				Total uptake of phosphorus (kg ha^{-1}) (days after planting)			
	30	60	90	110 (harvest)	30	60	90	110 (harvest)
0 (no shade)	0.14	0.15	0.11	0.11	4.15	19.14	23.50	29.03
25 (low shade)	-	0.15	0.16	0.12	2.25	8.93	13.39	14.87
50 (medium shade)	-	-	-	0.10	1.46	4.36	9.10	16.62
75 (highsshade)	-	-	-	-	1.30	2.97	5.01	4.22
SEm ±	-	-	-	-	0.50	1.33	1.22	2.27
CD (0.05)	-	-	-	-	1.55	4.12	3.76	7.01

NS = Not significant

The significant effect of shade on phosphorus content of leaf and stem + petiole was noticed only at certain stages of growth but the total uptake of phosphorus was significantly influenced by shading at all the stages of growth. The contents ranged from 0.295 to 0.434, 0.19 to 0.312 and 0.100 to 0.165 per cent, respectively in the case of leaf, stem + petiole and tubers, at all stages of growth in all the shade levels. The variation in content between treatments was wide and no general trend could be observed.

In spite of the non-significant effect of shade on the phosphorus content of plant parts at certain stages, the uptake of phosphorus was found to be significantly influenced by shading at different stages of growth. The total uptake of phosphorus showed a similar trend as in the case of total uptake of nitrogen and that of the total dry weight at all the growth stages, with the plants without shade and at intense shade recording the maximum and minimum uptake values, respectively. With advancing age, the uptake went on increasing at all shade levels and the extent of increase was more at low and medium shade levels.

3. Content and uptake of potassium

The data on the content of potassium in the leaf

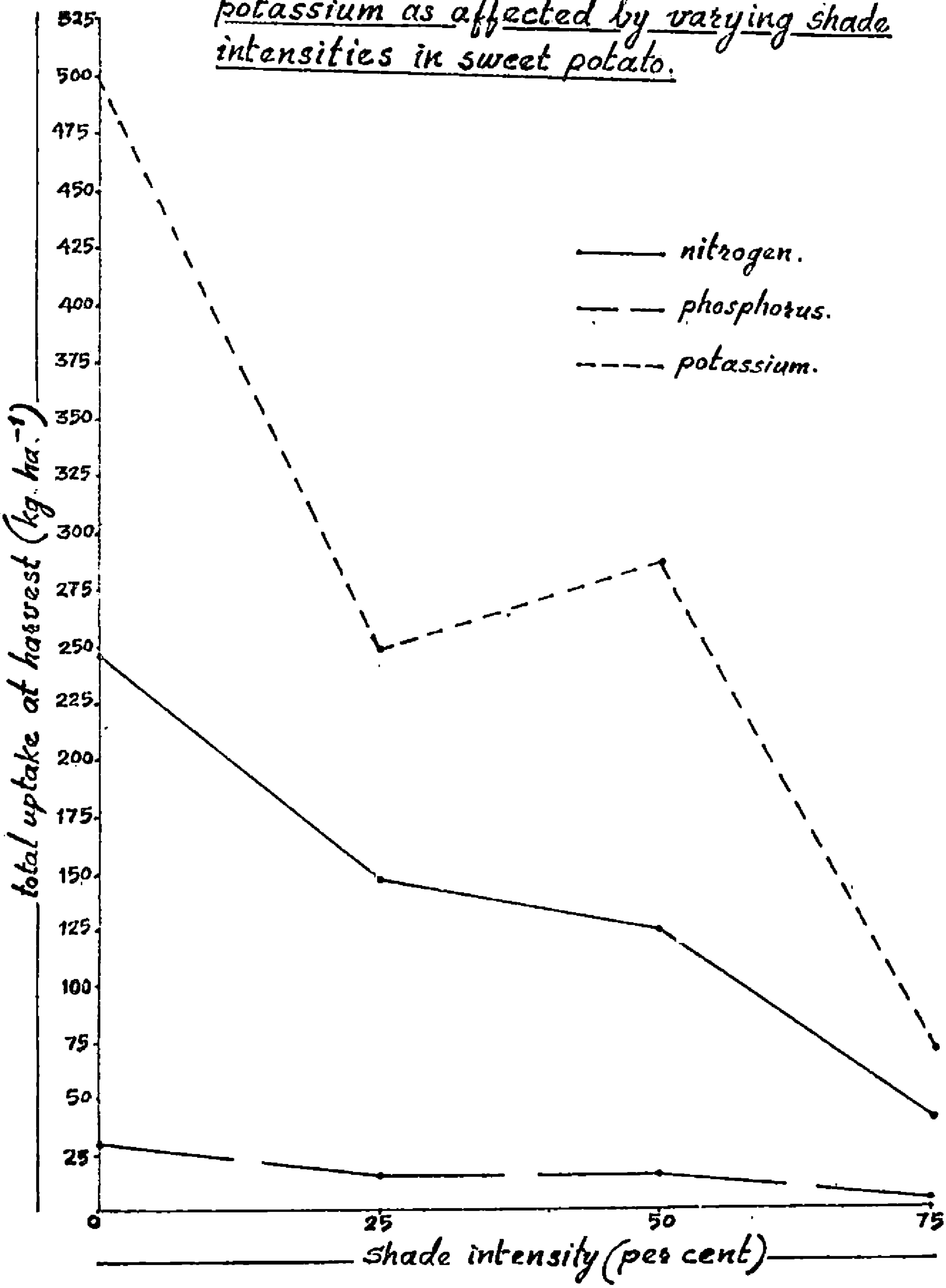
Table 9. Effect of shade on potassium content of leaf and stem + petiole of sweet potato at different growth stages

Shade intensity (per cent)	Leaf potassium content (per cent) (days after planting)				Stem + petiole content (per cent) (days after planting)			
	30	60	90	110 (harvest)	30	60	90	110 (harvest)
0 (no shade)	4.23	4.22	3.59	4.04	5.58	4.88	3.88	4.85
25 (low shade)	4.58	3.88	3.46	4.20	6.16	5.03	3.89	4.43
50 (medium shade)	4.58	4.40	3.72	4.34	6.65	5.22	4.42	5.53
75 (high shade)	4.79	4.42	3.85	4.50	6.84	5.60	4.17	4.75
SEm ±	0.04	0.10	0.04	0.02	0.11	0.18	0.05	0.03
CD (0.05)	0.12	0.30	0.12	0.06	0.33	0.05	0.15	0.09

Table 10. Effect of shade on potassium content of tuber and on total uptake of potassium by sweet potato at different growth stages

Shade intensity (per cent)	Tuber potassium content (per cent) (days after planting)				Total potassium uptake (kg ha^{-1}) (days after planting)			
	30	60	90	110 (harvest)	30	60	90	110 (harvest)
0 (no shade)	1.54	1.45	1.61	1.47	73.88	318.29	390.66	499.49
25 (low shade)	-	1.15	1.43	1.55	32.18	147.61	226.42	249.33
50 (medium shade)	-	-	-	1.64	26.36	75.23	168.55	286.71
75 (high shade)	-	-	-	-	22.11	54.65	82.57	72.02
SEm ±	-	-	-	-	8.92	18.05	22.60	42.67
CD (0.05)	-	-	-	-	27.48	55.64	69.64	131.49

Fig.5- Uptake of nitrogen, phosphorus and potassium as affected by varying shade intensities in sweet potato.



stem + petiole and tubers along with the total uptake of potassium are presented in Tables 9 to 10 and Fig.5. The analysis of variance is given in Appendix 8.

The effect of shade on the above characters was found to be significant at all the growth stages. The content ranged from 3.46 to 4.79, 3.88 to 6.84 and 1.15 to 1.64 per cent in the leaf, stem + petiole and tubers, respectively, at all shade levels, throughout the growth stages. As in the case of nitrogen and phosphorus contents, the potassium content also showed high variability between shade levels at different stages of growth.

The potassium uptake by individual plant components, viz. leaf, stem + petiole and tubers, was significantly influenced by shading at all growth stages. Total uptake of potassium by the plant closely followed the trend of total uptake of nitrogen and phosphorus and the total dry weight of plant.

II. Soil characters

Soil nutrient status

The data on the soil nutrient status after cropping with sweet potato are presented in the Table 11 and the analysis of variance is given in Appendix 9.

Shade had a significant effect on the contents of

Table 11. Nutrient status of the soil after the crop of sweet potato

Shade intensity (per cent)	Nutrient		
	Total nitrogen (per cent)	Available phosphorus (ppm)	Available potassium (ppm)
0 (no shade)	0.106	1.40	89.88
25 (low shade)	0.125	2.77	95.23
50 (medium shade)	0.087	1.51	97.15
75 (high shade)	0.108	3.30	115.20
SEm ±	0.004	0.202	1.472
CD (0.05)	0.013	0.624	1.536

total nitrogen, available phosphorus and available potassium in the soil after the cultivation of sweet potato. The available potassium content of the soil showed an increasing trend with increasing shade levels. However such definite pattern was not observed with total nitrogen and available phosphorus.

On comparison with the initial nutrient status, the total nitrogen showed a slight increase while a decrease was noted in the case of available phosphorus and available potassium contents.

DISCUSSION

The results of the present study indicated that there was a sharp decrease in yield due to shading in sweet potato. The percentage yields at 25 and 50 per cent shade levels were 21.3 and 1.8, respectively, of that in the open and at 75 per cent shade, there was no harvestable produce. The response to increasing levels of shade followed an exponential pattern. Based on the yield trend, sweet potato may be classified as 'shade-sensitive' and this crop may not hence be considered suited for intercropping.

The above drastic decrease in yield is inconsistent with the general growth performance of the plant measured in terms of dry matter accumulation and other growth observations. In the case of dry matter yield at harvest (Table 4), the percentage values were 48.8, 44.3 and 12.5 per cent, respectively (of that in the open) at 25, 50 and 75 per cent shade. As mentioned earlier, the pattern of response in terms of most of the other growth characters was similar to that of dry matter accumulation with minor individual exceptions. Assuming that total dry matter yield may be used as a measure of the photosynthetic accumulation by the plants, it may be concluded that the sweet potato plant failed to translocate the photosynthates to the economic plant part as shade intensities increased. The decrease in dry matter accumulation consequent to a decrease in illumination must normally be expected as a larger proportion of leaves would tend to fall below saturating light intensities or even below compensation points with increasing shade levels.

An assessment of the extent of mutual shading that might have occurred can be had from the data on leaf area index (Table 2). In general, the canopy was dense and LAI high. In the open, the LAI values were greater than 4.0 even from 30 days after planting and reached the peak of 11.0 at harvest. Though reports on the optimum LAI of sweet potato are not available from literature, a comparison with an optimum of 3.0 to 4.0 reported for sesame with horizontally oriented leaves (Arnon, 1975) would indicate that LAI of this sweet potato crop was probably superoptimal. One of the important factors that decides the optimum values of LAI is the leaf orientation. It has been reported that in sweet potato, mutual shading is reduced to an extent through the scattering of leaves in different positions because of the differences in the length of petioles (Onwueme, 1978). Even with such adaptations, there was presumably some parasitism by the lower leaves even in the open as evidenced by the near horizontal leaf orientation and the high leaf area indices. As had been pointed out earlier, with increase in shade levels, mutual leaf shading and parasitism would have gone up substantially. However, such excessive parasitism was counteracted to an extent by a steady and marked decrease in LAI with increasing shade levels.

The data on net assimilation rate (Table 4) would further indicate the efficiency of the leaves for photosynthate accumulation. If the above mentioned counterbalancing by a decrease in LAI was complete and effective, the NAR would have remained the same at all shade levels. The results, on the contrary, showed a decrease in this growth characteristic with increasing shade indicating again that the proportion of leaves at lower levels of illumination increased because of shading, even though shading was accompanied by a decrease in the leaf density. Based on the observations on LAI and NAR, it may thus be concluded that both decrease in photosynthetic area and a decrease in the mean efficiency of the leaves were responsible for the decrease in dry matter accumulation because of shading.

While the above two would adequately explain the variation in dry matter accumulation and other growth parameters, these would not explain the drastic difference in the response in these characters with that of tuber yield. Presumably, there was some other influence of shade that decided the partitioning and translocation of photosynthates to the tubers. A quantitative estimate of such a difference in the partitioning of assimilates can be had from the data of harvest index (Table 4) which was to the tune of 26.0 per cent at full illumination and which dropped down to 9.4, 1.2 and 0.0 per cent, respectively, at 25, 50 and 75 per cent shade levels.

While most of the growth characters followed the same trend as that of the dry matter accumulation, length of vine increased with increasing shade levels. Though reports and explanation for such a behaviour of sweet potato are not available, increased length (height) because of shading has been reported in crops like tobacco (Panikar et al.,1969), ginger (Aclan and Quisumbing, 1976) and cowpea (Tarila et al., 1977). The chlorophyll content of the leaf was not affected because of shading in sweet potato, though the general trend of reported results on other crops was that of an increased chlorophyll content because of shading (Clark, 1965 in strawberry; Evans and Murray, 1953; Guers, 1971; Okali and Owusu, 1975 in cocoa; Ramaswami, 1960 and Venkatamani, 1961 in tea; Khossien, 1970 in bean; Cooper and Qualls, 1967 in alfalfa and birdsfoot trefoil, Radha, 1979 in pineapple).

The content of the nutrients, nitrogen, phosphorus and potassium in tissues was nearly the same at all shade levels barring protracted deviations at certain stages. The total uptake of nutrients at harvest, on the contrary, showed wide variation with plants in the open recording the highest uptake and those at intense shade, the lowest. In general, the uptake of nutrients followed the same expected trend as that of dry matter accumulation. The fact that there was no decrease in the content of the nutrients because of dilution effect may be taken to indicate that the supply of nutrients was adequate from soil. That the extent of decrease in yield is much more than the extent of decrease in uptake of nutrients indirectly indicates that the utilisation efficiency of these nutrients would be less under shade than in the open.

Data on the soil nutrient status after cropping (Table 11) would indicate that the differences in the contents of nitrogen and phosphorus in soil between the shade levels, though were statistically significant, did not follow any distinct pattern. In the case of potassium, there was a nearly steady increase in the contents with increase, in shade levels. A comparison with the uptake of this nutrient at harvest (Table 10), would show that it followed just the reverse trend in the case of uptake. The larger uptake of potassium at lower shade levels might have thus contributed towards the observed variation in the content of this nutrient in the soil after cropping.

As compared to the pre-experimental nutrient status of the soil, there was a marked increase in the content of nitrogen and a decrease in the case of potassium after the crop season. The change in phosphorus content was inconsistent. While the decrease in potassium content could be explained as due to the substantial removal of this nutrient from the soil to the extent of 72.02 to 499.49 kg ha^{-1} at the different shade levels (Table 10), the increase in nitrogen content is difficult to explain. The only reason for this increase appears to be that during the collection of post-harvest soil samples, substantial quantities of organic debris from the organic manure initially added might have been included over and above the organic matter addition through leaf fall.

The general trend of the results and the conclusions out of these may be summarised as follows:

1. There was an exponential decrease in yield of sweet potato with increasing shade levels and hence this crop may be classified as 'shade-sensitive'. It may not therefore be a crop suited for intercropping.

2. There appears to be some influence of shade on the partitioning and translocation of assimilates. This is reflected in the marked differences in the responses to shading between dry matter accumulation and tuber yields.

3. Sweet potato appears to be a crop with adaptation for substantial adjustments in leaf area to avoid excessive leaf parasitism.

4. It appears that the utilisation efficiencies of the nutrients added would be markedly less under shade than in the open.

Coleus

Coleus

(*Coleus parviflorus*, Benth.)

RESULTS

I. Plant characters

A. Biometric observations

1. Plant height

The data are presented in Table 12 and the analysis of variance in Appendix 10.

Shade had significant effect on plant height only at 95 days after planting. Though varying, plant height showed an increasing trend upto intermediate (50 per cent) shade level and then decreased at the intense shade of 75 per cent, but was more than that in the open.

2. Number of branches

The data are presented in Table 12 and the analysis of variance in Appendix 10.

Shade had significant effect on the number of branches only at the initial stage of growth. The general trend was one of a decrease in the number of branches with increasing shade intensities at all stages of growth. The lowest values were recorded at the intense (75 per cent) shade level.

The number of branches increased with advancing age of the plant.

3. Leaf area index

The data are presented in Table 12 and the analysis of variance in Appendix 10.

Leaf area index in coleus was not significantly influenced by shade at any of the growth stages. At 95 days after planting, the value went on increasing with increasing intensities of shade upto the intermediate shade level and then had a decrease at the intense shade level, while at other stages the LAI values decreased with increasing shade levels. At harvest, the maximum LAI was recorded by plants at low shade intensity.

Over the stages, the LAI values increased with advancing age upto 95 days after planting in the case of low and medium shade levels while in the case of no shade and intense shade levels, the value went on decreasing after 65 days of growth.

4. Chlorophyll content of leaves

The data on the content of chlorophyll 'a', 'b' and total chlorophyll along with the ratio of chlorophyll a-b are presented in Table 13 and the analyses of variance in Appendix 11.

Table 12. Effect of shade on plant height, number of branches and leaf area index of coleus at various growth stages

Shade intensity (per cent)	Plant height (cm) (days after planting)				Number of branches plant^{-1} (days after planting)				Leaf area index (days after planting)			
	35	65	95	125 (harvest)	35	65	95	125 (harvest)	35	65	95	125 (harvest)
0 (no shade)	18.0	58.2	70.1	76.3	13.9	21.4	27.2	34.7	3.11	9.46	8.15	3.32
25 (low shade)	19.1	61.0	73.6	81.1	8.4	21.5	31.9	35.9	2.41	7.92	10.61	4.58
50 (medium shade)	20.0	62.7	77.5	80.0	7.3	17.9	26.8	30.6	2.55	8.52	10.38	3.09
75 (high shade)	18.0	53.8	58.3	77.1	6.1	16.3	18.2	27.7	1.65	6.42	5.59	3.82
SEm ±	1.4	2.6	3.0	3.3	1.6	1.7	3.6	4.6	0.42	1.42	1.80	1.05
CD (0.05)	NS	NS	9.4	NS	4.9	NS	NS	NS	NS	NS	NS	NS

NS = Not significant

Table 13. Effect of shade on chlorophyll 'a', 'b' and total chlorophyll (mg g^{-1} fresh weight); ratio of chlorophyll a-b of coleus leaves at various growth stages

Shade intensity (per cent)	Chlorophyll 'a' (days after planting)			Chlorophyll 'b' (days after planting)			Total chlorophyll (days after planting)			Chlorophyll a:b (days after planting)		
	80	115	125 (harvest)	80	115	125 (harvest)	80	115	125 (harvest)	80	115	125 (harvest)
0 (no shade)	0.48	0.45	0.47	0.57	0.63	0.81	0.99	1.08	1.29	0.81	0.72	0.59
25 (low shade)	0.70	0.67	0.47	0.86	0.77	0.83	1.56	1.44	1.31	0.82	0.85	0.57
50 (medium shade)	0.80	0.84	0.61	0.97	0.88	0.94	1.77	1.83	1.55	0.83	0.84	0.66
75 (high shade)	0.95	0.91	0.88	1.13	1.19	1.20	2.07	2.10	2.08	0.84	0.77	0.74
SEm ±	0.06	0.08	0.03	0.05	0.07	0.08	0.08	0.14	0.11	0.06	0.05	0.03
CD (0.05)	0.19	0.24	0.10	0.13	0.21	0.25	0.24	0.43	0.33	NS	NS	NS

NS= Not significant

The chlorophyll 'a', 'b' and total chlorophyll contents were found to be significantly affected by shade at all stages of growth. The content of total chlorophyll and its components went on increasing with increasing levels of shade, with the plants in the intense (75 per cent) shade level and those without shade recording the maximum and minimum contents, respectively.

Towards maturity of the crop, the contents of chlorophyll 'a' and total chlorophyll, in general, showed a declining trend, while that of chlorophyll 'b' remained nearly constant.

The effect of shade on the ratio of chlorophyll a-b was not-significant and it remained almost constant at the different shade levels. There was a drop in the ratio at harvest as compared to that at the early stages of growth.

5. Total dry weight

The data on the total dry weight per plant are presented in Table 14 and Fig. 6. The analysis of variance is given in Appendix 12.

Total dry weight per plant was significantly influenced by shading at all the growth stages. The general trend noticed was that of a decrease with increasing shade levels.

The maximum and minimum values were recorded by plants without shading and at intense shade respectively, at all stages of growth. The only exception was at the 95 days after planting.

Over the stages, the value went on increasing with advancing age, at all shade levels. However, at low and medium shade levels, there was a fall in dry matter accumulation at harvest. The increasing trend was almost steady in all shade levels, at the other stages of growth.

6. Net assimilation rate

The data are presented in Table 14 and the analysis of variance in Appendix 12.

There was significant effect of shade on NAR only between 35 and 65 days after planting, when the highest and lowest values were recorded by plants without shade and at intense shade levels, respectively. The effect of shade on NAR between 65 and 95 days after planting was not significant; there was however, a drastic decline in mean NAR when shading was more than 50 per cent.

With advancing age, there was a sharp decline in NAR.

7. Number of tubers

The data are presented in Table 14 and the analysis of variance in Appendix 12.

Table 14. Effect of shade on total dry weight, net assimilation rate, number of tubers, tuber yield, haulm yield and harvest index of coleus

Shade intensity (per cent)	Total dry weight (g plant^{-1}) (days after planting)				Net assimilation rate (g m^{-2} day^{-1})		Number of tubers plant^{-1} (days after planting)			Tuber yield (t ha^{-1} fresh weight)	Haulm yield (t ha^{-1} dry weight)	Harvest index
	35	65	95	125 (harvest)	Between 35 & 65 days	Between 65 & 95 days	65	95	125 (harvest)			
0 (no shade)	3.65	22.46	31.50	43.89	3.30	1.08	4.24 (2.18)	17.7	27.1	34.10	4.80	0.61
25 (low shade)	1.97	16.65	35.10	31.95	3.34	2.26	1.56 (1.43)	12.6	37.5	26.56	2.89	0.60
50 (medium shade)	1.78	13.38	24.04	23.57	2.14	1.36	0.86 (1.17)	6.7	33.0	20.04	3.54	0.54
75 (high shade)	1.19	8.13	9.90	17.24	1.99	0.15	0.00 (0.71)	1.7	39.8	9.92	2.24	0.49
SEm ±	0.39	1.20	3.70	5.05	0.35	0.58	0.22	1.2	3.9	2.11	0.53	0.03
CD (0.05)	1.20	7.16	11.39	15.57	1.06	NS	0.68	3.6	12.1	6.50	1.62	0.07

NS = Not significant

Figures in parenthesis represent $\sqrt{x + \frac{1}{2}}$ transformed values.

Fig. 6 – Effect of shade on total dry matter production of coleus at different stages of plant growth.

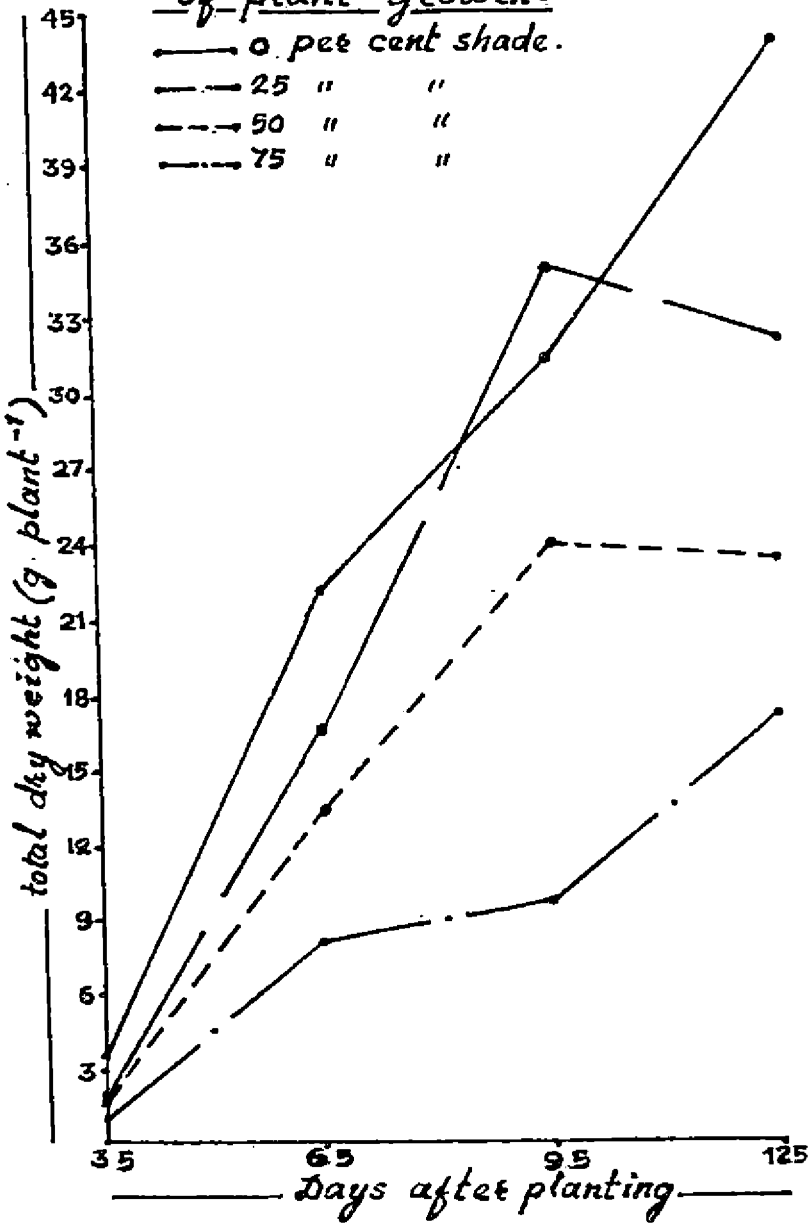
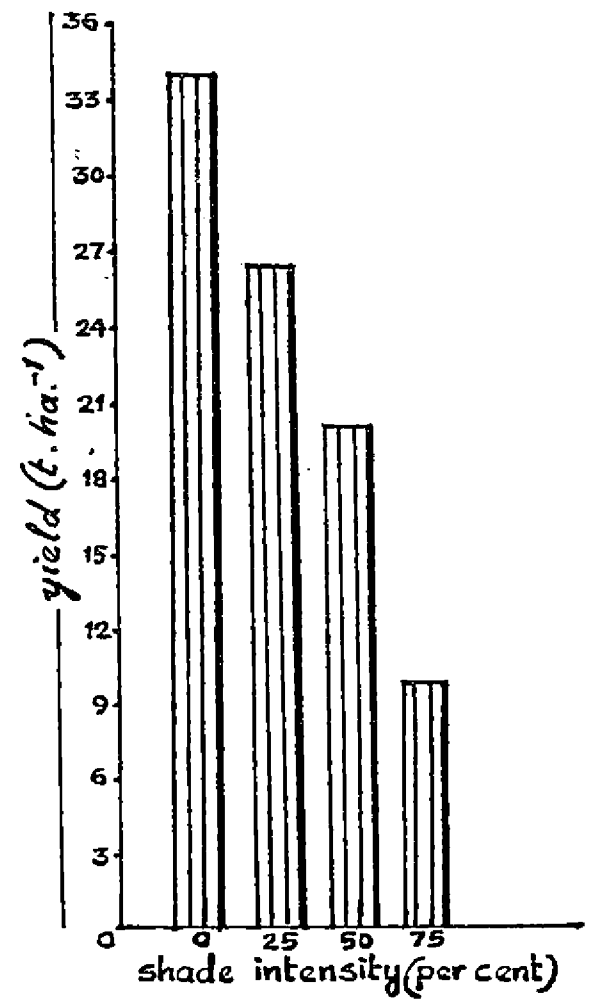


Fig. 7 – yield of coleus as affected by varying shade intensities.



Shade had significant effect on number of tubers at the early stages of growth, at 65 and 95 days after planting. The maximum and minimum values were recorded by plants in the open (0.0 per cent shade) and at the intense (75 per cent) shade level, respectively at these stages and it showed a drastic decline with increasing shade densities. The trend of results at harvest (125 days after planting) was markedly different with the plants in the open recording the lowest tuber number and those at the intense shade, the highest. The differences between the various shade levels were however, not statistically significant. At 35 days after planting, no tuber was formed in any of the shade levels, while at 65 days after planting no tuber was found at the intense shade of 75 per cent.

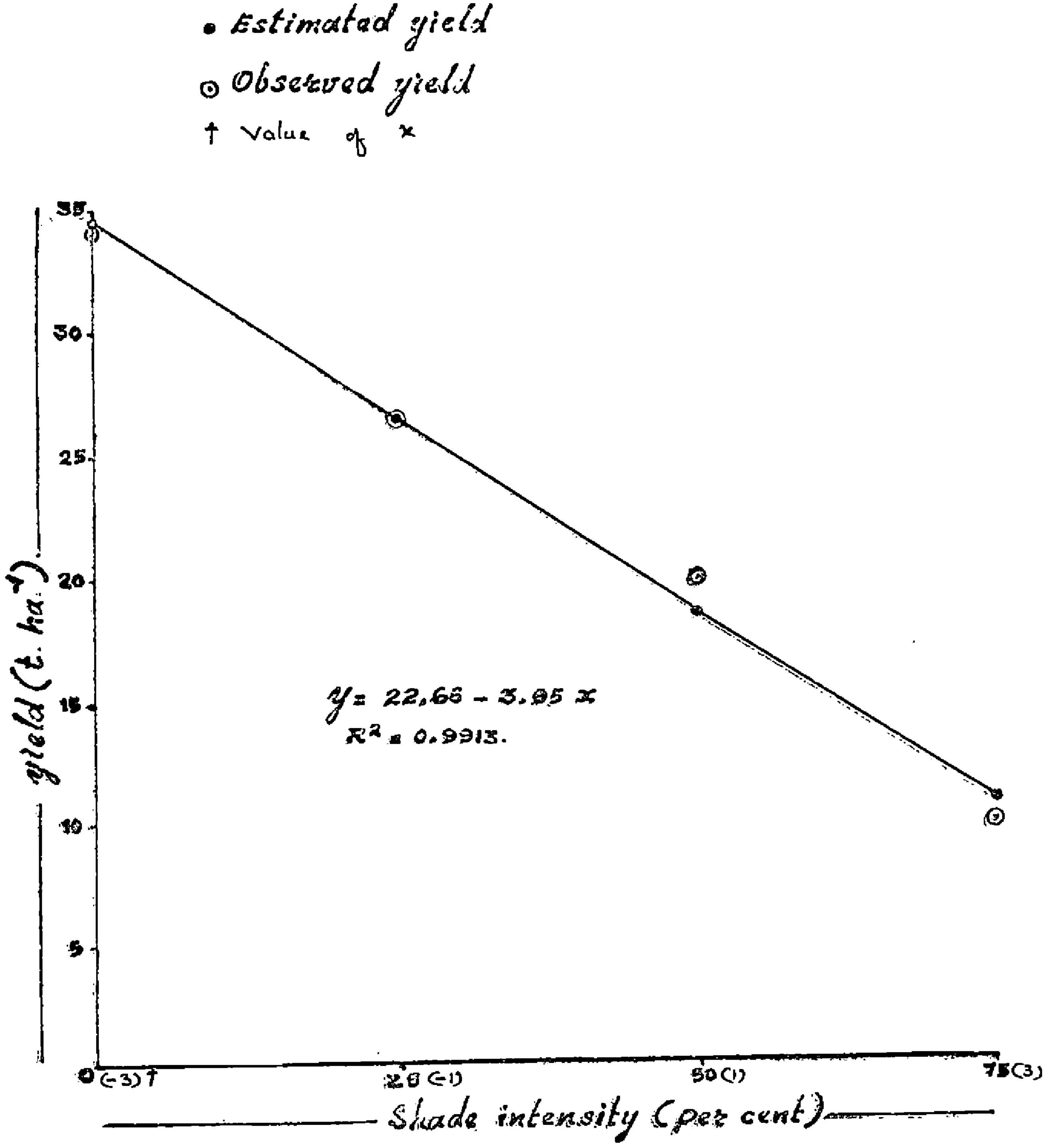
Over the stages, the value went on increasing with advancing age.

8. Tuber yield

The data are presented in Table 14 and Fig. 7. The analysis of variance is given in Appendix 12.

There was significant effect of shade on tuber yield in coleus. The maximum yield was obtained from the plants without shade and the minimum yield from the intensely shaded plants. The yield data showed a decreasing trend

Fig.-8. Yield response of coleus to varying shade intensities.



with increasing shade intensities. Also the differences between the shade levels were statistically significant. The yield obtained at low, medium and high shade levels, expressed as percentage of that at the open (no shade) were 77.7, 53.8 and 29.1 per cent, respectively.

Response curve

The tuber yield as a function of shade intensity showed a linear response (Fig. 8 and the analysis of variance in Appendix 48). The equation of the line is given below.

$$y = 22.66-3.95x$$

The co-efficient of determination R^2 of the above line being 0.9913, 99.13 per cent of total variation in the response can be explained by the fitted polynomial.

9. Yield of haulm

The data are presented in Table 14 and the analysis of variance in Appendix 12.

The effect of shade on haulm yield of coleus was not significant and it ranged from 2.24 to 4.80 t ha^{-1} dry matter. No general trend with increasing shade intensities was noticed.

Table 15. Effect of shade on nitrogen content of coleus leaf and stem + petiole at different growth stages

Shade intensity (per cent)	Leaf nitrogen content (per cent) (days after planting)				Stem + petiole nitrogen content (per cent) (days after planting)			
	35	65	95	125 (harvest)	35	65	95	125 (harvest)
0 (no shade)	3.39	1.75	1.57	1.25	1.60	0.75	0.56	0.62
25 (low shade)	4.11	2.14	1.25	1.38	2.01	0.93	0.65	0.58
50 (medium shade)	4.17	2.59	1.91	1.41	2.14	1.12	0.84	0.89
75 (high shade)	4.16	3.33	2.67	1.90	2.41	1.52	1.38	0.91
SEm ±	0.02	0.06	0.04	0.02	0.03	0.02	0.01	0.01
CD (0.05)	0.61	0.17	0.12	0.07	0.08	0.08	0.04	0.02

Table 16. Effect of shade on nitrogen content of tuber and on total uptake of nitrogen by coleus at different growth stages

Shade intensity (per cent)	Tuber nitrogen content (per cent) (days after planting)				Total uptake of nitrogen (kg ha^{-1}) (days after planting)			
	35	65	95	125 (harvest)	35	65	95	125 (harvest)
0 (no shade)		0.52	0.58	0.67	21.52	23.91	23.23	26.93
25 (low shade)		0.64	0.61	0.63	11.71	21.18	25.39	19.54
50 (medium shade)		-	0.62	0.85	12.96	20.31	24.86	18.28
75 (high shade)		-	0.50	0.96	11.53	16.14	15.87	15.62
SEm ±		-	0.04	0.02	2.92	3.27	4.16	3.73
CD (0.05)		-	NS	0.06	NS	NS	NS	NS

NS = Not significant

10. Harvest index

The data are presented in Table 14 and the analysis of varience in Appendix 12.

Shade significantly affected the harvest index in coleus and the value went on decreasing with increasing shade intensities, with plants in the open and at intense shade levels recording the maximum and minimum values, respectively.

B. Chemical studies

1. Content and uptake of nitrogen

The data on the content of nitrogen in the leaf, stem + petiole and tubers and the total uptake of nitrogen by plant as a whole are presented in the Table 15 to 16 and Fig. 9. The analyses of variance are given in Appendices 13 to 14.

Effect of shade on the nitrogen content of leaf, stem + petiole and tuber was significant at all the growth stages. The differences in the uptake of nitrogen between the various shade levels were not significant at any of the stages of growth. The nitrogen content in the plant components in general, showed an increasing trend with increasing shade intensities. In the case of uptake, the general

Table 17. Effect of shade on phosphorus content of coleus leaf and stem + petiole at different growth stages

Shade intensity (per cent)	Leaf phosphorus content (per cent) (days after planting)				Stem + petiole phosphorus content (per cent) (days after planting)			
	35	65	95	125 (harvest)	35	65	95	125 (harvest)
0 (no shade)	0.38	0.23	0.23	0.21	0.27	0.19	0.14	0.13
25 (low shade)	0.40	0.29	0.23	0.23	0.29	0.23	0.20	0.13
50 (medium shade)	0.42	0.36	0.24	0.20	0.24	0.25	0.17	0.15
75 (high shade)	0.43	0.38	0.22	0.18	0.28	0.18	0.21	0.14
SEm ±	0.01	0.01	0.01	0.01	0.01	0.01	0.005	0.005
CD (0.05)	0.02	0.02	0.03	0.02	NS	0.04	0.02	0.01

NS = Not significant

Table 18. Effect of shade on phosphorus content of tuber and on total uptake of phosphorus by coleus at different growth stages

Shade intensity (per cent)	Tuber phosphorus content (per cent) (days after planting)				Total uptake of phosphorus (kg ha^{-1}) (days after planting)			
	35	65	95	125 (harvest)	35	65	95	125 (harvest)
0 (no shade)		0.20	0.22	0.19	2.51	3.91	5.09	6.26
25 (low shade)		0.21	0.22	0.21	1.19	3.64	6.32	4.30
50 (medium shade)		-	0.22	0.22	1.35	3.37	4.21	3.71
75 (high shade)		-	0.17	0.17	1.18	1.82	1.84	2.33
SEm ±		-	0.01	0.01	0.32	0.56	0.67	0.70
CD (0.05)		-	NS	0.02	0.99	NS	2.06	2.16

NS = Not significant

trend was that of a decrease with increasing shade levels, with the intense shade and that without shade levels recording the maximum and minimum contents, respectively, and vice versa in the case of total uptake of nitrogen.

Over the stages, the content in the leaf and stem + petiole showed a decreasing trend with advancing age until harvest. In the case of tuber, a slight increase was noticed at harvest. Total uptake of nitrogen showed an increasing trend upto the pre-harvest stage. At the time of harvest, it decreased except in the case of plants in the open.

2. Content and uptake of phosphorus

The data on the content of phosphorus in leaf, stem + petiole and tubers and the total uptake of phosphorus are presented in Tables 17 to 18 and Fig. 9. The analyses of variance are given in Appendices 14 to 15.

There was significant effect of shade on phosphorus content in leaf, stem + petiole and tuber and on the total uptake of phosphorus at almost all stages of plant growth. The content ranged from 0.18 to 0.43, 0.13 to 0.29 and 0.17 to 0.22 per cent in leaf, stem + petiole and tuber, respectively. The results were highly variable and the only general trend that could be noticed was that the

Table 19. Effect of shade on potassium content of coleus leaf and stem + petiole at various growth stages

Shade intensity (per cent)	Leaf potassium content (per cent) (days after planting)				Stem + petiole potassium content (per cent) (days after planting)			
	35	65	95	125 (harvest)	35	65	95	125 (harvest)
0 (no shade)	4.50	2.37	2.12	1.52	6.90	4.20	3.40	2.82
25 (low shade)	5.39	3.08	2.34	1.89	7.90	5.99	4.28	3.68
50 (medium shade)	5.21	3.25	2.36	1.54	7.97	6.33	4.76	4.40
75 (high shade)	5.09	3.98	3.22	1.99	7.99	6.77	5.14	4.40
SEm ±	0.05	0.05	0.08	0.05	0.05	0.05	0.21	0.09
CD (0.05)	0.14	0.17	0.26	0.15	0.15	0.14	0.66	0.27

Table 20. Effect of shade on potassium content of tuber and on total uptake of potassium by coleus at different growth stages

Shade intensity (per cent)	Tuber potassium content (per cent) (days after planting)				Total uptake of potassium (kg ha^{-1}) (days after planting)			
	35	65	95	125 (harvest)	35	65	95	125 (harvest)
0 (no shade)		2.35	2.04	2.20	32.77	59.82	84.81	84.98
25 (low shade)		1.80	2.16	2.30	18.07	63.19	90.85	71.93
50 (medium shade)		-	1.95	2.30	19.39	52.61	60.89	57.95
75 (high shade)		-	1.86	2.30	15.57	36.42	33.50	43.05
SEm ±		-	0.11	0.09	4.11	7.62	12.80	9.68
CD (0.05)		-	NS	NS	12.68	NS	39.45	29.82

NS = Not significant

phosphorus content showed an increasing trend with increasing shade intensities at the early stages of growth. The total phosphorus uptake also did not show any distinct pattern between the shade levels except at 65 and 125 days of growth when the uptake went on decreasing with increasing shade levels.

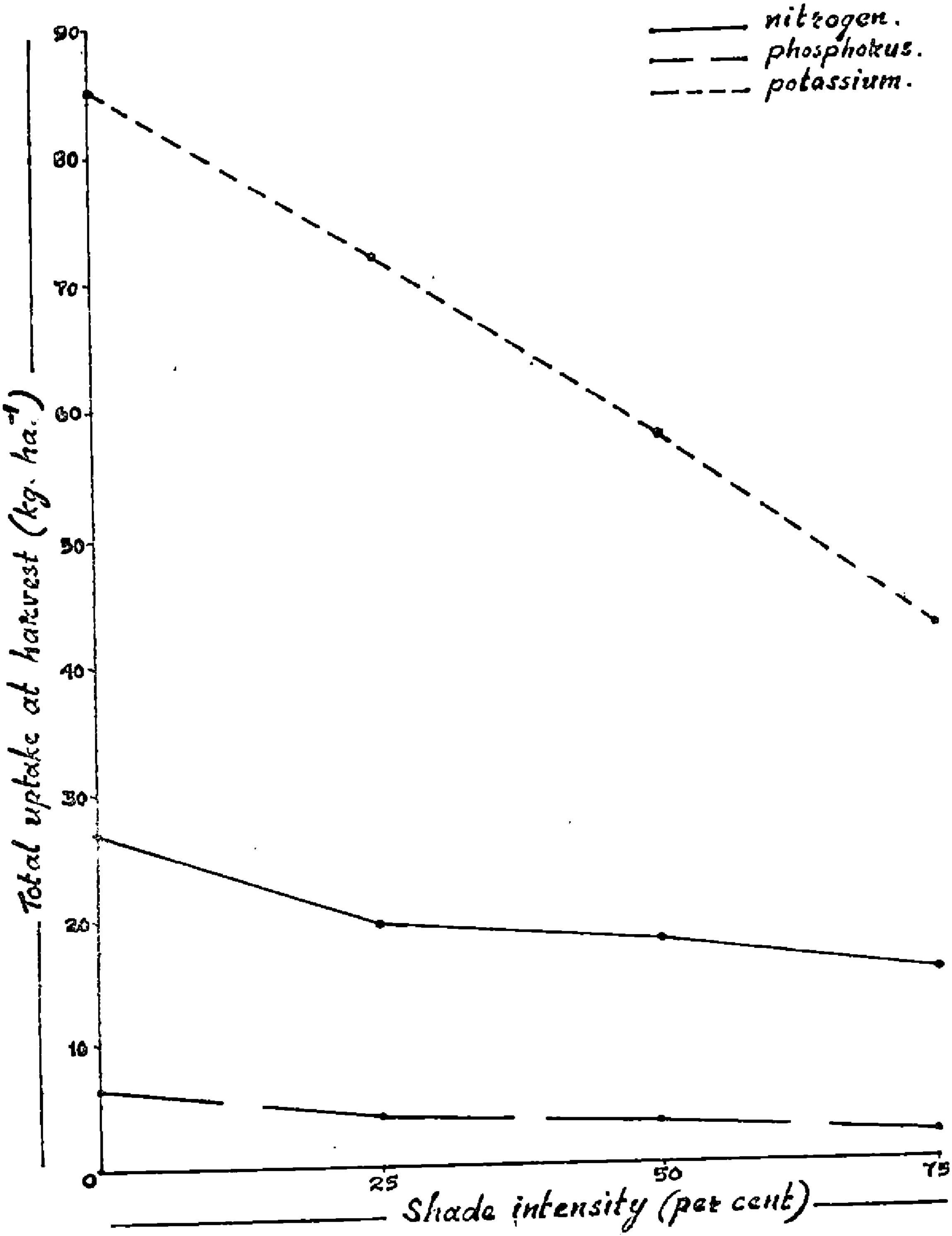
With age, the leaf phosphorus content showed a declining trend at all stages of growth. Similar observation could be made in the case of stem + petiole at lower shade levels. At medium and high shade levels, no distinct trend could be noticed. In general, the total uptake of phosphorus went on increasing with advancing age, at all the shade levels.

3. Content and uptake of potassium

The data on the content of potassium in leaf, stem + petiole and tubers and the total uptake of potassium are given in Table 19 to 20 and Fig. 9. The analyses of variance are given in Appendices 15 to 16.

Significant effect of shade on the potassium content of leaf and stem + petiole was observed at all the growth stages. In the case of tuber potassium content, significance could be noted only at 35 days after planting and in the case of total uptake at 35 and 95 days of growth. Except at 35 and 95 days after planting, in the case of leaf and

Fig. 9- Uptake of nitrogen, phosphorus and potassium as affected by varying shade intensities in Coleus.



phosphorus content showed an increasing trend with increasing shade intensities at the early stages of growth. The total phosphorus uptake also did not show any distinct pattern between the shade levels except at 65 and 125 days of growth when the uptake went on decreasing with increasing shade levels.

With age, the leaf phosphorus content showed a declining trend at all stages of growth. Similar observation could be made in the case of stem + petiole at lower shade levels. At medium and high shade levels, no distinct trend could be noticed. In general, the total uptake of phosphorus went on increasing with advancing age, at all the shade levels.

3. Content and uptake of potassium

The data on the content of potassium in leaf, stem + petiole and tubers and the total uptake of potassium are given in Table 19 to 20 and Fig. 9. The analyses of variance are given in Appendices 15 to 16.

Significant effect of shade on the potassium content of leaf and stem + petiole was observed at all the growth stages. In the case of tuber potassium content, significance could be noted only at 35 days after planting and in the case of total uptake at 35 and 95 days of growth. Except at 35 and 95 days after planting, in the case of leaf and stem + petiole the potassium content went on increasing with increasing shade level at all the growth stages. No distinct trend was noticed in the case of tuber potassium content and it ranged from 1.80 to 2.35 per cent. The total uptake of potassium did not show any distinct trend.

Over the stages, the content in the leaf and stem + petiole showed a declining trend while tuber potassium content, in general, showed a slight increase. Uptake of potassium was increasing with advancing age upto 95 days after planting and it showed a slight decline at the intermediate shade levels. It went on increasing upto harvest in the case of plants without shade and at intense shade.

II. Soil characters

Soil nutrient status

The data on the soil nutrient status after the cultivation of coleus are presented in Table 21 and the analysis of variance in Appendix 17.

The differences in the content of total nitrogen and available potassium in the soil at different shade levels were significant. No distinct trend could be observed in total nitrogen and available phosphorus content with increasing shade levels but the available potassium content in the soil was higher at higher shade levels.

Table 21. Effect of shade on nutrient status of soil after the crop of coleus

Shade intensity (per cent)	Total nitrogen (per cent)	Available phosphorus (ppm)	Available potassium (ppm)
0 (no shade)	0.10	1.62	73.34
25 (low shade)	0.07	2.30	77.57
50 (medium shade)	0.10	1.92	82.56
75 (high shade)	0.08	1.29	101.57
SEm ±	0.003	0.27	1.94
CD (0.05)	0.009	0.83	5.98

Comparison with the pre-experimental soil nutrient status showed a slight increase in the total nitrogen content at all the shade levels except at low shade. Available phosphorus showed a slight increase at low and medium shade levels. The potassium content was much lower after the crop season, the extent of decrease being lower at higher shade levels.

DISCUSSION

The results of the present study indicated that the decrease in yield of tuber in coleus was proportionate to the intensity of shade and was almost linear. The maximum yield was obtained in plots without shade and the yields obtained at 25, 50 and 75 per cent shade levels were 77.7, 58.8 and 29.1 per cent, respectively, of that in the open. As evidenced by the inversely proportional and linear response of tuber yield to shade, it may be concluded that coleus is a plant with no special adaptation for growth under shade and may hence be classified as 'shade-intolerant'. Such a shade response will qualify this crop as suitable for intercropping only under conditions of ample light infiltration. As a rough indication, it may be noted that in intercropping situations with about 50 per cent light infiltration, the yield will be half as much as that in the open.

Among the two components that contributed towards tuber yield viz., tuber number and tuber weight, there was a positive influence of shade on the number of tubers. However, the contribution by this component towards the final yield was meagre and in fact, the relation between the tuber number and tuber yield appeared to be inverse. As indicated from the data on plant height (Table 12), the plants under shade tended to grow longer at least upto intermediate shade levels and they apparently were slender and weak. The shoots tended to trail on the soil surface which induced tuber formation at the nodes in contact with the soil. Though this contributed substantially towards the tuber number (Table 14), these failed to develop properly and thus influence the final tuber yield.

An insight into the probable mechanism responsible for the shade response of this crop can be had from the comparison of the response on dry matter accumulation of the crop (Table 14). Total dry weight of the plant at the different stages followed an identical decrease as that of tuber yield, because of shading. Assuming again, that dry matter accumulation would be a measure of photosynthetic accumulation, it may be considered that the photosynthetic factors were almost exclusively responsible for the observed responses to shade.

It may also be worthwhile to discuss the components that were responsible for the variation in dry matter yield. Among the two components that contribute towards photosynthate accumulation viz. leaf area and leaf efficiency, there was increase in leaf area because of shading upto the intermediate (50 per cent) shade level followed by a conspicuous decline at intense (75 per cent) shade. The increase in leaf area index because of shading may perhaps be a plant adaptation to expose larger photosynthetic surface under limited illumination. However, as indicated by the high leaf area indices and the almost inverse relation between dry matter accumulation and the LAI upto the intermediate shade level, it may be concluded that such a plant adaptation was not adventageous in plant communities of this crop. A comparison of the LAI values (Table 12) would reveal that the mean values were well above 4.00 at and beyond 65 days after planting and the mean maximum of 9.46 was noted in the open, 65 days after planting. The fact that the leaf orientation in coleus is apparently near-horizontal and that the leaf area indices were comparatively high indicate that there was probably strong mutual shading even in the open. Since there was increase in LAI due to shading, there was probably much more of mutual shading at these shade levels. These would have normally decreased the efficiency of leaves to photosynthesise by making a larger proportion of lower leaf surfaces either at sub-saturation or parasitic levels. Therefore, even though there was increase in the photosynthetic surface because of shading, it did not result in an increase in dry matter yield.

A quantitative estimation of the efficiency of the leaves to photosynthesise can be had from the data on net assimilation rate (Table 14). However, these figures are available only upto 95 days after planting as further calculation of this growth characteristic could not be done because of leaf shedding after this stage. The available data upto the period of 95 days after planting, generally indicated a decrease in the efficiency of the leaves due to shading.

Even though the patterns of yield and dry matter accumulation followed a predictable decrease with increasing shade levels, the trend in plant height (Table 12) appeared to be different. With increasing shade levels, the plants tended to be taller and this effect was nearly consistent. Such an induction of plant height increase by shade is in conformity with the results reported on many other crops (Panikar, et al., 1969 in tobacco; Aclan and Quisumbing, 1976 in ginger and Tarila et al., 1977 in cowpea).

The contents of to (chlorophyll 'a' and 'b') (Table 13) were significantly influenced by shading and their contents went on increasing with increasing shade levels. This is in agreement with the findings of Clark (1905), Evans and Murray (1953), Guers (1971), Ramaswami (1960), Venkatamani (1961), Khossien (1970), Okali and Owusu (1975), Bjorkman and Holmgren (1963), Cooper and Qualls (1967) and Radha (1979). The differences in the ratio of chlorophyll a-b remained non-significant and it was lowest at the later stages at all shade levels which showed that the content of chlorophyll 'b' increased while that of chlorophyll 'a' decreased.

The contents of the nutrients nitrogen, phosphorus and potassium in the plant parts showed a persistent increase because of shading. One reason attributable to this is the dilution effect at high light intensities because of higher dry matter production but the involvement of other physiological factors on the accumulation of nutrients cannot be ruled out. The induction of an increase in contents of mineral nutrients by shading has been widely reported in several crops (Myhr and Saeho, 1969; Kraybill, 1922; Guers, 1971; Fretz and Dunham, 1971; Cantliffe, 1972; Rodriguez et al., 1973; Radha, 1979 and Wong and Wilson, 1980). The uptake of these nutrients, on the contrary, registered a conspicuous decrease with increasing shade levels, the differences between shade levels being statistically significant in the case of phosphorus and potassium at most of the stages. Though in the case of nitrogen, this did not attain levels of statistical significance, the trend was steady and conspicuous. These decreases in uptake of nutrients because of shading would indicate that the effect of decreasing dry matter production had the dominant influence in deciding total uptake and it could more than compensate the increased contents of nutrients resulting from shading.

Another ancillary conclusion is that the crop requirement of nutrients would be substantially less under shade. If the uptake is taken as an index of crop requirement, the quantity of fertilizer needed by this crop would be 72.56, 67.88 and 58.0 per cent, respectively, in the case of nitrogen at 25, 50 and 75 per cent shade levels. The corresponding values for phosphorus would be 68.69, 59.27 and 37.22 per cent and in the case of potassium 84.64, 68.19 and 50.66 per cent, respectively.

Analysis of the soil after harvest of the crop (Table 21) showed a steady increase in the content of available potassium with increasing shade levels. There was no consistent pattern in the case of total nitrogen and available phosphorus. As compared to pre-experimental soil status, the potassium content after harvest of the crop was markedly less and that of nitrogen conspicuously more. The available phosphorus content showed only slight, but protracted changes. The reasons for the decrease in the content of available potassium and for the increase in nitrogen content had been discussed already, while dealings with sweet potato.

The general conclusion on the results and discussion may be summarised as follows.

1. There was a significant decrease in the yield of tuber which was proportionate to the intensity of shade and was almost linear. Hence, it may be considered that coleus is a plant with no special adaptation for growth under shade and may therefore be classified as 'shade-intolerant'. This would qualify this crop as suitable for intercropping only under conditions of ample light infiltration.

2. Photosynthetic factors appear to be almost exclusively responsible for the observed responses to shade.

3. There was an increase in leaf area because of shading upto the intermediate (50 per cent) shade level, but it did not result in an increase in dry matter yield. Strong mutual shading appeared to be probable even in the open.

4. The fertilizer requirement by the crop would be substantially less under shading. Indications are that the nutrient requirements of a crop upto 50 per cent shade intensity may be about 70 per cent of that for a sole crop in the open.

Colocasia

Colocasia

(*Colocasia esculenta* (L.) Schott.)

RESULTS

I. Plant characters

A. Biometric observations

1. Plant height

The data are presented in Table 22 and the analysis of variance in Appendix 18.

Shade had a significant effect on plant height in colocasia only at 60 and 90 days after sprouting when the plant height went on decreasing with increasing shade intensity. The plants in the intense (75 per cent) shade recorded the lowest height which was statistically inferior to that at other shade levels. The treatment receiving full illumination (0 per cent shade) recorded the maximum height which was at par with 25 and 50 per cent shade. At the earlier and later stages, the differences between shade levels was not significant.

Over the stages, the plant height increased upto 60 days of sprouting and after this stage a steady decrease in height was noticed. The extent of decline after 60 days of sprouting appeared to be steeper at lower shade intensities.

2. Girth at collar

The data are presented in Table 22 and the analysis of variance in Appendix 18.

Girth at collar was significantly affected only at 60 days after sprouting, when the highest and lowest values were recorded by plants without shading and at high shade intensities. The girth at intense shade was statistically inferior to that at other shade levels.

Collar girth was maximum at 60 days after sprouting in all shade levels, and then alternate decrease and increase was noticed after 60 days of growth until 150 days after sprouting. Again, as in the case of plant height, extent of decrease in girth was more conspicuous at lower shade intensities.

3. Number of tillers

The data are presented in Table 23 and the analysis of variance in Appendix 19.

Shade had a significant effect on this character at all stages of plant growth excepting 30 days after sprouting. At these stages, the plants at full illumination recorded the maximum value. Lowest value was noted at intense (75 per cent) shade level at all stages. There

Table 22. Effect of shade on height of plant and girth at collar of colocasia at different growth stages

Shade intensity (per cent)	Height of plants (cm) (days after sprouting)					Girth at collar (cm) (days after sprouting)				
	30	60	70	120	150	30	60	90	120	150
0 (no shade)	55.3	82.6	73.5	51.8	45.6	11.2	16.3	8.5	11.8	7.9
25 (low shade)	59.1	78.1	65.9	59.2	52.0	10.2	13.7	8.7	10.1	8.9
50 (medium shade)	68.2	68.6	62.4	57.1	51.2	11.4	12.4	8.8	9.3	9.0
75 (high shade)	57.5	51.9	50.8	55.1	51.9	9.4	9.0	8.1	9.6	8.7
SEm ±	4.3	5.0	3.5	3.2	3.0	0.9	1.0	0.4	0.7	0.4
CD (0.05)	NS	15.6	10.6	NS	NS	NS	3.0	NS	NS	NS

NS = Not significant

Table 23. Effect of shade on tiller production and leaf area index of colocasia at various growth stages

Shade intensity (per cent)	Number of tillers plant^{-1} (days after sprouting)					Leaf area index (days after sprouting)				
	30	60	90	120	150	30	60	90	120	150
0 (no shade)	4.3	11.2	11.3	13.5	12.4	0.67	1.43	0.83	0.83	0.41
25 (low shade)	4.9	7.7	9.7	11.9	11.7	0.71	1.13	1.07	0.74	0.55
50 (medium shade)	3.7	5.5	7.0	10.3	8.1	0.76	0.55	0.67	0.80	0.54
75 (high shade)	3.1	3.4	4.9	5.2	5.6	0.68	0.57	0.55	0.31	0.48
SEm ±	0.7	1.0	1.0	1.3	1.4	0.10	0.30	0.13	0.09	0.07
CD (0.05)	NS	3.1	3.1	3.9	4.5	NS	NS	NS	0.29	NS

NS = Not significant

was a steady decrease in the number of tillers with increasing shade intensities at all the stages of growth. Though the differences between the individual treatments were not always significant, the general trend was one of decrease in the number of tillers with increasing shade levels.

With advancing age, the number of side sprouts showed an increasing trend upto 120 days after sprouting followed by a slight fall between 120 and 150 days of growth except at the intense shade level.

4. Leaf area index

The data are presented in Table 23 and the analysis of variance in Appendix 19.

Significant effect of shade on leaf area index in colocasia was noticed only at 120 days after sprouting when the LAI in the open was found to be significantly lower than at all other shade levels which themselves were on par. No general trend of treatment differences could be noted mainly because this observation was violated by the damage of the crop.

Over the stages, LAI was found to be maximum at 60 days after sprouting at lower shade levels and then there was a decreasing trend until 150 days after sprouting.

Table 24. Effect of shade on content of chlorophyll 'a' and 'b' (mg g^{-1} fresh weight) of colocasia leaves at various growth stages

Shade intensity (per cent)	Chlorophyll 'a' (days after sprouting)				Chlorophyll 'b' (days after sprouting)			
	80	110	140	170	80	110	140	170
0 (no shade)	1.51	1.70	1.44	1.29	1.83	2.18	1.90	0.91
25 (low shade)	1.30	1.70	1.48	1.22	1.57	2.13	1.94	0.85
50 (medium shade)	1.59	1.90	1.58	1.48	1.83	2.47	2.06	1.10
75 (high shade)	1.58	1.78	1.71	1.58	1.92	2.24	2.29	1.28
SEm ±	0.04	0.04	0.03	0.03	0.11	0.06	0.06	0.06
CD (0.05)	0.12	0.13	0.10	0.09	NS	0.20	0.17	0.18

NS = Not significant

Table 25. Effect of shade on total chlorophyll content (mg g^{-1} fresh weight) and chlorophyll a-b ratio of colocasia leaves at various growth stages

Shade intensity (per cent)	Total chlorophyll (days after sprouting)				Chlorophyll a:b (days after sprouting)			
	80	110	140	170	80	110	140	170
0 (no shade)	3.34	3.88	3.34	2.20	0.84	0.78	0.76	1.43
25 (low shade)	2.87	3.83	3.42	2.07	0.83	0.80	0.77	1.44
50 (medium shade)	3.66	4.36	3.64	2.58	0.79	0.77	0.77	1.36
75 (high shade)	3.50	4.02	4.00	2.86	0.82	0.79	0.75	1.27
SEm ±	0.10	0.11	0.09	0.07	0.01	0.01	0.01	0.05
CD (0.05)	0.31	0.33	0.27	0.22	0.04	0.02	NS	NS

NS = Not significant

Other than this general observation, no valid conclusion on the trend could be drawn on the stage-wise variation of individual treatments.

5. Chlorophyll content of leaves

The data on contents of chlorophyll 'a', 'b' and total chlorophyll; ratio of chlorophyll a-b are presented in Table 24 to 25 and the analyses of variance in Appendices 20 to 21.

At almost all stages, the effect of shade on the contents of chlorophyll 'a', 'b' and total chlorophyll were found to be significant. Still no general trend on the variation with increasing shade levels could be discerned. The effect of shade on chlorophyll a:b was found to be significant only at early stages. Here again, no general conclusion could be drawn on the trend of results.

Stage-wise comparison of the chlorophyll contents showed that the content of chlorophyll 'a' remained the same while that of chlorophyll 'b' decreased after 140 days of growth. Consequently total content decreased and the ratio increased.

6. Total dry weight

The data are presented in Table 26 and Fig.10. The analysis of variance is given in Appendix 22.

Table 26. Effect of shade on total dry weight, tuber yield, haulm yield and harvest index of colocasia

Shade intensity (per cent)	Total dry weight (g plant^{-1}) (days after sprouting)						Yield of tuber (t ha^{-1} fresh weight)		Yield of haulm (t ha^{-1} dry weight)	Harvest index
	30	60	90	120	150	180 (harvest)	Total tuber	Side tuber		
0 (no shade)	12.6	54.7	66.6	99.8	105.4	131.4	17.51	12.54	0.21	0.948
25 (low shade)	12.1	35.6	55.0	70.3	95.5	112.5	16.77	11.06	0.28	0.947
50 (medium shade)	12.2	15.8	28.6	61.4	75.3	109.2	15.77	9.75	0.41	0.922
75 (high shade)	9.0	11.4	20.2	20.4	41.5	61.0	7.29	3.47	0.39	0.875
SEm ±	1.6	6.9	6.4	7.6	10.0	12.9	1.81	1.34	0.07	0.012
CD (0.05)	NS	NS	19.7	23.5	30.9	39.7	5.58	4.12	NS	0.038

NS = Not significant

Fig. 10 - Effect of shade on total dry matter production of colocasia at different growth stages.

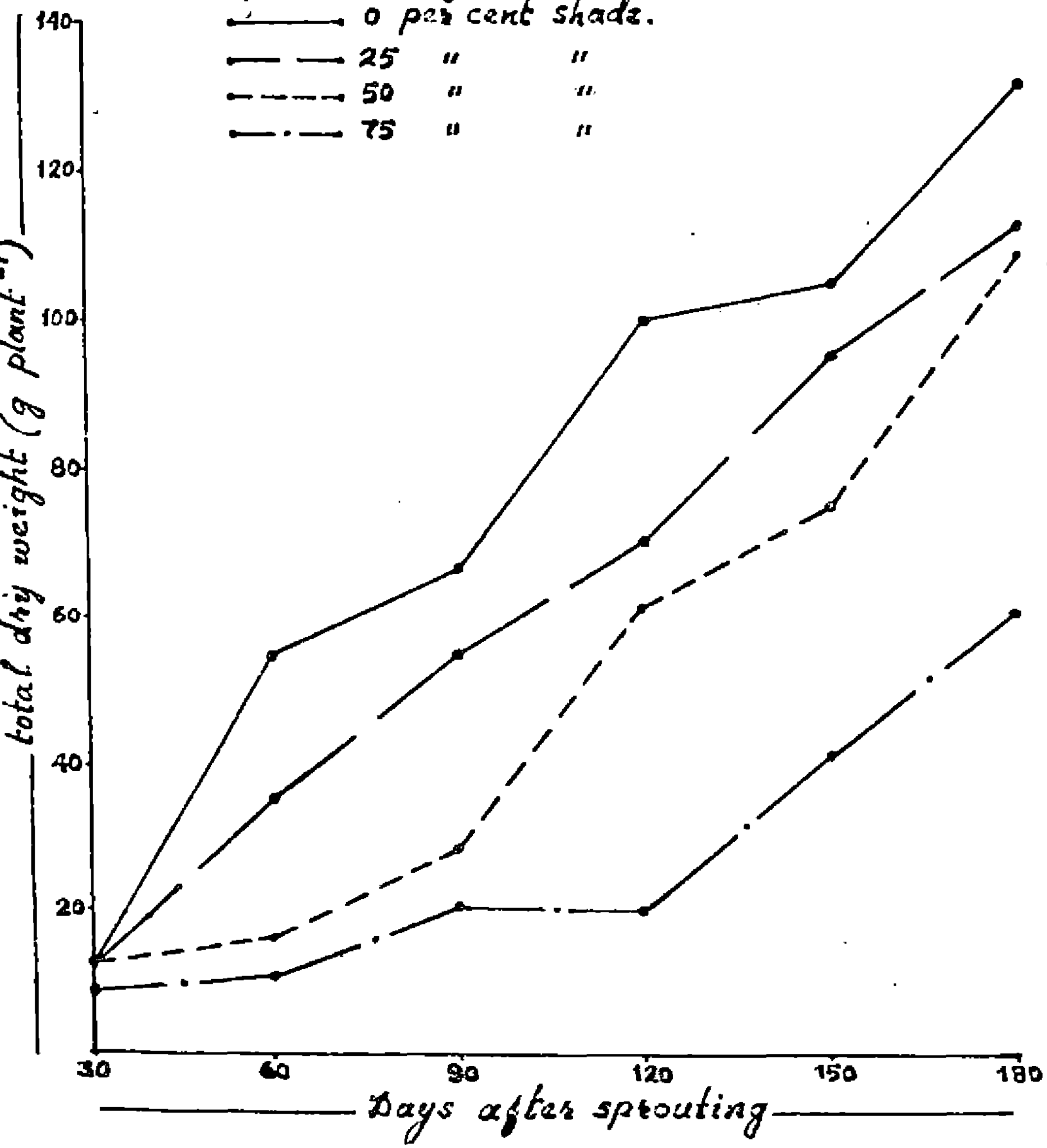
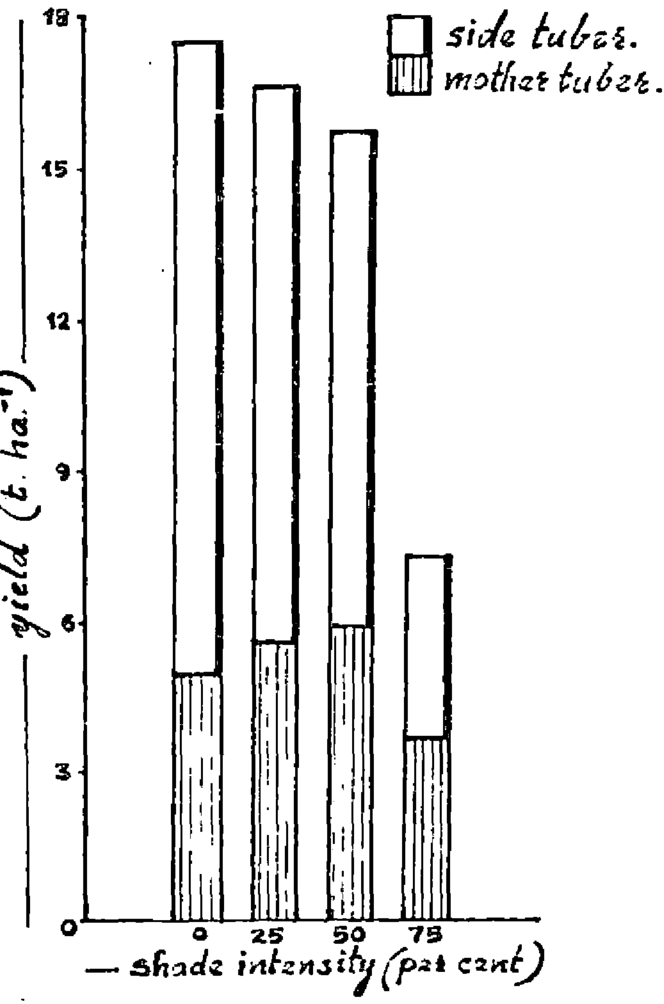


Fig. 11 - Yield of colocasia as affected by varying shade intensities.



The results indicated that shade had a significant effect on plant dry weight throughout the growth stages except at the initial stages. Barring the initial stage, in general, there was a decline in plant dry weight with increasing intensities of shade. However, the treatment differences were significant from 90th day onwards.

The plant dry weight showed a marked and steady increase over the stages. The extent of such increase was progressively higher with decreasing shade levels.

7. Net assimilation rate

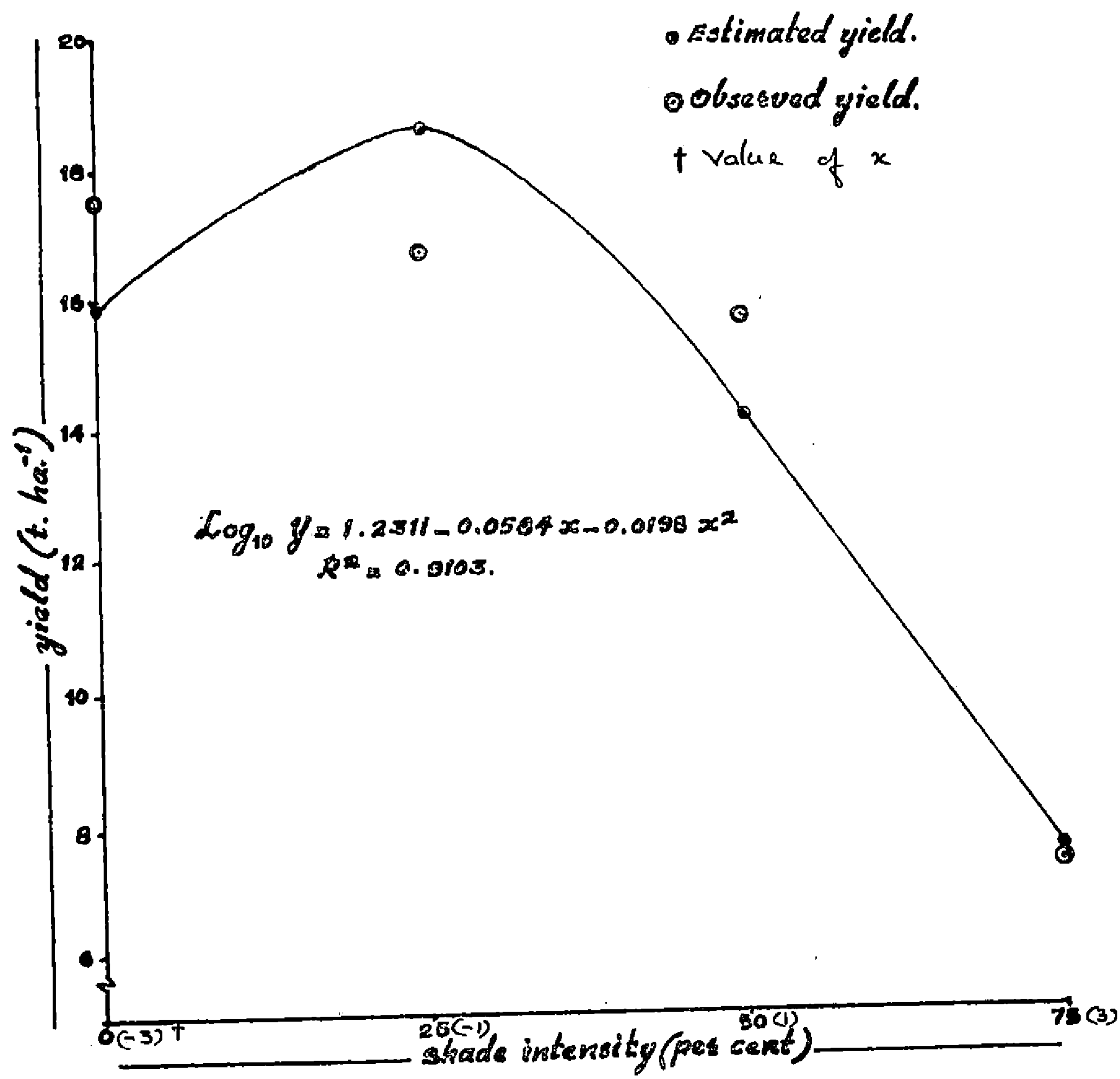
NAR was also calculated between different stages but the data are not presented since these were violated much by occasional damage ofthe crop by blight (Phytophthora palmivora (Butler) Butler) and also by the attack by wild boar.

8. Tuber yield

The data are presented in Table 26 and Fig. 11. The analysis of variance is given in Appendix 22.

The tuber yield was significantly affected by shade. The plants in the open recorded the highest yield of both total tubers and side tubers, and that at the intense shade level the lowest yield. The yield showed a declining trend

Fig.12. Yield response of colocasia to varying shade levels.



with increasing shade intensities. However, the yield at full illumination was statistically at par with low (25 per cent) and medium (50 per cent) shade levels. It was also noticed that the proportion of side tubers to total tuber yield decreased with increasing shade intensities i.e. 71.62, 65.75, 61.83 and 47.6 per cent at full illumination, low, medium and high shade levels, respectively. Calculated as percentage of the yield in the open, the yields at low, medium and high shade levels were 95.8, 90.1 and 41.6 per cent, respectively.

Response curve

Effect of different intensities of shade on tuber yield of colocasia was not linear but was exponential. The logarithms of yield as a function of shade intensity was found to give a parabolic fit to the data (Fig. 12 and the analysis of variance in Appendix 48). The equation of the curve is as follows.

$$\log_{10} y = 1.2311 - 0.0584x - 0.0198x^2$$

The co-efficient of determination of the curve was found to be 0.9103, which showed that 91.03 per cent of the total variation in the response can be explained by the fitted polynomial.

9. Yield of haulm

The data are presented in Table 26 and the analysis of variance in Appendix 22.

The influence of shade on haulm yield was not significant and it ranged from 0.21 to 0.41 t ha^{-1}. Minimum yield was obtained from the plants in the open.

10. Harvest index

The data are presented in Table 26 and the analysis of variance in Appendix 22.

It was noticed that shade had a significant effect on the harvest index of colocasia. The value showed a declining trend with increasing shade intensities. The plants in the open and at intense shade level recorded the maximum and minimum values, respectively, but the values at 25 and 50 per cent shade were statistically at par with that in the open.

B. Chemical studies

1. Content and uptake of nitrogen

The data on the content of nitrogen in leaf, pseudostem and tubers and the total uptake of nitrogen by the plant are presented in Tables 27 to 28 and Fig. 13. The analyses of variance are given in Appendices 23 to 24.

Table 27. Effect of shade on nitrogen content of leaf and pseudostem of colocasia at different growth stages

Shade intensity (per cent)	Leaf nitrogen content (per cent) (days after sprouting)						Pseudostem nitrogen content (per cent) (days after sprouting)					
	30	60	90	120	150	180 (harvest)	30	60	90	120	150	180 (harvest)
0 (no shade)	3.84	4.20	4.07	3.86	3.81	3.08	2.14	1.81	1.87	1.64	1.50	1.63
25 (low shade)	4.33	3.99	4.18	4.30	3.75	3.00	2.43	1.69	1.98	1.89	1.53	1.54
50 (medium shade)	4.17	4.09	4.71	4.11	3.83	2.85	2.26	2.06	2.02	1.88	1.34	1.38
75 (high shade)	4.01	4.89	4.75	4.44	4.25	3.07	2.06	1.94	2.10	2.36	1.85	1.74
SEm ±	0.03	0.07	0.11	0.06	0.07	0.04	0.03	0.10	0.03	0.02	0.03	0.03
CD (0.05)	0.11	0.23	0.35	0.19	0.21	0.12	0.10	NS	0.09	0.07	0.08	0.10

NS = Not significant

Table 28. Effect of shade on nitrogen content of tuber and on total nitrogen uptake of colocasia at various growth stages

Shade intensity (per cent)	Tuber nitrogen content (per cent) (days after sprouting)						Total nitrogen uptake (kg ha^{-1}) (days after sprouting)					
	30	60	90	120	150	180 (harvest)	30	60	90	120	150	180 (harvest)
0 (no shade)	-	0.44	0.47	1.22	1.18	1.26	14.38	38.30	34.48	55.32	53.62	63.79
25 (low shade)	-	0.45	0.44	1.34	1.18	1.24	15.37	25.72	32.41	44.95	49.22	53.65
50 (medium shade)	-	0.60	0.46	0.44	1.14	1.38	14.39	13.68	20.70	25.61	38.81	56.90
75 (high shade)	-	0.56	0.48	0.67	1.26	1.49	10.56	12.12	16.15	12.14	26.25	35.08
SEm ±	-	0.02	0.01	0.03	0.01	0.03	1.94	5.40	4.03	4.25	5.20	6.85
CD (0.05)	-	0.05	0.03	0.08	0.03	0.08	NS	16.63	12.42	13.11	16.04	NS

NS = Not significant

In general, the content of nitrogen in the leaf, pseudostem and tubers and the total uptake of nitrogen were found to be significantly affected by the different shade levels, throughout the growth stages. The average nitrogen content ranged from 2.85 to 4.89, 1.34 to 2.43 and 0.44 to 1.49 per cent, respectively, in the case of leaf, pseudostem and tubers. The mean total uptake of nitrogen ranged from 10.56 to 63.79 kg ha^{-1}. Though the differences in nitrogen content between different shade levels were statistically significant at all stages of growth, the variability in the results were too high to draw any general conclusion. The total uptake of nitrogen showed a trend of decrease with increasing shade intensities. It may be noted that the total dry matter accumulation by the plant also showed an identical trend.

Over the stages, the content did not show much reduction at later stages of growth in the case of leaf and pseudostem, while in the tubers, a slight increase was noticed at the corresponding period, at all the shade intensities. The total uptake of the nutrients went on increasing with advancing age, the maximum uptake values being recorded at the harvest stage, at all the shade levels.

Table 29. Effect of shade on phosphorus content of leaf and pseudostem of colocasia at different growth stages

Shade intensity (per cent)	Leaf phosphorus content (per cent) (days after sprouting)						Pseudostem phosphorus content (per cent) (days after sprouting)					
	30	60	90	120	150	180 (harvest)	30	60	90	120	150	180 (harvest)
0 (no shade)	0.46	0.44	0.39	0.43	0.43	0.27	0.56	0.60	0.48	0.43	0.57	0.38
25 (low shade)	0.52	0.43	0.37	0.45	0.40	0.23	0.59	0.48	0.43	0.47	0.51	0.43
50 (medium shade)	0.54	0.54	0.38	0.43	0.42	0.23	0.45	0.73	0.39	0.46	0.45	0.32
75 (high shade)	0.57	0.57	0.42	0.51	0.40	0.23	0.60	0.61	0.40	0.53	0.43	0.35
SEm ±	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.03	0.01	0.01	0.01	0.01
CD (0.05)	0.04	0.02	NS	0.04	NS	0.03	0.03	0.08	0.03	0.02	0.04	0.04

NS = Not significant

Table 30. Effect of shade on tuber phosphorus content and on total uptake of phosphorus by colocasia at different growth stages

Shade intensity (per cent)	Tuber phosphorus content (per cent) (days after sprouting)						Total uptake of phosphorus (kg ha^{-1}) (days after sprouting)					
	30	60	90	120	150	180 (harvest)	30	60	90	120	150	180 (harvest)
0 (no shade)	-	0.22	0.25	0.18	0.21	0.33	2.42	8.48	7.98	8.60	9.03	16.16
25 (low shade)	-	0.23	0.12	0.22	0.16	0.29	2.49	5.12	4.92	7.98	7.40	11.91
50 (medium shade)	-	0.24	0.11	0.14	0.32	0.19	2.26	3.05	2.63	5.02	9.51	7.64
75 (high shade)	-	0.26	0.14	0.25	0.27	0.16	1.97	2.19	2.18	2.85	4.65	3.72
SEm ±	-	0.03	0.01	0.01	0.03	0.02	0.30	1.07	0.73	1.11	1.14	1.14
CD (0.05)	-	NS	0.03	0.03	0.09	0.06	NS	3.31	2.24	3.42	3.52	3.52

NS = Not significant

2. Content and uptake of phosphorus

The data on the content of phosphorus in leaves, pseudostem and tubers along with the total uptake of phosphorus are presented in Tables 29 to 30 and Fig. 13. The analyses of variance are given in Appendices 25 to 26.

There was significant effect of shade on the content of this nutrient in the leaf, pseudostem and tuber in almost all the growth stages. The average content ranged from 0.23 to 0.57[illegible], 0.321 to 0.73[illegible] and 0.1[illegible] to 0.[illegible]33 per cent, respectively, in the leaf, pseudostem and tuber. As in the case of nitrogen content in the plant parts, the variability in the phosphorus content due to shading was also too high to draw out any general conclusion. Between the plant components, the content was the highest in pseudostem and the least in tubers, at all the stages of growth. Just like nitrogen uptake, the phosphorus uptake by plants also showed an identical trend as that of total dry weight.

Comparison between the stages, showed that the content in the leaf and pseudostem decreased after 120 days after sprouting, while the content in the tuber remained nearly the same. The total uptake of the nutrient showed a steady increase upto 150 days after sprouting followed by

Table 31. Effect of shade on leaf and pseudostem potassium content of colocasia at different growth stages

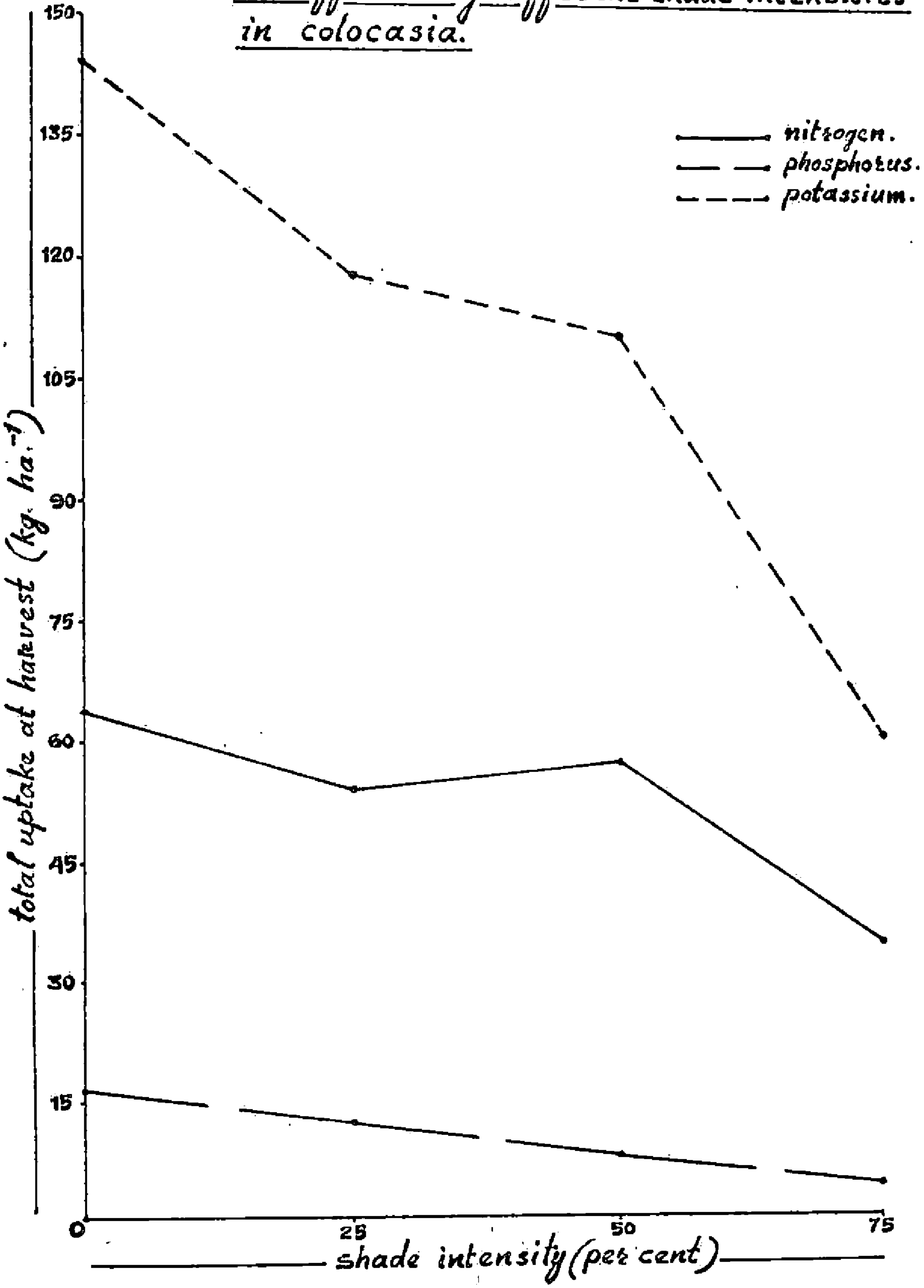
Shade intensity (per cent)	Leaf potassium content (per cent) (days after sprouting)						Pseudostem potassium content (per cent) (days after sprouting)					
	30	60	90	120	150	180 (harvest)	30	60	90	120	150	180 (harvest)
0 (no shade)	5.75	5.06	4.29	4.43	4.01	2.96	8.88	8.67	7.01	7.39	6.70	5.87
25 (low shade)	6.62	5.26	4.74	4.66	4.14	3.14	9.45	8.83	7.35	7.70	7.08	5.82
50 (medium shade)	5.69	4.81	4.71	4.60	4.70	3.48	9.64	9.12	8.01	8.03	7.29	5.78
75 (high shade)	5.92	5.27	5.09	5.31	4.90	3.72	9.77	8.92	8.31	8.55	7.76	6.98
SEm ±	0.11	0.07	0.06	0.09	0.08	0.09	0.10	0.08	0.08	0.07	0.09	0.15
CD (0.05)	0.35	0.22	0.19	0.28	0.23	0.30	0.30	0.24	0.26	0.22	0.28	0.47

Table 32. Effect of shade on tuber potassium content and on total uptake of potassium by colocasia at different growth stages

Shade intensity (per cent)	Tuber potassium content (per cent) (days after sprouting)						Total uptake of potassium (kg ha^{-1}) (days after sprouting)					
	30	60	90	120	150	180 (harvest)	30	60	90	120	150	180 (harvest)
0 (no shade)	-	2.63	2.60	2.48	2.34	2.89	34.43	106.01	95.56	118.14	106.10	144.09
25 (low shade)	-	2.81	2.63	2.76	2.25	2.53	40.12	75.81	82.06	92.99	98.75	118.06
50 (medium shade)	-	3.26	2.54	2.49	2.28	2.62	35.91	34.53	47.34	81.17	83.71	110.46
75 (high shade)	-	3.58	2.92	2.72	2.38	2.71	25.75	27.05	37.34	35.58	51.46	60.45
SEm ±	-	0.03	0.07	0.06	0.07	0.06	4.89	14.23	10.23	9.91	9.76	12.00
CD (0.05)	-	0.10	0.22	0.17	NS	0.19	NS	43.96	31.52	30.55	30.06	36.98

NS = Not significant

Fig. 13. Uptake of nitrogen, phosphorus and potassium as affected by different shade intensities in colocasia.



a decrease in the case of medium and high shade levels and substantial increase in the case of plants in the open and at low shade intensity.

3. Content and uptake of potassium

The data on the potassium content in the leaf, pseudostem and tubers along with the total uptake of potassium are given in Table 31 to 32 and Fig. 13. The analyses of variance are given in Appendices 27 to 28.

The effect of shade on the content and uptake of potassium was significant at all the stages of growth. Barring the slight variations at some of the stages, the leaf and pseudostem contents of this element increased with increasing shade intensities. The range in potassium in the leaf, pseudostem and tubers were, respectively, from 2.96 to 6.62, 5.78 to 9.77 and 2.25 to 3.58 per cent. The pseudostem and tuber potassium contents were almost one and a half times more and two times less than that in the leaf, respectively at all the growth stages. The potassium uptake closely followed the pattern of nitrogen and phosphorus uptake, which decreased with increasing shade intensities.

With advancing age, the contents in all the plant components showed a decreasing trend at all the shade

Table 33. Nutrient status of the soil after the crop of colocasia

Shade intensity (per cent)	Soil nutrients		
	Total nitrogen (per cent)	Available phosphorus (ppm)	Available potassium (ppm)
0 (no shade	0.101	1.08	117.12
25 (low shade)	0.113	3.05	127.87
50 (medium shade)	0.098	1.57	137.09
75 (high shade)	0.117	2.93	144.0
SEm ±	0.003	0.19	2.02
CD (0.05)	0.008	0.59	6.25

intensities whereas the uptake showed an increasing trend, thus maximum uptake was noticed at the harvest stage.

II. Soil characters

Soil nutrient status

The data on the soil nutrient status after the crop of colocasia are presented in Table 33 and the analysis of variance in Appendix 29.

There was significant effect of shade on soil nutrient status after the crop of colocasia. No general trend with increasing shade levels was noticed except in the case of available potassium, which increased with increasing intensities of shade.

On comparison with the pre-experimental nutrient status (Table 1) it was observed that available phosphorus content decreased while available potassium content increased. The total nitrogen content was found to be slightly increased after cropping with colocasia.

DISCUSSION

The discussion of the results on colocasia may be done only with the reservation that there had been some damage of the experimental crop at different stages. The damages occurred because of the incidence of blight (Phytophthora palmivora (Butler) Butler) that mainly affected the leaves and because of damage to the tender leaves at the early stages by the wild boar. Attempt on indexing the degrees of damage was not made as it occurred at varying periods at widely varying intensities. As it was felt that damage was grossly minor, the yield levels even with damage were reasonably high and the results were still dependable, the data are presented and discussed.

Results on tuber yield indicated that the yield decreased because of shading. But the extent of decrease with increasing shade levels followed a different pattern from that of other crops, with the yield decrease being small upto 50 per cent shading. Substantial yield decrease occurred only at the intense shade level of 75 per cent. Expressed as percentage of the yield in the open, the yield at 25, 50 and 75 per cent shade levels were 95.8, 90.1 and 41.6 per cent, respectively. A major difference in the tuber development pattern was that the contribution by side tubers was higher at lower shade intensities. The corresponding values of the percentage weight of side tubers (expressed as percentage of the total tuber weight) were 71.6, 66.0, 61.8 and 47.6 per cent, respectively, at full illumination, low, medium and high shade levels. The pattern of total tuber yield with increasing shade levels followed an exponential trend and the equation of the curve was as follows.

$$\text{Log}_{10} y = 1.2311 - 0.0584x - 0.0198x^2$$

As would be evident from a graphical presentation of this function, the yield decrease was very small upto 50 per cent shade and there was a sharp decline afterwards. Statistical analysis of the yield data showed that the yields in the open, 25 and 50 per cent shades were at par and the yield at intense shade of 75 per cent was significantly lower. Based on this yield trend it may be safe to assume that this crop has some mechanism by which yield decrease is inhibited upto reasonable shade levels and that this crop may therefore be classified as 'shade-tolerant'. It would therefore qualify this crop to be a suitable intercrop in shade situations atleast upto 50 per cent light infiltration.

A discussion on the probable mechs

for such a shade tolerance of this crop may be made with the help of the other growth and growth analysis observations. A comparison with total dry matter accumulation (Table 26) would indicate that the patterns of response on tuber yield and dry matter accumulation were nearly identical. This similarity in the trend along with the fact that the differences in the harvest index were minor between shade levels may be taken to indicate that photosynthetic mechanism was mainly responsible for the variation in yield. Unlike in the case of sweet potato, there was practically little influence of shade on the translocation of photosynthates.

An explanation for the above dry weight and tuber yield responses may be obtained from the data on leaf area index (Table 23). Unlike in the case of crops like sweet potato and coleus, where the canopies were dense, it was relatively a sparse canopy in colocasia. The LAI values were well below 1.0 at almost all the stages with the mean maximum being only 1.43 in the open, 60 days after sprouting. Even in this treatment, the LAI values were well below 1.0 at all the other stages. As indicated by such low leaf area indices, there was practically little chance of canopy overlapping and mutual shading at any of the shade levels. Reports generally show that individual leaf layers of most of the crop plants reach photosynthetic saturation at one-fourth the total solar intensity (Wit, 1967). In the absence of a significant mutual shading, rate of photosynthesis cannot therefore be expected to decrease with reasonable shading. As indicated from the data, it was only at the intense shade of 75 per cent, that the leaves functioned at sub-saturation light intensities.

Unlike in the case of most of the other crops tested, leaf density in colocasia was almost unaffected by shading. It was this inherent inability of the plant to increase the photosynthetic surface under shade that was probably responsible, at least partly, for the lack of decrease in yield because of shading. To put it in other words, the colocasia plant is inherently incapable of utilising the solar radiation efficiently when grown in the open. It would also follow that when grown in plant communities, there is scope for substantial increase in the yield of the crop by raising the plant population. To conclude, it is the inability of the plant to produce dense canopies and the wide spacing that was given, that were responsible for the shade tolerance of this crop. One related conclusion that may be drawn from the general yield response and the general trend of LAI values is that there is scope for increasing the yield of this crop substantially by an increase in plant population when planted in the open.

A dependable measure of the degree of mutual shading could have been obtained from the data on net assimilation rate, but because the values were highly violated by crop damage, the results were highly variable and, hence, not presented.

As had been indicated earlier, the ability of the plants for translocating the carbohydrates to the economic part was not affected by shading. The harvest index values in the open, 25, 50 and 75 per cent shade levels were, respectively, 94.8, 94.7, 92.2 and 87.5 per cent. Though the differences do not appear to be conspicuous, the harvest index values at medium and high shade levels were significantly lower than those in the open and in the low shade level.

The effect of shade on the growth parameters was nearly similar to that of dry weight and tuber yield. Unlike in the case of sweet potato and coleus, there was no persistent trend of an increase in plant height because of shading.

The chlorophyll content of leaves (Tables 24 and 25) was found to be significantly influenced by shading and the contents of total chlorophyll and its components were found to be increased by shading upto 50 and 75 per cent. Similar observations of increase in chlorophyll content because of shading have been reported in crops like strawberry (Clark, 1965), cocoa (Evans and Murray, 1953; Guers, 1971; Okali and Owusu, 1975), tea (Ramaswami, 1960 and Venkataramani, 1961), bean (Khossien, 1970), alfalfa and birdsfoot trefoil (Cooper and Qualls, 1967) and in pineapple (Radha, 1979). With advancing age, the content was found to decrease. The ratio of chlorophyll a-b at the last stage of chlorophyll estimation (170 days after sprouting) was found to increase sharply at all shade levels. Probably, a faster rate of destruction of chlorophyll 'b' than 'a' is thus indicated.

The contents of the mineral nutrients, nitrogen, phosphorus and potassium in the plant parts followed no distinct trend, though treatment differences were significant at some stages. The fact that the contents of the nutrients did not vary with differences in dry matter accumulation, may be taken to indicate that nutrient supplying power of the soil was adequate. The uptake of nutrients, on the contrary, followed the same expected trend as that of dry matter accumulation, though the differences in uptake upto intermediate (50 per cent) shade level were not appreciable and often not significant. It may therefore be reasonable to assume that the fertilizer requirement for this crop grown as an intercrop, may also be nearly the same as that of a sole crop cultivated in the open. The total quantities of nutrient removed by plants at harvest in the open were 63.8, 16.2 and 144.1 kg ha^{-1} of nitrogen, phosphorus and potassium, respectively.

The nutrient content of the soil after cropping (Table 33) followed the same trend as that of sweet potato and coleus with the potassium content increasing with increasing shade levels. Compared to pre-experimental soil analysis data (Table 1), there was a general increase in the content of nitrogen and a substantial decrease in the content of potassium. Variations in phosphorus content between shade levels showed wide fluctuations. Discussion on these aspects has been covered in detail while dealing with sweet potato.

The general conclusions on the results and discussion may be summarised as follows:

1. There was a marginal non-significant decrease in yield because of shading upto 50 per cent in the case of colocasia, though the highest yields were obtained in the open. This crop may therefore be considered as 'shade-tolerant' and would be highly suitable for intercropping.

2. Photosynthetic mechanism appears to be responsible for the shade response in this crop. There appears to be no marked influence of shade on the transloca-tion of carbohydrates to the tubers.

3. At the normal planting density, colocasia produces only a sparse canopy, though it appears that the crop can stand much denser canopies in the open and that the yield can be substantially increased by closer planting when grown as sole crop.

4. Unlike in the case of sweet potato and coleus, leaf area in colocasia does not substantially increase because of shading.

5. The crop requirement of fertilizer nutrients does not appear to be very much affected by shading upto 50 per cent. The fertilizer requirement for the sole crop of colocasia may therefore hold good in the case of intercropped colocasia also as long as shading is not intense.

Turmeric

Turmeric
(*Curcuma longa* L.)

RESULTS

I. Plant characters

A. Biometric observations

1. Plant height

The data are presented in Table 34 and the analysis of variance in Appendix 30.

Significant effect of shade on plant height was noticed only at the later stages of growth. In general, the height of plants went on increasing with increasing intensities of shade upto the intermediate (50 per cent) shade level and then showed a decrease at the intense (75 per cent) shade level. As normally expected, the plant height went on increasing with advancing age at all shade intensities.

2. Number of tillers

The data are presented in Table 34 and the analysis of variance in Appendix 30.

Significant effect of shade on tiller production by the plant was noticed at 60 and 180 days after sprouting.

At these stages, the number of tillers per plant went on decreasing with increasing shade intensities. At 120 days of growth, the maximum number of tiller was noticed at the low shade level.

Over the stages, no general trend in the tiller production was noticed.

3. Leaf area index

The data are presented in Table 34 and the analysis of variance in Appendix 30.

The LAI in turmeric was significantly influenced by shading only at 60 days of growth. The mean values varied widely due to different shade levels at different stages and it ranged from 2.21 to 15.77. The lowest LAI values were noticed at the intense shade level at all stages of growth.

There was sharp increase in the LAI values with advancing age, the maximum extent of increase being noticed at the intermediate shade level.

4. Chlorophyll content of leaves

The data on the content of chlorophyll 'a', 'b', total chlorophyll and the ratio of chlorophyll a-b are presented in Table 35 and the analysis of variance in Appendix 31.

Table 34. Effect of shade on plant height, number of tillers and leaf area index of turmeric at different growth stages

Shade intensity (per cent)	Height of plant (cm) (days after sprouting)			Number of tillers plant^{-1} (days after sprouting)			Leaf area index (days after sprouting)		
	60	120	180	60	120	180	60	120	180
0 (no shade)	64.7	104.5	115.5	5.3	2.5	4.1	4.05	9.57	15.77
25 (low shade)	55.9	109.0	126.0	4.3	3.0	2.1	2.89	10.57	11.97
50 (medium shade)	65.7	119.4	144.0	3.9	2.1	2.2	2.89	11.46	13.44
75 (high shade)	57.5	107.0	133.9	2.1	1.7	1.9	2.21	8.91	9.61
SEm ±	3.5	3.7	3.5	0.6	0.4	0.4	0.27	1.18	2.00
CD (0.05)	NS	NS	10.8	1.8	NS	1.1	0.82	NS	NS

NS = Not significant

Table 35. Effect of shade on content (mg g^{-1} fresh weight) of chlorophyll 'a', 'b' and total chlorophyll; ratio of chlorophyll a-b of turmeric leaves at different growth stages

Shade intensity (per cent)	Chlorophyll 'a' (days after sprouting)		Chlorophyll 'b' (days after sprouting)		Total chlorophyll (days after sprouting)		Chlorophyll a-b (days after sprouting)	
	100	160	100	160	100	160	100	160
0 (no shade)	0.78	0.63	1.10	0.78	1.88	1.41	0.71	0.81
25 (low shade)	0.95	0.69	1.26	0.85	2.21	1.54	0.76	0.82
50 (medium shade)	1.14	0.87	1.43	1.07	2.57	1.94	0.79	0.81
75 (high shade)	1.18	0.97	1.54	1.19	2.73	2.16	0.77	0.82
SEm ±	0.04	0.05	0.05	0.07	0.08	0.11	0.01	0.03
CD (0.05)	0.12	0.14	0.14	0.21	0.25	0.35	0.04	NS

NS = Not significant

The content of total chlorophyll and its components were significantly influenced by shading at all stages of growth. Also the ratio of chlorophyll a-b was significantly affected by shading, except at 160 days of growth. The content of total chlorophyll as well as its components increased with increasing shade intensities. The content at full illumination was found to be statistically lower than at the different shade intensities viz. 25, 50 and 75 per cent shade levels. The ratio of chlorophyll a-b also increased with increasing shade intensity upto medium shade and then decreased.

Comparison between the stages showed that the total chlorophyll as well as both of its components decreased with advancing age of the crop in all shade levels. But the ratio of chlorophyll a-b increased with advancing age.

5. Total dry weight

The data are presented in Table 36 and Fig. 14. The analysis of variance is given in Appendix 32.

There was significant effect of shade on total dry weight of plant only at the 60 days of growth. The general trend noticed was that of a decrease in total dry weight with increasing shade intensity. The dry weight at full illumination which was significantly higher than that at

Table 36. Effect of shade on total dry weight, net assimilation rate, tuber yield, haulm yield and harvest index of turmeric

Shade intensity (per cent)	Total dry weight (g plant^{-1}) (days after sprouting)					Net assimilation rate (g m^{-2} day^{-1})		Tuber yield (t ha^{-1} fresh weight)	Haulm yield (t ha^{-1} dry weight)	Harvest index
	60	120	180	220 (harvest)	Harvest (t ha^{-1})	Between 60 to 120 days	Between 120 to 180 days			
0 (no shade)	12.63	37.42	95.22	83.34	10.85	1.40	1.66	48.91	4.94	0.587
25 (low shade)	7.66	38.08	81.43	94.01	10.41	1.60	1.63	48.84	3.62	0.657
50 (medium shade)	7.24	37.72	78.41	89.62	12.05	1.58	1.54	53.26	5.10	0.577
75 (high shade)	4.67	24.99	62.49	55.69	7.89	1.36	1.49	28.89	2.75	0.649
SEm ±	0.94	3.99	11.02	7.05	0.755	0.18	0.41	3.31	0.44	0.025
CD (0.05)	2.88	NS	NS	21.72	2.327	NS	NS	10.19	1.35	NS

NS = Not significant

Fig.14 - Effect of shade on total dry matter production of turmeric at harvest.

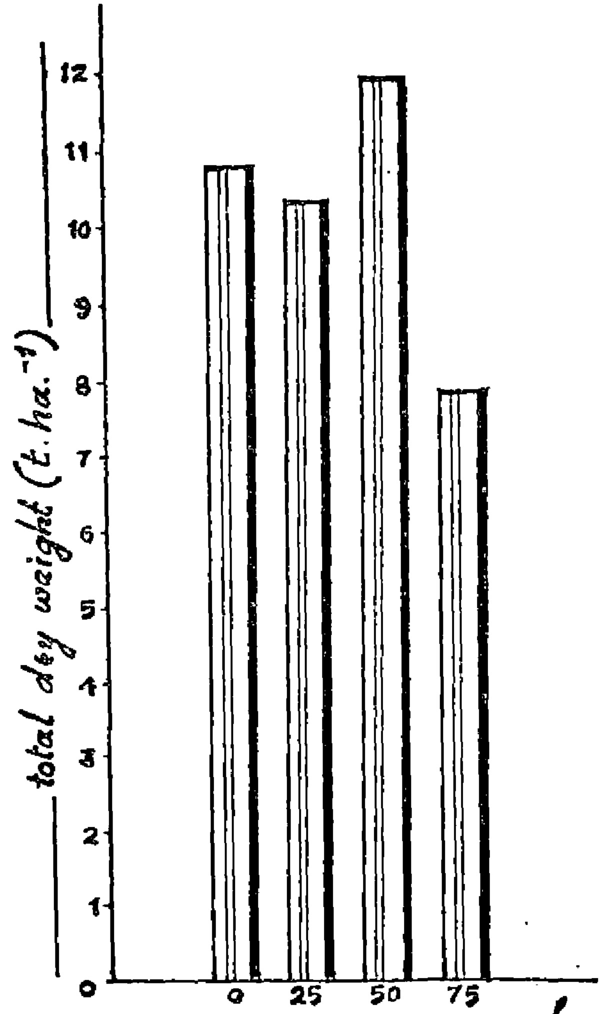
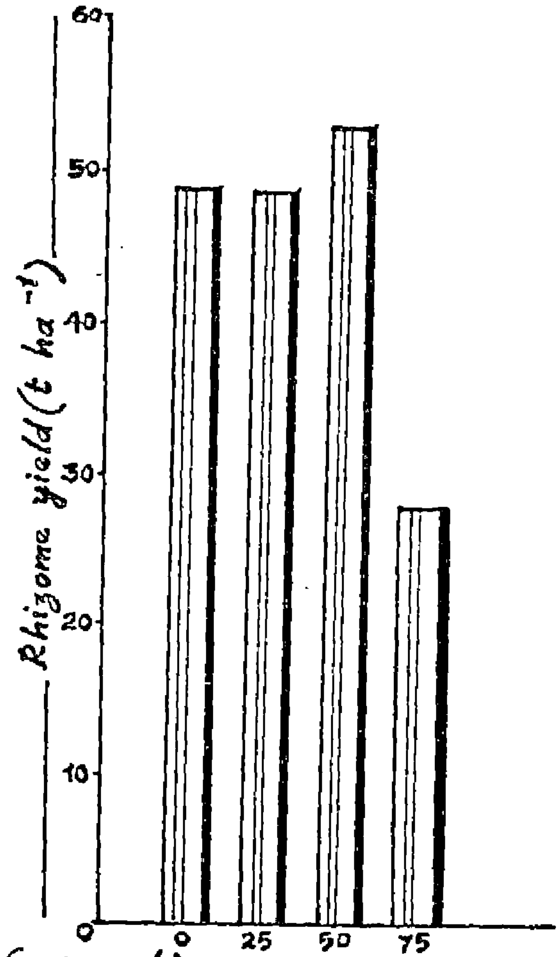


Fig.15 - Yield of turmeric as affected by varying shade intensities.



shade intensity (per cent)

other shade treatments, at 60 days of growth, fell short of statistically significant superiority at later stages.

Over the stages, the plant dry weight increased markedly with advancing age of the plant upto 180 days after sprouting. Beyond this stage, the change in dry weight was not impressive.

6. Net assimilation rate

The data are presented in Table 36 and the analysis of variance in Appendix 32.

The effect of shade on NAR between 60 and 120 days after sprouting was found to be not significant. No general trend in NAR with increasing levels of shade could be noticed.

Similarly, no marked stage-wise variation in NAR was evident.

7. Yield

The data are presented in Table 36 and Fig. 15. The analysis of variance is given in Appendix 32.

The rhizome yield was found to be significantly influenced by the shade treatments. Maximum yield was recorded at the intermediate (50 per cent) shade level which was followed by that at full illumination. This was closely followed by the low (25 per cent) shade intensity and the lowest yield was noted at the intense (75 per cent) shade level. The yield at intense shade was significantly lower than that at other shade intensities, which were at par.

The yields obtained at the low, medium and high shade levels were 99.86, 108.89 and 57.78 per cent respectively, of that in the open.

Response curve

The yield of rhizome obtained at different shade intensities have been represented as a function of shade and a cubic polynomial fitted to the logarithms of yield was found to give a close fit of the response curve obtained (Fig. 16, and the analysis of variance is given in Appendix 48). The equation of the curve obtained is as follows:

$$\log_{10} y = 1.7234 + 0.0267x - 0.0165x^2 - 0.0072x^3$$

The co-efficient of determination R^2 was found to be 0.9999. It showed that 99.99 per cent of total variation in the response can be explained by the fitted polynomial.

8. Yield of haulm

The data are presented in Table 36 and the analysis of variance in Appendix 32.

Fig.16. Yield response of turmeric to different levels of shade.

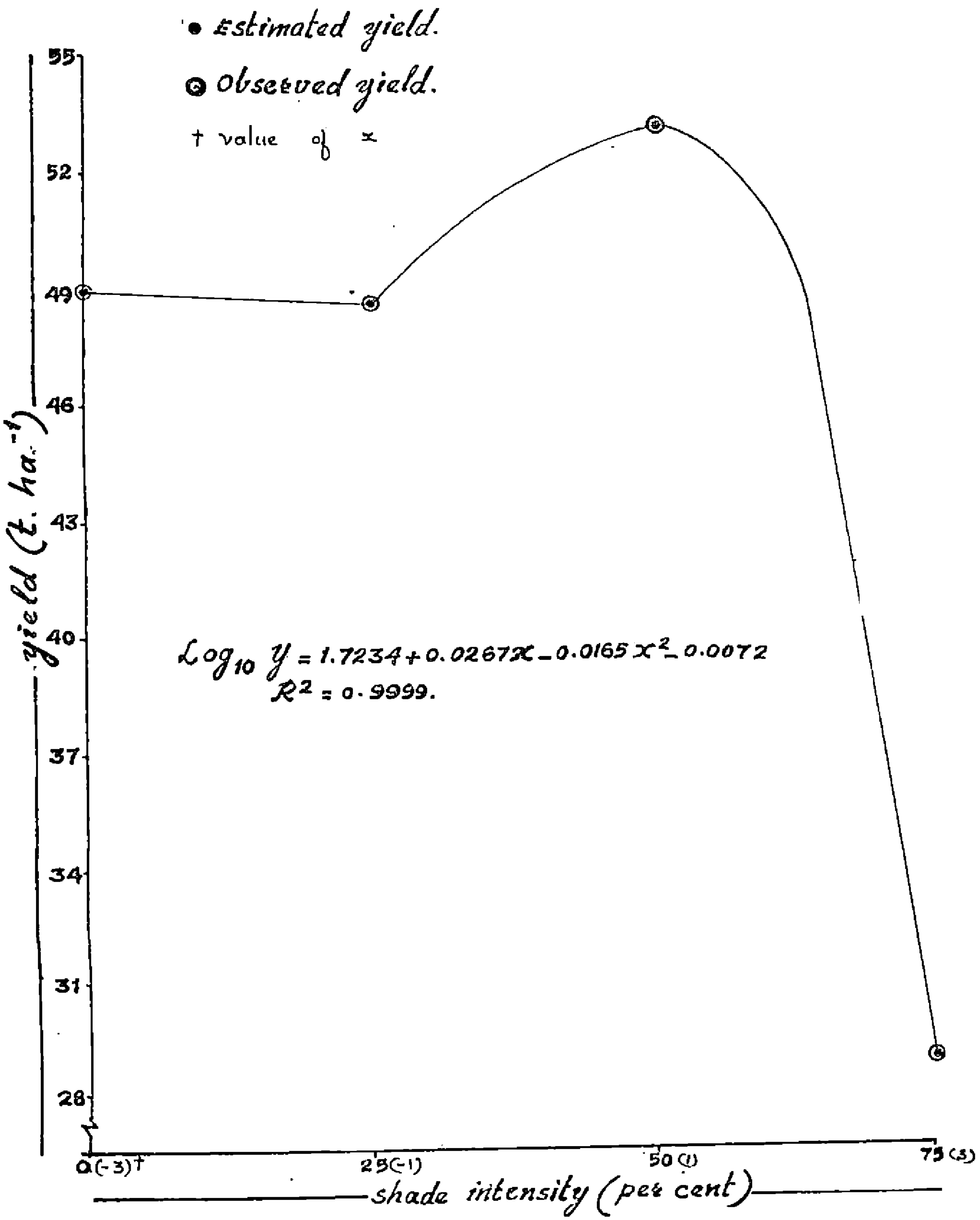


Table 37. Effect of shade on nitrogen content of leaf and pseudostem of turmeric at different growth stages

Shade intensity (per cent)	Leaf nitrogen content (per cent) (days after sprouting)				Pseudostem nitrogen content (per cent) (days after sprouting)			
	60	120	180	220 (harvest)	60	120	180	220 (harvest)
0 (no shade)	2.42	1.73	1.31	0.72	1.20	0.68	0.56	0.52
25 (low shade)	2.72	1.79	1.56	0.84	1.55	0.61	0.55	0.67
50 (medium shade)	2.84	1.88	1.62	0.88	1.67	0.66	0.57	0.55
75 (high shade)	2.66	2.07	1.76	1.02	1.51	0.86	0.67	0.64
SEm ±	0.02	0.02	0.01	0.04	0.02	0.01	0.01	0.01
CD (0.05)	0.06	0.07	0.03	0.72	0.07	0.04	0.02	0.02

Table 38. Effect of shade on nitrogen content of rhizome and on total uptake of nitrogen by turmeric at different growth stages

Shade intensity (per cent)	Rhizome nitrogen content (per cent) (days after sprouting)				Total uptake of nitrogen ($kg\ ha^{-1}$) (days after sprouting)			
	60	120	180	220 (harvest)	60	120	180	220 (harvest)
0 (no shade)	1.47	0.83	0.82	1.39	52.12	96.50	192.06	186.70
25 (low shade)	1.71	0.87	0.80	1.27	36.50	100.88	172.95	215.42
50 (medium shade)	1.80	0.96	0.90	1.38	37.96	107.52	178.92	216.85
75 (high shade)	2.02	1.06	0.97	1.45	22.95	70.84	157.49	139.82
SEm ±	0.04	0.02	0.02	0.02	4.39	10.45	24.77	17.50
CD (0.05)	0.14	0.05	0.07	0.05	13.52	NS	NS	53.93

NS = Not significant

The effect of shade on haulm yield was not significant; also no general trend with increasing shade levels could be observed.

9. Harvest index .

The data are presented in Table 36 and the analysis of variance in Appendix 32.

The harvest index in turmeric was not significantly influenced by shading and the maximum value was noticed at low (25 per cent) shade level and the minimum at the intermediate (50 per cent) shade level.

B. Chemical studies

1. Content and uptake of nitrogen

The data on the nitrogen content of leaf, pseudostem and rhizome along with the total uptake of nitrogen are presented in Tables 37 to 38 and Fig. 17. The analyses of variance are given in Appendices 33 to 34.

Effect of shade on the nitrogen content of leaf, pseudostem and rhizome was significant at all stages of growth, but total uptake of the nutrient was significant only at the 60 and 220 days of growth. In general, the leaf and rhizome nitrogen contents increased with increasing shade intensities, whereas the pseudostem content varied

Table 39. Effect of shade on phosphorus content of leaf and pseudostem of turmeric at different growth stages

Shade intensity (per cent)	Leaf phosphorus content (per cent) (days after sprouting)				Pseudostem phosphorus content (per cent) (days after sprouting)			
	60	120	180	220 (harvest)	60	120	180	220 (harvest)
0 (no shade)	0.25	0.20	0.15	0.11	0.27	0.21	0.13	0.14
25 (low shade)	0.28	0.20	0.20	0.11	0.33	0.22	0.22	0.13
50 (medium shade)	0.26	0.22	0.21	0.11	0.39	0.24	0.18	0.15
75 (high shade)	0.28	0.25	0.23	0.14	0.33	0.25	0.16	0.12
SEm ±	0.01	0.01	0.01	0.01	0.01	0.01	0.03	0.01
CD (0.05)	NS	0.02	0.04	0.01	0.02	0.03	NS	0.02

NS = Not significant

Table 40. Effect of shade on phosphorus content of rhizome and on total uptake of phosphorus by turmeric at different growth stages

Shade intensity (per cent)	Rhizome phosphorus content (per cent) (days after sprouting)				Total uptake of phosphorus (kg ha^{-1}) (days after sprouting)			
	60	120	180	220 (harvest)	60	120	180	220 (harvest)
0 (no shade)	0.21	0.18	0.23	0.41	6.96	16.35	37.71	37.58
25 (low shade)	0.23	0.25	0.21	0.30	4.82	18.54	36.91	45.34
50 (medium shade)	0.24	0.28	0.33	0.31	5.04	20.06	44.99	45.08
75 (high shade)	0.27	0.25	0.25	0.29	3.10	13.88	30.53	25.10
SEm ±	0.01	0.01	0.01	0.06	0.64	1.87	6.11	4.01
CD (0.05)	0.03	0.04	0.04	NS	1.96	NS	NS	12.35

NS = Not significant

widely with increasing shade levels and no general pattern could be noticed. In the case of uptake of this nutrient, there was no perceptible differences in the mean values between full illumination, low and medium shade intensities, but that at intense shade were generally lower.

The contents of nitrogen in all the plant components showed a declining trend with advancing age of the plant except that at harvest the rhizome nitrogen content showed an increase as compared to the earlier stage. The uptake went on increasing with advancing age upto harvest except at full illumination in which the increase was noted only upto 180 days of growth.

2. Content and uptake of phosphorus

The data on the phosphorus content of leaf, pseudostem and rhizome and on the total uptake of phosphorus by the plant as a whole are presented in Table 39 to 40 and Fig. 17. The analysis of variance are given in the Appendices 35 to 36.

In general, significant effect of shade on phosphorus content of different plant components and the uptake of this nutrient was observed at almost all stages of growth. The content was found to increase with increase in shade in the case of leaf, whereas this was noticed only upto 120 days of growth in the case of pseudostem and rhizomes.

Table 41. Effect of shade on potassium content of leaf and pseudostem of turmeric at different growth stages

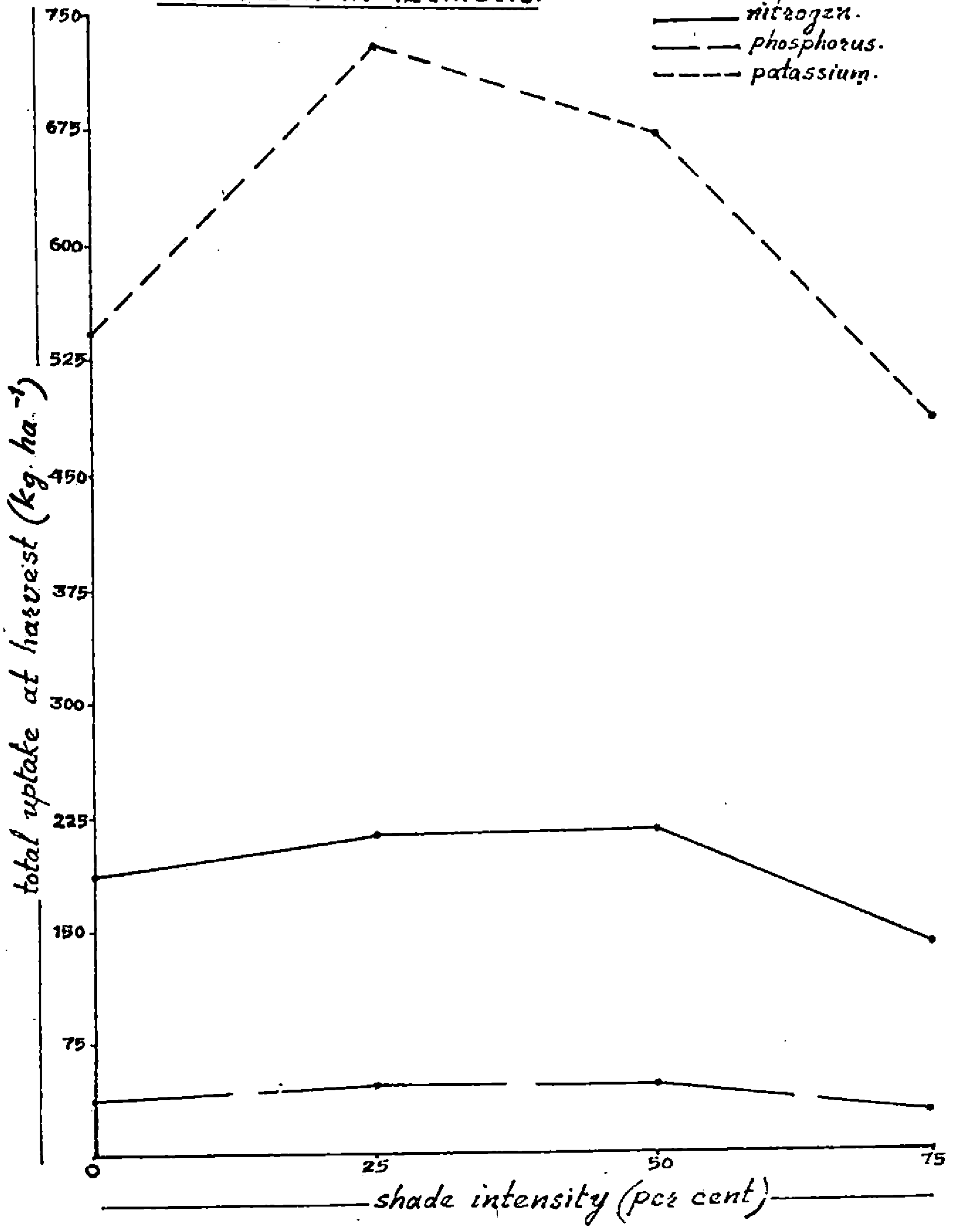
Shade intensity (per cent)	Leaf potassium content (per cent) (days after sprouting)				Pseudostem potassium content (per cent) (days after sprouting)			
	60	120	180	220 (harvest)	60	120	180	220 (harvest)
0 (no shade)	5.06	4.17	3.78	2.79	6.47	4.40	3.26	2.41
25 (low shade)	5.44	4.66	4.22	3.68	7.02	5.54	3.78	3.50
50 (medium shade)	5.43	4.40	4.37	3.62	7.70	4.86	3.65	3.24
75 (high shade)	5.25	4.90	4.36	4.25	7.84	6.16	4.50	4.04
SEm ±	0.06	0.08	0.12	0.07	0.12	0.06	0.07	0.09
CD (0.05)	0.19	0.26	0.36	0.22	0.37	0.19	0.22	0.27

Table 42. Effect of shade on potassium content of rhizome and on total uptake of potassium by turmeric at different growth stages

Shade intensity (per cent)	Rhizome potassium content (per cent) (days after sprouting)				Total uptake of potassium (kg ha^{-1}) (days after sprouting)			
	60	120	180	220 (harvest)	60	120	180	220 (harvest)
0 (no shade)	4.82	3.25	2.74	3.31	153.82	327.04	671.68	546.10
25 (low shade)	5.45	3.80	3.54	3.40	98.51	404.45	688.14	731.27
50 (medium shade)	5.22	3.70	3.45	3.34	102.19	369.56	660.23	677.04
75 (high shade)	5.40	4.36	3.80	3.71	63.68	249.71	578.00	489.27
SEm ±	0.08	0.06	0.09	0.07	13.30	42.68	92.66	53.05
CD (0.05)	0.25	0.18	0.27	0.21	40.93	NS	NS	163.78

NS = Not significant

Fig. 17 - Uptake of nitrogen, phosphorus and potassium as affected by varying shade intensities in turmeric.



In the case of uptake, the lowest values were noticed at the highest shade, though not significant.

Over the stages, the content went on decreasing with advancing age in all plant parts including rhizomes whereas the uptake increased with time at all shade levels.

3. Content and uptake of potassium

The data on the potassium content in leaf, pseudostem and rhizome and the total uptake of potassium are given in Tables 41 to 42 and Fig. 17. The analyses of variance are given in Appendices 37 to 38.

The effect of shade on the potassium content of leaf, pseudostem and rhizome was significant at all growth stages. The uptake was significantly influenced only at 60 and 220 days of growth. The content increased with increasing intensities of shade. In the case of total uptake, the low and medium shade levels recorded higher values, those of intense shade and that in the open being low and comparable.

With advancing age of the crop the content in all the plant components decreased gradually so that by harvest the components contained the lowest content of the nutrient. whereas the uptake went on increasing with advancing age upto the 190 days of growth. After this stage, there was

Table 43. Soil nutrient status after the crop of turmeric

Shade intensity (per cent)	Nutrients		
	Total nitrogen (per cent)	Available phosphorus (ppm)	Available potassium (ppm)
0 (no shade)	0.139	2.93	92.53
25 (low shade)	0.112	2.42	110.98
50 (medium shade)	0.113	3.60	97.15
75 (high shade)	0.065	2.87	120.96
SEm ±	0.002	0.37	2.20
CD (0.05)	0.005	1.16	6.78

a slight increase at some intensities of shade and a decline in some others.

II. Soil characters

Soil nutrient status

The data on the content of total nitrogen, available phosphorus and available potassium in the soil after the crop are presented in Table 43 and the analysis of variance in Appendix 39.

The effect of shade on the nutrient status of the soil though was significant, no general trend in the nutrient content with increasing intensities of shade could be noticed. Comparison with the pre-experimental nutrient status indicated that the available phosphorus content increased and that of available potassium decreased The total nitrogen was lower at high shade levels after the cropping as compared to the pre-experimental soil level.

DISCUSSION

The yield of rhizomes in turmeric was the highest at 50 per cent shade intensity and as compared to the yield in the open, the percentage yield at this shade level was 108.89. At the low shade level of 25 per cent, the yield was nearly the same (99.86 per cent) as that in the open. Intense (75 per cent) shading led to a substantial decrease in yield to the tune of 42.22 per cent. The differences in yield between the full illumination, 25 and 50 per cent shade levels were however, not statistically significant. Of the various regression models tested to define the variation in yield as a function of shade intensity a cubic polynomial fitted to the logarithm of yield was found to be the best, the coefficient of determination R^2 being 0.9999. As there is an increase in yield because of shading, this crop may well be classified as 'shade-loving' and as the yield even at the intense shade level is reasonable, this crop will be highly suitable for intercropping.

A comparison with dry matter yield (Table 36) indicated no strict similarity with the trend in rhizome yield. The data on harvest index indicated that there was also no improvement in translocation of photosynthates towards the economic part because of shading. As these data on dry matter accumulation and harvest index did not justify the observed trend in rhizome yield, it is difficult to interpret the results. Assuming that the sampling error in dry matter estimation was substantial, an attempt was made to extrapolate the dry matter yield at harvest from the data on yield of rhizome and haulm and the moisture percentage of sample plants at harvest. These extrapolated data are also presented in Table 36. On statistical analysis of those data on dry matter yield, it was also found that the coefficient of variation for these data was lower (15.22) than that for the sample (19.55).

A study of the extrapolated dry weight values would indicate that the dry matter accumulation and rhizome yield followed a nearly identical pattern. Taking the yield in the open as 100 per cent, the corresponding values for rhizome yield at 25, 50 and 75 per cent shade levels were 99.86, 109.89 and 57.78 per cent, respectively and those of dry matter yield 95.9, 111.1 and 72.7 per cent respectively. The above similarity in the trend of dry weight and rhizome yield indicates that the photosynthetic rate had a dominant role in deciding the observed response to shade.

An explanation for the above variation in dry matter accumulation can be had from an evaluation of the data on leaf area index (Table 34) and net assimilation rate (Table 36). As would be evident from the relatively high LAI values especially after 120 days of growth, the turmeric canopy was fairly dense. The mean maximum LAI value of 15.8 was noticed at full illumination 180 days after sprouting. Even though the leaf orientation was apparently near vertical, as the LAI values were excessively high and much higher than the optimum reported for cereals with near vertical leaf orientation (4 to 7 for rice as reported by Yoshida, 1972), there was presumably substantial mutual shading and probably some leaf parasitism. The extent of leaf parasitism would have normally increased because of shading, but such a probable effect is not reflected on the dry matter accumulation and it may have to be presumed that there were other factors involved in this. One of these factors could probably be the stomatal closure at intense illumination as has been reported in the case of coffee (Hardy, 1958). However, reports on such a stomatal behaviour of turmeric were not available from literature. Assuming that this was the factor responsible for the shade response of this crop, it may be deduced from the data on dry matter accumulation that the stomatal closure had the dominant influence upto the intermediate shade level. Beyond this level, availability of light for photosynthesis, probably, became the decisive limiting factor.

A study of the data on LAI would also show that though not statistically significant, the mean LAI values were substantially low at intense shade level. An adaptation of the plant to avoid excessive parasitism by an adjustment of LAI is thus indicated in this crop also.

Data on net assimilation rate indicated lack of significant difference between the different shade levels. If the above explanation of a stomatal inhibition at higher illumination was operative, the NAR would have been the highest at 50 per cent shade. A comparison of the mean values indicated higher NAR values at 50 and 75 per cent shade than in the open between the first two stages of observation (60 and 120 days after sprouting) whereas between the second and third stages (120 and 180 days after sprouting), the highest mean values were noted in the open. The only justification for the lack of persistent superiority in NAR at the intermediate shade level appears to be that the sampling errors were high especially in the determination of dry matter yield as had been indicated earlier.

Data on harvest index did not show significant differences between shade levels. Data on harvest index recalculated from extrapolated values also did not show statistical significance. It may thus be concluded that, in general, the extent of translocation of carbohydrates to the economic part was not affected by shading.

Among the other growth characters, plant height followed nearly the same trend as that of dry matter accumulation and rhizome yield. Tiller number, on the contrary, showed a steady decrease with increase in shade intensity. However, as would be evident from the data on LAI, this decrease in tiller number did not substantially influence the leaf area.

Contents of chlorophyll 'a', 'b' and total chlorophyll (Table 35) were found to increase steadily with increasing shade levels and the differences between the different shade levels also were significant. Though reports on the increased chlorophyll content because of shading on turmeric were not available from literature, increase in chlorophyll content because of shading has been reported in crops like strawberry (Clark, 1965), cocoa (Evans and Murray, 1953; Guers, 1971; Okali and Owusu, 1975), tea (Ramaswami, 1960 and Venkatamani, 1961), bean Khossien, 1970), alfalfa and birdsfoot trefoil (Cooper and Qualls, 1967) and pineapple (Radha, 1979). The ratio of chlorophyll a-b remained constant at 160 days after sprouting though at the earlier stage (120 days), an increase in ratio with shading was noted. With age, the content of chlorophyll and its components chlorophyll 'a' and 'b', decreased but the ratio of chlorophyll a-b increased. The probable reasons for such a phenomenon have been discussed already while dealing with colocasia.

In general, the contents of mineral nutrients, nitrogen, phosphorus and potassium in the plant parts increased with increasing shade intensities and the differences between different shade levels were significant at almost all the stages. This observation cannot be explained as due to the dilution effect as the dry matter accumulation and yield were the highest at the intermediate shade level. Reports on such an influence of shade are not available in literature. The only indication that can be given is that there appears to be a tendency to accumulate nutrients in the tissues under shade in turmeric. The total uptake of nutrients at harvest showed significant differences between the shade levels and the pattern of variation was nearly the same as that of dry matter accumulation and rhizome yield. Calculated as percentage of the uptake in the open, the total crop removals at 50 per cent shade were 116.2, 120.0 and 124.0 per cent, respectively, of nitrogen, phosphorus and potassium. As indicated by these percentage uptake values, it appears that a crop of turmeric at 50 per cent shade level would need an additional 20 per cent of the applied fertilizer nutrients, than that cultivated in the open.

The nutrient status of the soil showed statistically significant differences after the crop season. Though significant, the differences between increasing shade levels were highly variable. Comparison with the pre-experimental soil nutrient status (Table 1) indicated an increase in the content of total nitrogen and available phosphorus and a decrease in available potassium. The reasons for these have been discussed earlier.

The conclusions from the above discussion may be given as follows:

1. Yield of rhizomes in turmeric followed a cubic response with increasing shade intensities and the highest yield was noted at 50 per cent shade level. Though there is a substantial decrease in yield with further increase in shade, the yield levels are still high at the intense (75 per cent) shade level. Turmeric may therefore be classified as 'shade-loving' and it may be concluded either that this crop is highly suited for intercropping or even that this is more suited to intercropping than for cultivation as a sole crop in the open.

2. Differences in the photosynthetic rate appear to have the decisive influence on the shade response of this crop.

3. Turmeric produces a relatively dense canopy under natural conditions. But excessive leaf parasitism induced by shading in this crop is at least partly counter-acted by a decrease in canopy density.

4. The harvest index of the crop is not very much influenced by shading upto intermediate shade levels.

5. It appears that the fertilizer requirement of turmeric shaded to 50 per cent may be about 20 per cent more than the general recommendation given for a sole crop in the open.

Ginger

Ginger
(*Zingiber officinale* Rosc.)

I. Plant characters

A. Biometric observations

1. Plant height

The data are presented in Table 44 and the analysis of variance in Appendix 40.

Effect of shade on plant height was significant at all stages of growth except at the first stage. The value, in general, went on increasing with increasing levels of shade, and the plants in the open recorded the least value which was significantly lower than that at the other shade levels.

2. Number of tillers

The data are presented in Table 44 and the analysis of variance in Appendix 40.

Tiller production was significantly influenced by shade only at the initial stage of growth, a decrease in the mean number of tillers was noticed with increasing shade intensities, at all stages of growth.

The tiller number showed an increase with advancing age.

3. Leaf area index

The data are presented in Table 44 and the analysis of variance in Appendix 40.

The effect of shade on LAI in ginger was not significant at any of the growth stages. The mean LAI values ranged from 0.50 to 0.75, 2.13 to 3.45 and 5.48 to 7.18 at the 60, 120 and 180 days after sprouting.

Over the stages, the LAI values showed a sharp increase, but this increase was more conspicuous at 25 and 50 per cent shade levels.

4. Chlorophyll content of leaves

The data on the content of chlorophyll 'a', 'b' and total chlorophyll along with the ratio of chlorophyll a-b, are presented in Table 45 and the analyses of variance in Appendix 41.

Effect of shade on the content of total chlorophyll as well as its components was significantly influenced by shading. The content of these showed an increasing trend with increasing shade intensities. In spite of the significant effect of shade on total chlorophyll and its components, the effect of shade on the ratio of chlorophyll a-b remained non-significant at both of the stages.

Table 44. Effect of shade on plant height, number of tillers and leaf area index of ginger at different growth stages

Shade intensity (per cent)	Height of plant (cm) (days after sprouting)			Number of tillers $plant^{-1}$ (days after sprouting)			Leaf area index (days after sprouting)		
	60	120	180	60	120	180	60	120	180
0 (no shade)	28.8	46.7	46.6	8.7	16.1	16.0	0.75	3.45	6.21
25 (low shade)	31.1	54.8	58.6	5.0	15.5	14.9	0.50	3.11	6.56
50 (medium shade)	28.4	57.5	63.9	6.2	9.0	13.9	0.55	2.13	7.18
75 (high shade)	28.1	57.0	66.5	5.7	11.8	13.3	0.60	2.24	5.48
SEm ±	2.2	1.9	2.4	0.8	2.1	1.1	0.11	0.48	0.67
CD (0.05)	NS	5.8	7.5	2.6	NS	NS	NS	NS	NS

NS = Not significant

Table 45. Effect of shade on content (mg g^{-1} fresh weight) of chlorophyll 'a', 'b' and total chlorophyll; ratio of chlorophyll a-b of ginger leaves at different growth stages

Shade intensity (per cent)	Chlorophyll 'a' (days after sprouting)		Chlorophyll 'b' (days after sprouting)		Total chlorophyll (days after sprouting)		Chlorophyll a-b (days after sprouting)	
	100	160	100	160	100	160	100	160
0 (no shade)	0.95	0.84	1.22	1.04	2.17	1.88	0.79	0.81
25 (low shade)	1.13	1.18	1.36	1.42	2.50	2.60	0.83	0.85
50 (medium shade)	1.37	1.33	1.75	1.75	3.12	3.09	0.78	0.78
75 (high shade)	1.46	1.56	1.80	1.83	3.25	3.39	0.82	0.85
SEm ±	0.04	0.19	0.08	0.06	0.11	0.11	0.03	0.03
CD (0.05)	0.14	0.18	0.24	0.20	0.35	0.34	NS	NS

NS = Not significant

The content of chlorophyll varied erratically with advancing age, but the ratio of chlorophyll a-b remained almost the same at all the stages of growth.

5. Total dry weight

The data are presented in Table 46 and Fig. 18. The analysis of variance is given in Appendix 42.

The effect of shade on total dry matter production by a plant was significant only at 120 days after sprouting. The maximum and minimum values were noted at full illumination and at intense shade levels, respectively. The value showed a decreasing trend with increasing shade intensities at all the stages of growth.

Over the stages, the total dry matter production increased with advancing age, the extent of increase being maximum at the low (25 per cent) shade level.

6. Net assimilation rate

The data are presented in Table 46 and the analysis of variance in Appendix 42.

The effect of shade on net assimilation rate in ginger was not significant between any of the growth stages.

Table 46. Effect of shade on total dry matter production, net assimilation rate, rhizome yield, haulm yield and harvest index of ginger

Shade intensity (per cent)	Total dry weight (g plant^{-1}) (days after sprouting)				Net assimilation rate (g m^{-2} day^{-1})		Rhizome yield (t ha^{-1} fresh weight)	Haulm yield (t ha^{-1} dry weight)	Harvest index
	60	120	180	225 (harvest)	Between 60 & 120 days	Between 120 & 180 days			
0 (no shade)	3.97	23.48	66.66	54.62	2.44	2.39	21.05	2.38	0.642
25 (low shade)	2.11	20.90	62.70	60.92	2.77	2.26	22.22	3.32	0.566
50 (medium shade)	2.40	12.92	61.47	49.63	1.89	2.82	19.54	3.31	0.524
75 (high shade)	2.31	12.72	42.48	47.75	1.96	1.96	14.03	2.81	0.500
SEm ±	0.56	2.72	6.07	5.48	0.24	0.41	1.40	0.37	0.030
CD (0.05)	NS	8.38	NS	NS	NS	NS	4.32	NS	0.092

NS = Not significant

Table 47. Effect of shade on nitrogen content of leaf and pseudostem of ginger at different growth stages

Shade intensity (per cent)	Leaf nitrogen content (per cent) (days after sprouting)			Pseudostem nitrogen content (per cent) (days after sprouting)		
	60	120	180	60	120	180
0 (no shade)	4.10	2.85	2.54	3.08	1.14	0.93
25 (low shade)	4.04	2.97	2.66	2.64	1.26	1.00
50 (medium shade)	3.84	2.65	2.70	2.75	1.38	0.92
75 (high shade)	3.99	3.64	3.02	2.86	1.43	0.81
SEm ±	0.06	0.01	0.03	0.06	0.03	0.09
CD (0.05)	NS	0.05	0.11	0.20	0.11	NS

NS = Not significant

Fig. 18 - Effect of shade on total dry matter production of ginger at different stages of plant growth.

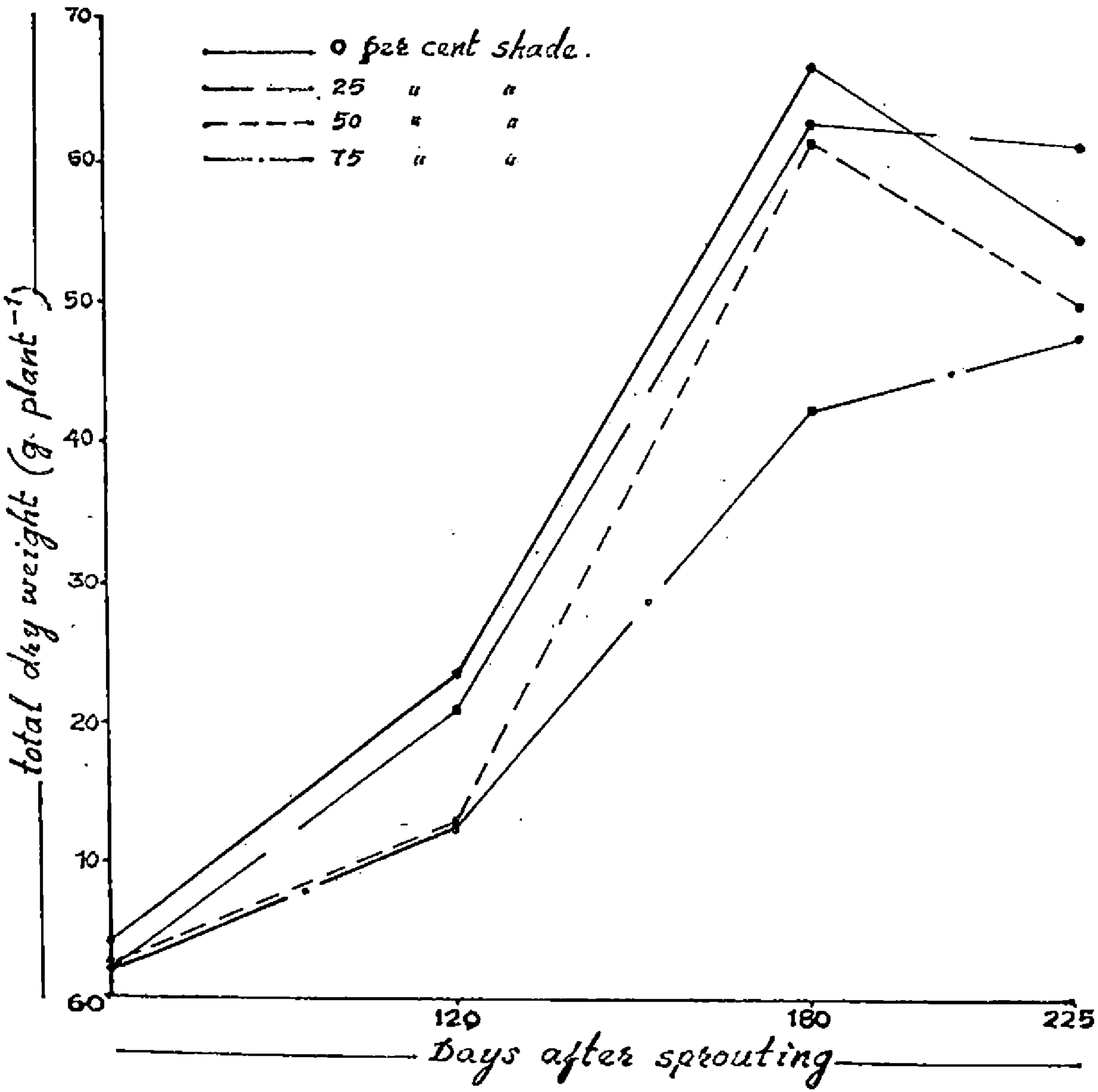
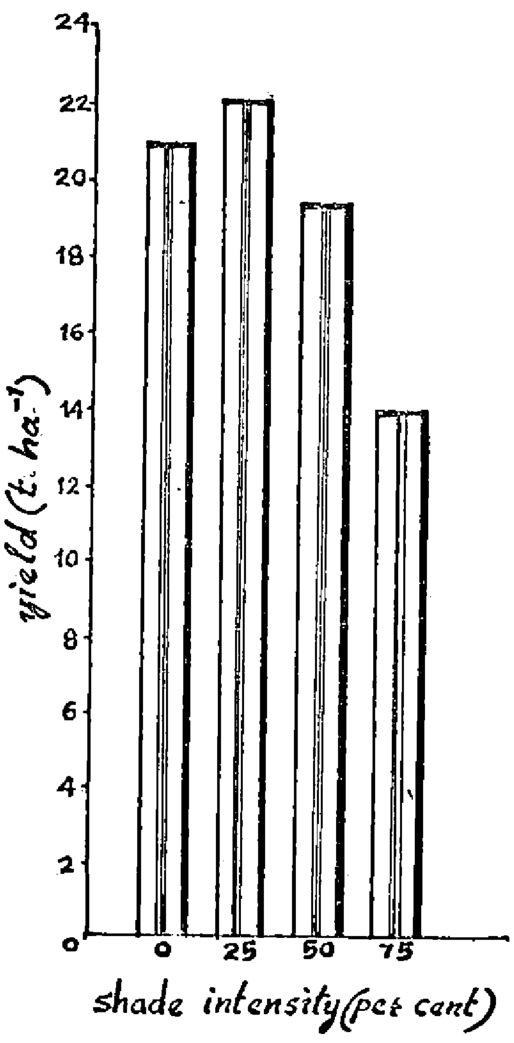


Fig. 19 - Yield of ginger as affected by varying shade intensities.



The values ranged from 1.89 to 2.82 g m^{-2} day^{-1}. No general trend in NAR with increasing shade level could be noticed. With advancing age, the NAR showed a decrease at low shade and in the open, while it showed an increase at medium shade level and at high shade it remained nearly static.

7. Yield (Rhizome yield)

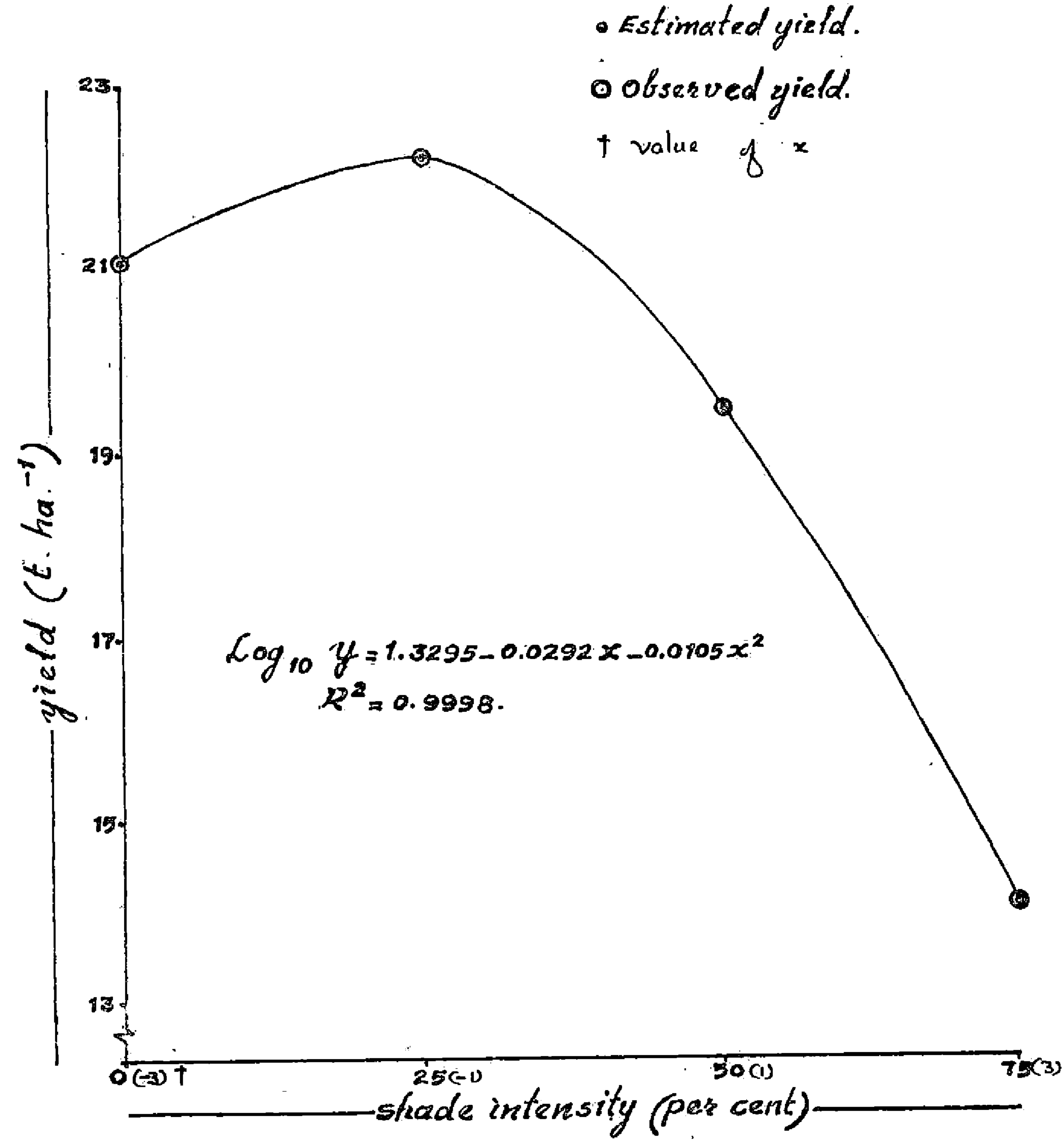
The data are presented in Table 46 and Fig. 19. The analysis of variance is given in Appendix 42.

Shade had a significant effect on the rhizome yield in ginger. The yield increased with increasing shade upto the low (25 per cent) shade intensity, and showed a declining trend with further increase in shade intensity. Thus the maximum yield of 22.22 t ha^{-1} was recorded at 25 per cent shade intensity. The yields obtained at low, medium and high shade levels were 105.6, 92.83 and 66.65 per cent, respectively, of that at full illumination. The yield at intense (75 per cent) shade was significantly lower than at the other shade intensities.

Response curve

The yield of rhizomes obtained at increasing intensities of shade have been represented graphically as a function of shade and a quadratic equation fitted to the

Fig. 20- Yield response of ginger to varying levels of shade.



logarithms of yield was found to be the better fit to the response curve thus obtained (Fig. 20 and the analysis of variance in Appendix 48). The equation of the curve is as follows:

$$\log_{10} y = 1.3295 - 0.0292x - 0.0105x^2$$

The co-efficient of determination R^2 was found to be 0.9998 which indicate that the proposed model almost fully describes the biological phenomenon. The optimum intensity of shade for ginger as worked out from the equation is 20.12 per cent.

8. Yield of haulm

The data are presented in Table 46 and the analysis of variance in Appendix 42.

The effect of shade on yield of haulm in ginger was not significant. The mean yield was, however, the lowest at intense shade level and highest in the open.

9. Harvest index

The data are presented in Table 46 and the analysis of variance in Appendix 42.

The effect of shade on the harvest index in ginger was significant. However, values showed a decreasing trend with increasing intensities of shade, which ranged from 50 to 64.2 per cent.

B. Chemical studies

1. Content and uptake of nitrogen

The data on the content of nitrogen in leaf, pseudostem and rhizome along with the total uptake of nitrogen are presented in Tables 47 to 48 and Fig. 21. The analyses of variance are given in Appendices 43 to 44.

The effect of shade on the nitrogen content of leaf and pseudostem was significant at all stages of growth excepting one, while in the case of rhizome significant effect was noticed only at the harvest stage. But the differences in uptake of nitrogen between the different shade levels was not significant at all growth stages. The content varied from 2.54 to 4.10, 0.81 to 3.08 and 0.93 to 3.71 per cent, respectively, in the leaf, pseudostem and rhizomes at different stages.

With age, the content of nitrogen in all the plant components showed a decreasing trend upto 180 days after sprouting. But in the case of rhizome, there was an increase in nitrogen content from 180th day to harvest. Even so, the percentage content of this nutrient at harvest was only about half as much as at 60 days after sprouting. The total uptake of nitrogen by the plants went on increasing at a rapid rate with advancing age of the plant upto

Table 48. Effect of shade on nitrogen content of ginger rhizomes and on total uptake of nitrogen by ginger at different growth stages

Shade intensity (per cent)	Rhizome nitrogen content (per cent) (days after sprouting)				Total uptake of nitrogen (kg ha^{-1}) (days after sprouting)			
	60	120	180	225 (harvest)	60	120	180	225 (harvest)
0 (no shade)	2.88	1.08	0.94	1.47	23.03	62.87	134.00	118.95
25 (low shade)	3.43	1.07	1.12	1.44	11.83	60.53	144.37	128.39
50 (medium shade)	3.66	1.14	0.98	1.49	13.29	36.75	135.12	107.89
75 (high shade)	3.71	1.07	0.93	1.87	12.75	41.36	98.35	125.80
SEm ±	0.33	0.03	0.05	0.018	3.04	7.21	14.29	14.73
CD (0.05)	NS	NS	NS	0.056	NS	NS	NS	NS

NS = Not significant

Table 49. Effect of shade on phosphorus content of ginger leaf and pseudostem at different growth stages

Shade intensity (per cent)	Leaf phosphorus content (per cent) (days after sprouting)			Pseudostem phosphorus content (per cent) (days after sprouting)		
	60	120	180	60	120	180
0 (no shade)	0.25	0.26	0.25	0.40	0.19	0.21
25 (low shade)	0.27	0.29	0.23	0.36	0.32	0.21
50 (medium shade)	0.28	0.33	0.30	0.35	0.28	0.22
75 (high shade)	0.27	0.32	0.26	0.38	0.29	0.17
SEm ±	0.02	0.01	0.008	0.01	0.01	0.01
CD (0.05)	NS	0.04	0.024	NS	0.04	0.07

NS = Not significant

180 days and then it decreased excepting at the intense shade level. The rate of uptake with advancing age was greatest in the case of plants which were grown at 25 per cent shade intensity.

2. Content and uptake of phosphorus

The data on the content of phosphorus in the leaf, pseudostem and rhizome and the total uptake of phosphorus are given in Tables 49 to 50 and Fig. 21. The analyses of variance are given in Appendices 44 to 45.

The effect of shade on the phosphorus content of plant component and total uptake of phosphorus remained significant at almost all the growth stages. No general trend in the variation of the phosphorus content with increasing shade intensities could be noticed. The content of this element varied from 0.23 to 0.33, 0.17 to 0.40 and 0.17 to 0.61 per cent, respectively in the leaf, pseudostem and rhizomes at different growth stages.

The changes in the content of phosphorus with advancing age was similar to that in the case of nitrogen content in the leaf, pseudostem and rhizome. Phosphorus uptake showed a discernible increase with advancing stages of growth upto 180 days of growth.

Table 50. Effect of shade on phosphorus content of ginger rhizomes and on total uptake of phosphorus by ginger at different growth stages

Shade intensity (per cent)	Rhizome phosphorus content (per cent) (days after sprouting)				Total uptake of phosphorus ($kg\ ha^{-1}$) (days after sprouting)			
	60	120	180	225 (harvest)	60	120	180	225 (harvest)
0 (no shade)	0.57	0.24	0.17	0.24	2.43	8.95	19.42	19.41
25 (low shade)	0.48	0.26	0.21	0.28	1.21	9.53	21.91	30.02
50 (medium shade)	0.61	0.20	0.21	0.26	1.47	5.39	22.61	18.26
75 (high shade)	0.58	0.25	0.17	0.29	1.36	5.21	13.20	17.99
SEm ±	0.02	0.02	0.01	0.01	0.34	1.12	2.20	3.55
CD (0.05)	0.06	NS	0.03	0.02	NS	3.46	6.79	10.94

NS = Not significant

Table 51. Effect of shade on potassium content of leaf and pseudostem of ginger at different growth stages

Shade intensity (per cent)	Leaf potassium content (per cent) (days after sprouting)			Pseudostem potassium content (per cent) (days after sprouting)		
	60	120	180	60	120	180
0 (no shade)	3.72	3.50	2.74	7.50	6.40	5.86
25 (low shade)	4.20	3.76	2.98	7.50	6.90	5.90
50 (medium shade)	4.72	3.92	2.95	7.80	6.74	6.30
75 (high shade)	4.40	4.32	3.55	8.48	7.47	6.61
SEm ±	0.08	0.12	0.08	0.07	0.09	0.09
CD (0.05)	0.25	0.36	0.24	0.21	0.29	0.29

3. Content and uptake of potassium

The data on the content of potassium in the leaf, pseudostem and rhizome and on the total uptake of potassium are presented in Tables 51 to 52 and Fig. 21. The analyses of variance are given in Appendices 46 to 47.

Influence of shade on the potassium content of leaf, pseudostem and rhizome was significant at all the stages of growth. However, the effect on total uptake of potassium remained non-significant. No general trend in the nutrient content with increasing shade level was apparent in any of the plant components. Yet, comparatively lower concentration of potassium in plant parts were obtained almost always in plants grown at full illumination.

The change in potassium content with age was similar to that of nitrogen and phosphorus in the different plant parts. The total uptake of phosphorus showed a sharp increase with advancing stages of growth at all shade levels.

II. Soil characters

Soil nutrient status

The data on the total nitrogen, available phosphorus and available potassium in the soil after the crop are

Table 52. Effect of shade on potassium content of ginger rhizomes and on total uptake of potassium by ginger at different growth stages

Shade intensity (per cent)	Rhizome potassium content (per cent) (days after sprouting)				Total uptake of potassium (kg ha^{-1}) (days after sprouting)			
	60	120	180	225 (harvest)	60	120	180	225 (harvest)
0 (no shade)	5.76	4.17	2.00	2.80	37.65	172.11	268.87	279.17
25 (low shade)	5.84	4.39	2.38	2.80	19.57	163.81	305.78	320.75
50 (medium shade)	5.82	4.56	2.60	3.02	23.33	102.18	324.53	271.20
75 (high shade)	6.18	4.10	2.75	3.25	22.42	99.84	246.64	308.89
SEm ±	0.10	0.08	0.07	0.06	5.96	21.82	31.34	25.50
CD (0.05)	0.31	0.24	0.21	0.18	NS	NS	NS	NS

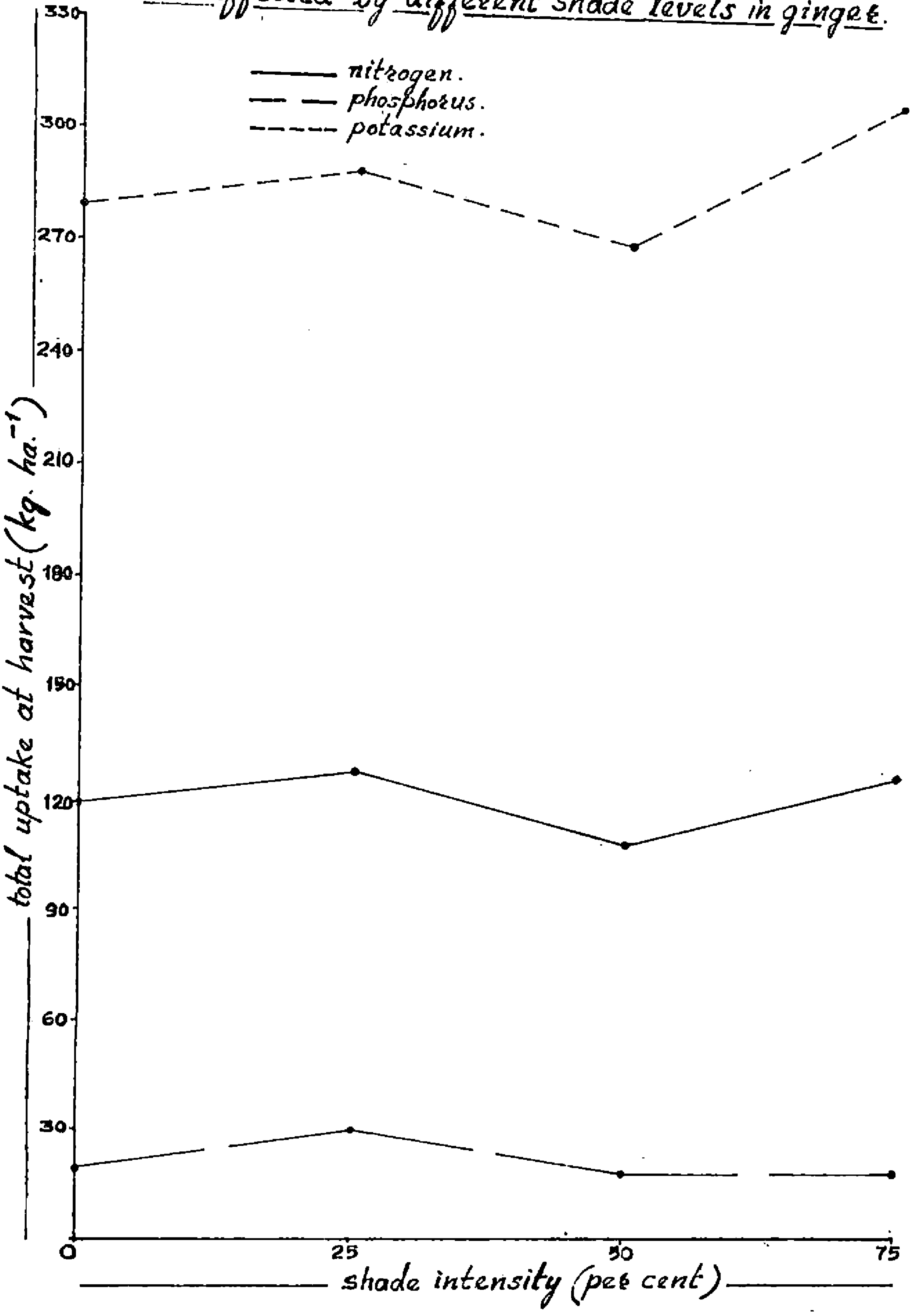
NS = Not significant

Table 53. Soil nutrient status after the crop of ginger

Shade intensity (per cent)	Nutrient		
	Total nitrogen (per cent)	Available phosphorus (ppm)	Available potassium (ppm)
0 (no shade)	0.109	2.12	96.0
25 (low shade)	0.140	2.24	98.3
50 (medium shade)	0.109	1.63	112.0
75 (high shade)	0.087	2.24	124.8
SEm ±	0.001	0.30	1.52
CD (0.05)	0.005	NS	4.19

NS = Not significant

Fig. 21 - Uptake of nitrogen, phosphorus and potassium as affected by different shade levels in ginger.



presented in Table 53 and the analysis of variance in Appendix 47.

The differences in soil nitrogen and available potassium contents between the shade levels were significant. In the case of potassium, the content were higher at higher shado levels. The nitrogen contents in soil appeared to follow the same trend as that of crop yield with the highest content at the low shade, followed by that in the open. The lowest nitrogen content was corresponding with the intense shade level. The differences in available phosphorus content were not significant.

Comparison with the pre-experimental nutrient status indicated a decrease in available phosphorus and available potassium and an increase in the nitrogen content because of the cropping.

DISCUSSION

There was increase in the yield of rhizomes in ginger with shading upto low (25 per cent) intensity. At higher shade levels, a decreasing trend in yield was noticed but the extent of decrease was marginal upto intermediate (50 per cent) shade. Even at intense (75 per cent) shade, the decrease in yield was not as conspicuous as in crops like colocasia and coleus. Taking the yield in the open as 100, the comparable yields for 25, 50 and 75 per cent shade levels were 105.6, 92.8 and 66.7 per cent, respectively. Statistical analysis of the data indicated that there was no significant difference in yield upto 50 per cent shade intensity. Among the regression models tested, the quadratic equation fitted to the logarithms of yield was found to be the best to define the variation in yield with increasing shade intensities. The optimum shade level calculated from the equation was 20.12 per cent. The fact that the yield trend is quadratic and that there is no statistically significant decrease in yield upto 50 per cent shading may qualify this crop to be classed as 'shade-loving'. It would thus make this crop highly suitable for intercropping. The results also indicate that the crop would give reasonable returns even at intense shade levels.

Dry matter accumulation by plants (Table 46) followed nearly the same trend as that of rhizome yield and the percentage values at 25, 50 and 75 per cent shade levels were 111.53, 90.86 and 87.42, respectively. These data on dry matter accumulation show that shading did not result in any appreciable decrease in the rate of photosynthesis upto the intermediate levels of 50 per cent shade. Not only that there was no decrease in photosynthesis, but shading also tended to increase the dry matter accumulation by the plants. Such a better performance of this crop under shade than in the open has been reported earlier by Aclan and Quisumbing (1976). In crops like tomato (Edmond et al., 1964), tea (Joseph, 1979), siratro and green panic (Wong and Wilson, 1980) also, such trend has been reported. The explanation given for the better performance of crops under shade than in the open is that there is often a threshold, illumination intensity beyond which the stomata of such shade loving plants tend to close (Hardy, 1958 on coffee). Though the involvement of such a factor on ginger also cannot be excluded, the influence of such a factor had been necessarily meagre on this crop.

An evaluation of the results on leaf area index (Table 44) would show that the crop produced reasonably dense canopies after about 120 days of growth. The mean LAI at this stage was well above 4.0 at all shade intensities. Unlike in the case of sweet potato and coleus, the density of the canopy was not very high and the mean maximum LAI was only 7.2. The fact that the LAI was not very high at any of the growth stages, and that ginger leaves are nearly erect in position, exclude the possibility of strong mutual shading and leaf parasitism in the open. Even though a decrease in the intensity of illumination might have adversely affected the photosynthetic rate at increasing shade intensities, these effects were not probably conspicuous upto 50 per cent shade. If at all this was operating, the effect of this factor was, probably, more than compensated by the advantage of better stomatal opening at 25 per cent shade intensity. At intense shade levels, light became the dominant limiting factor as expected and dry matter accumulation decreased substantially. Decreased yield in ginger when shading was over 50 per cent had been reported by Minoru and Hori (1969) and Aclan and Quisumbing (1976). Another conspicuous observation from the results on LAI is that there was no statistically significant increase in canopy density because of shading.

The harvest index ranged from a mean of 50.0 to 64.2 per cent at the different shade levels. The highest value of 64.2 per cent was noticed at full illumination and there was a steady decline with increasing shade levels. There are thus indications of the influence of shade on the partitioning of assimilates by the crop. Even though the highest HI values were noted in the open, the influence of such high HI values was not reflected on rhizome yield, presumably because these were more than compensated by the higher rate of photosynthesis at the low shade level.

The differences in mean net assimilation rate at different shade levels were not significant. The only conspicuous difference was between the intense shade level and other shade regimes.

Other growth characters like plant height and tiller number followed slightly different patterns as compared to dry matter accumulation and yield. In the case of tiller number, there was almost a steady decrease with increase in shade intensities at the last stage of observation though the differences were not statistically significant. In the case of plant height, there was steady increase with increase in shade intensity upto the intense shade level. The differences in plant height were also statistically significant. Aclan and Quisumbing (1976) observed that ginger plants grown under full sunlight were shorter and had lesser number of leaves per tiller but yields were just as high as those obtained under 75 and 50 per cent light intensities. When shading was over 50 per cent, yield decreased. It was also reported that ginger performed best when grown under slight shade but not in excess of 50 per cent shading. The present results are also almost in agreement with that of the above one. As had been mentioned earlier, similar report of increased plant height under shade are available on other crops like tobacco (Panikar et al., 1969) and cowpea (Tarila et al.,1979).

The total chlorophyll and its components 'a' and 'b' increased with increasing shade intensities and the differences between the various shade levels were statistically significant. This is in agreement with the observations made by Evans and Murray (1953); Ramaswami (1960), Venkatamani (1961); Clark (1965); Cooper and Qualls (1967); Guers (1971); Okali and Owusu (1975) and Radha (1979). The ratio of chlorophyll a-b did not show any distinct trend of variation with increasing shade intensities and the differences between the different shade levels remained non-significant.

The differences in the content of nitrogen, phosphorus and potassium in the plant parts were statistically significant at most of the stages. The results were however, highly variable, though there was a tendency towards a higher content of these nutrients under shade as compared to that in the open. The differences in the uptake of nutrients except in the case of phosphorus were significant at all stages of plant growth. Here again, variability was very high and the only valid conclusion out of the data is that the treatment giving the highest yield (low shade level) also recorded the highest uptake values. Calculated as percentage of the uptake in the open, the crop removal of nitrogen, phosphorus and potassium at this low shade level were 107.94, 154.66 and 114.89 per cent, respectively. At medium and intense shade levels, the uptake was nearly the same as that in the open. It may therefore be concluded that the fertilizer requirement of ginger under low shade will be around 110 per cent in the case of nitrogen and potassium and about 150 per cent in the case of phosphorus. The results also indicate that there is little scope for bringing down the fertilizer doses at medium and intense shade levels, though the yields are comparatively low.

The variation in the content of mineral nutrients in soil between shade levels and the general trend of nutrient contents as compared to the pre-experimental soil analysis figures (Table 1) were nearly similar to those of other crops like coleus and colocasia. The reasons for such a trend have been discussed already.

The salient features from the above discussion may be summarised as follows.

1. The shade response of yield of rhizomes in ginger followed a quadratic pattern with the shade optimum at about 20.11 per cent. As the performance of the crop is better under shade than in the open, this crop may be considered shade-loving. Even at intense shade level, the rhizome yield is reasonable. These would make this crop highly suitable as an intercrop in coconut gardens.

2. Dry matter accumulation by the plant followed nearly the same pattern as that of rhizome yield. Indications are thus that photosynthetic mechanism had a decisive role on the shade response of this crop.

3. In addition to the photosynthetic factors, partitioning of assimilates also appears to have been influenced by shade. Plants receiving more of illumination tended to translocate a higher proportion of carbohydrate to the rhizome.

4. Leaf area in ginger is not appreciably altered by shading.

5. Mutual shading and the consequent leaf parasitism may not be high in a sole crop of ginger when cultivated in the open. These factors probably assume importance only at intense shade levels.

6. The fertilizer requirement for intercropped ginger may be 10 to 50 per cent higher than that of a sole crop at the low shade levels. At the medium and high shade levels, requirement of fertilizers may be almost the same as that of a crop in the open.

SUMMARY

SUMMARY

An experiment was conducted at the College of Horticulture, Vellanikkara to study the shade response of common rainfed intercrops of coconut, viz. sweet potato, coleus, colocasia, turmeric and ginger. Results of the experiment are summarised below.

1. Based on shade response of these crops, sweet potato may be classified as shade-sensitive, coleus as shade-intolerant, colocasia as shade-tolerant; and ginger and turmeric as shade-loving. Sweet potato showed a drastic decrease in yield with increasing shade intensity, while in colocasia the decrease in yield was not marked upto 50 per cent shade intensity. Coleus showed a linear decrease in yield almost in proportion to the increase in shade intensity. Turmeric and ginger gave maximum yields at 50 and 25 per cent shade intensities, respectively.

2. Coleus showed a linear response to varying shade intensities. A quadratic equation fitted to the logarithm of (y + 1), (where y is the yield at different shade intensities), was found to give a close fit to the yield response of sweet potato to varying levels of shade. In colocasia and ginger, a quadratic polynomial and in turmeric a cubic polynomial fitted to the logarithm of yield were the better fit to the response curves obtained.

3. Photosynthetic mechanism appears to have dominant role in the shade response of all the crops excepting sweet potato. In the case of sweet potato, partitioning and translocation of assimilates was adversely affected by shading.

4. Crops like sweet potato, coleus and turmeric produced dense canopies. The canopy density of ginger was relatively lower. Colocasia produced only a sparse canopy at the normal planting density, even in the open, thus indicating that there is scope for increasing the yield of this crop substantially by closer planting when grown as a sole crop in the open. Sweet potato exhibited a marked decrease in canopy density at higher shade intensities.

5. Excepting colocasia, plant height (length of vine in sweet potato) in all the crops increased with increasing intensities of shade.

6. Number of branches (tillers) in all the crops significantly decreased with increasing levels of shade.

7. The effect of shade on content of chlorophyll 'a', 'b' and total chlorophyll in leaves was significant in all the crops excepting sweet potato. In coleus, ginger and turmeric the chlorophyll content increased with increasing shade intensities, while no general trend was noticed in colocasia.

8. The ratio of chlorophyll a-b remained almost a constant in sweet potato, coleus and ginger, while in turmeric, the ratio increased with increasing shade intensity upto medium shade and then decreased. In the case of colocasia, no general trend was noticed.

9. Contents of nitrogen, phosphorus and potassium in all the plant components of the different crops increased with increasing intensities of shade.

10. The uptake of these nutrients by the individual crops followed an identical pattern as that of dry matter accumulation. Thus in sweet potato, coleus and colocasia, the uptake decreased with increased shade intensity while in turmeric and ginger, the maximum uptake values were recorded at medium and low shade intensities, respectively.

11. It appears that in sweet potato, the utilization efficiencies of the nutrients added would be markedly less under shade than in the open. The nutrient removal by a crop of coleus grown under intermediate shade level was about 70 per cent of that for a sole crop in the open. The nutrient removal by colocasia was nearly the same as that in the open upto the intermediate (50 per cent) shade level. Turmeric grown at about 50 per cent shade removed about 20 per cent more

of fertilizer nutrients than a sole crop in the open. An additional 10 per cent of the nutrients was removed by a crop of ginger under low (25 per cent) shade intensity. In all the crops excepting ginger, nutrient uptake decreased considerably at intense (75 per cent) shade levels. Ginger plants recorded higher uptake values at this shade levels as compared to the open.

12. It was concluded from the investigations that sweet potato is unsuitable for intercropping. Coleus might be suitable only under conditions of ample light infiltration. The crops colocasia, turmeric and ginger may be considered highly suited for intercropping.

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APPENDICES

Appendix 1. Weather data (weekly average) for the period May 1980 to January 1981

Month and date	Week No.	Temperature °C Maximum	Temperature °C Minimum	Rainfall in (mm)	Relative humidity (per cent) Fore noon	Relative humidity (per cent) After-noon	Sunshine (No. of hours of bright sunshine)	Soil temperature °C (5 cm depth) Fore-noon	Soil temperature °C (5 cm depth) After-noon
(1980)									
May 28-June 3	22	31.9	23.1	11.6	95.8	82.6	4.0	25.6	32.8
June 4-10	23	31.2	23.3	45.4	94.3	87.6	1.1	24.9	29.2
11-17	24	32.2	22.9	14.5	95.0	76.8	5.8	26.1	30.5
18-24	25	29.5	23.2	40.8	95.3	94.3	1.7	24.9	28.3
25-July 1	26	29.3	22.7	36.2	94.3	93.6	1.6	24.4	28.8
July 2-8	27	28.8	22.3	43.3	94.0	88.4	3.1	23.8	29.4
9-15	28	29.1	22.3	56.0	95.0	91.3	2.0	23.5	30.6
16-22	29	29.8	22.9	33.7	95.4	93.6	4.1	24.7	30.0
23-29	30	29.9	22.2	29.1	95.7	82.7	2.5	24.9	28.7
30-August 5	31	29.0	22.3	7.5	95.9	80.1	2.7	24.4	29.5
6-12	32	30.2	22.5	12.8	95.3	86.4	5.6	24.3	28.7
13-19	33	30.5	22.1	50.6	97.1	82.3	2.4	24.3	30.6
20-26	34	29.7	22.6	12.9	93.1	84.1	4.7	25.0	30.1
27-September 2	35	30.4	22.2	11.1	95.9	73.4	5.6	24.7	31.9
Sept.3-9	36	30.7	22.4	2.9	95.7	67.4	6.3	24.7	35.1
10-16	37	31.6	23.4	0.0	95.7	61.4	8.2	26.1	41.2
17-23	38	32.4	22.8	2.9	89.9	62.4	9.1	28.4	39.2
24-30	39	32.1	23.2	13.4	95.8	74.5	6.3	25.3	32.0
October 1-7	40	31.7	23.8	12.0	92.3	74.0	6.3	25.6	35.0
8-14	41	32.4	23.5	7.7	95.7	69.7	5.2	25.5	36.0
15-21	42	32.2	21.2	18.4	97.7	72.8	4.3	26.2	32.9
22-28	43	31.5	20.9	4.7	90.8	69.7	6.4	25.8	34.1
29-November 4	44	32.7	20.6	3.2	87.3	49.8	9.6	24.9	33.0
5-11	45	32.8	23.0	4.0	90.5	62.8	8.5	25.3	32.1
12-18	46	32.0	23.0	12.7	92.2	70.9	5.4	26.9	37.5
19-25	47	31.6	23.1	14.2	89.1	76.3	7.1	25.3	36.0
26-December 2	48	31.8	21.9	0.0	86.1	69.9	8.9	24.2	37.2
3-9	49	32.1	20.8	0.0	87.6	67.4	9.3	24.6	36.9
10-16	50	33.0	22.6	0.0	89.9	63.7	9.0	24.0	38.0
17-23	51	32.3	22.5	0.0	84.7	62.4	8.2	23.9	38.7
24-31	52	31.9	21.3	0.0	85.2	65.1	7.6	24.1	38.5
(1981)									
Jan. 1-7	1	33.5	20.4	0.0	82.7	56.1	9.0	24.0	38.0
8-14	2	32.9	20.5	0.0	82.1	46.0	9.7	24.1	39.1
15-21	3	33.1	22.1	0.0	83.0	45.4	10.1	24.1	39.3
22-28	4	34.0	22.2	0.0	82.6	49.1	9.9	24.0	39.2

Source: B Class observatory, Vellanikkara, Trichur.

Appendix 2. The weekly average daily range in meteorological parameters relating to individual crops tried

Meteorological parameters	Crop				
	Sweet potato	Coleus	Colocasia	Turmeric	Ginger
Temperature °C					
Maximum	29.0 to 32.4	29.0 to 32.4	29.0 to 33.0	29.0 to 33.5	29.0 to 33.5
Minimum	22.1 to 23.8	20.9 to 23.8	20.8 to 23.8	20.4 to 23.8	20.4 to 23.8
Rainfall					
Intensity (mm)	2679.4	2907.9	3754.2	3754.2	3754.2
Frequency (days)*	75	82	104	104	104
Sunshine					
Number of hours of bright sunshine	1.6 to 9.1	1.6 to 9.1	1.6 to 9.6	1.1 to 9.7	1.1 to 10.1
Relative humidity (per cent)					
Forenoon	89.9 to 97.1	89.9 to 97.1	84.7 to 97.7	82.1 to 97.7	82.1 to 97.7
Afternoon	61.4 to 94.3	61.4 to 94.3	61.4 to 94.3	45.4 to 94.3	45.4 to 94.3
Soil temperature at 5 cm depth (°C)					
Forenoon	23.5 to 28.4	23.5 to 28.4	23.5 to 28.4	23.5 to 28.4	23.5 to 28.4
Afternoon	28.3 to 39.2	28.3 to 39.2	28.3 to 39.2	28.3 to 39.3	28.3 to 39.3

* A rainy day is one in which the rainfall intensity is ≥ 2.5 mm.

Appendix 3. Analyses of variance for the effect of shade on length of vine, number of branches and leaf area index of sweet potato

Source	df	Mean squares										
		Length of vine (days after planting)			Number of branches plant^{-1} (days after planting)				Leaf area index (days after planting)			
		30	60	90	30	60	90	110 (harvest)	30	60	90	110 (harvest)
Block	4	602.03	2497.29	9514.26**	8.88*	9.37	9.66	15.48	0.63	2.07	8.59*	5.70
Treatment	3	462.44	6727.35*	15990.18**	41.68**	244.74**	191.07**	172.35**	2.62*	33.23**	19.75**	58.18**
Error	12	310.31	1346.55	1583.70	2.72	4.75	9.64	14.80	0.50	2.36	1.72	4.07

* Significant at 5 per cent level
** Significant at 1 per cent level

Appendix 4. Analyses of variance for the effect of shade on content of chlorophyll 'a', 'b' and total chlorophyll; ratio of chlorophyll a-b of sweet potato leaves

Source	df	Mean squares											
		Chlorophyll 'a' (days after planting)			Chlorophyll 'b' (days after planting)			Total chlorophyll (days after planting)			Chlorophyll a:b (days after planting)		
		80	95	110 (harvest)	80	95	110 (harvest)	80	95	110 (harvest)	80	95	110 (harvest)
Block	4	0.01	0.02	0.003	0.01	0.03	0.02	0.03	0.08	0.04	0.0014	0.004	0.002
Treatment	3	0.01	0.02	0.036*	0.02	0.01	0.09	0.06	0.04	0.24	0.0001	0.002	0.002
Error	12	0.01	0.02	0.009	0.02	0.03	0.03	0.06	0.10	0.07	0.0009	0.002	0.001

* Significant at 5 per cent level

Appendix 5. Analyses of variance for the effect of shade on total dry weight, net assimilation rate, tuber yield, haulm yield and harvest index of sweet potato

Source	df	Mean squares								
		Total dry weight plant^{-1} (days after planting)				Net assimilation rate		Tuber yield	Haulm yield	Harvest index
		30	60	90	110 (harvest)	Between 30 & 60 days	Between 60 & 90 days			
Block	4	15.64	215.03	348.17	997.42	0.72	0.40	0.06*	3.14*	0.005
Treatment	3	212.32**	5656.81**	13656.51**	14637.35**	4.94**	1.90	0.93**	113.80**	0.023*
Error	12	20.74	83.67	383.25	644.34	0.35	3.35	0.015	0.80	0.005

* Significant at 5 per cent level
** Significant at 1 per cent level

Appendix 6. Analyses of variance for the effect of shade on nitrogen content of leaf and stem + petiole and for total uptake of nitrogen by sweet potato

Source	df	Mean squares											
		Leaf nitrogen content (days after planting)				Stem + petiole nitrogen content (days after planting)				Total uptake of nitrogen (days after planting)			
		30	60	90	110 (harvest)	30	60	90	110 (harvest)	30	60	90	110 (harvest)
Block	4	0.132	0.014*	0.080	0.010	0.003	0.014*	0.024	0.009**	72.31	803.17	1435.26	3024.41
Treatment	3	0.077	0.234**	0.552**	0.030*	0.178**	0.195**	0.036	0.035**	862.15**	15360.43**	17970.28**	35766.60**
Error	12	0.065	0.004	0.068	0.015	0.004	0.004	0.019	0.001	89.04	368.25	583.58	2501.16

* Significant at 5 per cent level
** Significant at 1 per cent level

Appendix 7. Analyses of variance for the effect of shade on phosphorus content of leaf and stem + petiole and total uptake of phosphorus by sweet potato

Source	df	Mean squares											
		Leaf phosphorus content (days after planting)				Stem + petiole phosphorus content (days after planting)				Total uptake of phosphorus (days after planting)			
		30	60	90	110 (harvest)	30	60	90	110 (harvest)	30	60	90	110 (harvest)
Block	4	0.0012**	0.0004	0.0002	0.0023	0.0050*	0.0063*	0.0005	0.00054*	1.44	18.36	10.71	30.89
Treatment	3	0.0063**	0.0071	0.0067**	0.0024	0.011**	0.0017	0.0002	0.00241**	8.54**	267.85**	315.34**	516.56**
Error	12	0.0001	0.0021	0.0001	0.0010	0.0002	0.0017	0.0004	0.00015	1.27	8.88	7.46	25.85

* Significant at 5 per cent level
** Significant at 1 per cent level

Appendix 8. Analyses of variance for the effect of shade on potassium content in leaf and stem + petiole and total uptake of potassium in sweet potato

Source	df	Mean squares											
		Leaf potassium content (days after planting)				Stem + petiole potassium content (days after planting)				Total uptake of potassium (days after planting)			
		30	60	90	110 (harvest)	30	60	90	110 (harvest)	30	60	90	110 (harvest)
Block	4	0.17**	0.24*	0.05**	0.033**	0.09	0.07*	0.04*	0.107**	393.70	4024.15	5317.46	13664.70
Treatment	3	0.27**	0.31**	0.14**	0.193**	1.59**	0.48**	0.33**	1.071**	2846.50**	71673.86**	84440.78**	153965.35**
Error	12	0.01	0.05	0.01	0.002	0.06	0.014	0.012	0.004	397.75	1629.76	2553.22	5103.60

* Significant at 5 per cent level
** Significant at 1 per cent level

Appendix 9. Analyses of variance for the effect of shade on the soil nutrient status after the crop of sweet potato

Source	df	Nutrient		
		Total nitrogen	Available phosphorus	Available potassium
Block	4	0.0001	1.356	52.99*
Treatment	3	0.0012**	10.228**	756.56**
Error	12	0.0001	0.475	13.52

* Significant at 5 per cent level

** Significant at 1 per cent level

Appendix 10. Analyses of variance for the effect of shade on plant height, number of branches and leaf area index of coleus

Source	df	Mean squares											
		Plant height (days after planting)				Number of branches (days after planting)				Leaf area index (days after planting)			
		35	65	95	125 (harvest)	35	65	95	125 (harvest)	35	65	95	125 (harvest)
Block	4	1.89	44.55	115.36	154.61	4.67	36.52	104.70	313.07	0.87	9.79	2.77	5.50
Treatment	3	4.37	75.40	342.94**	126.08	59.81*	33.10	162.07	32.60	1.81	8.18	27.43	1.85
Error	12	9.21	34.32	46.51	52.85	12.76	14.04	64.98	104.24	0.86	10.10	16.25	5.51

* Significant at 5 per cent level
** Significant at 1 per cent level

Appendix 11. Analyses of variance for the effect of shade on the contents of chlorophyll 'a', 'b' and total chlorophyll ratio of chlorophyll a-b of coleus leaves

Source	df	Mean squares											
		Chlorophyll 'a' (days after planting)			Chlorophyll 'b' (days after planting)			Total chlorophyll (days after planting)			Chlorophyll a:b (days after planting)		
		80	110	125 (harvest)	80	110	125 (harvest)	80	110	125 (harvest)	80	110	125 (harvest)
Block	4	0.009	0.05	0.01	0.01	0.05	0.07	0.02	0.17	0.11	0.012	0.02	0.01
Treatment	3	0.195**	0.20**	0.18**	0.28**	3.06**	0.16*	1.04**	0.99**	0.67**	0.001	0.02	0.03
Error	12	0.019	0.03	0.005	0.01	0.02	0.03	0.003	0.10	0.006	0.014	0.01	0.01

* Significant at 5 per cent level
** Significant at 1 per cent level

Appendix 12. Analyses of variance for the effect of shade on total dry matter production, net assimilation rate, number of tubers, tuber yield, haulm yield and harvest index of coleus

Source	df	Mean squares: Total dry weight (days after planting) 35	65	95	125 (harvest)	Net assimilation rate: Between 35 & 65 days	Between 65 & 95 days	Number of tubers (days after planting) 65	95	125 (harvest)	Tuber yield	Haulm yield	Harvest index
Block	4	0.54	30.43	81.22	58.72	0.35	1.82	0.12	5.05	681.87**	24.08	0.31	0.003
Treatment	3	5.53**	180.09**	621.91**	663.78*	2.66*	3.78	1.88**	241.96**	155.69	525.48**	5.50*	0.017**
Error	12	0.76	26.98	68.30	127.72	0.59	1.65	0.24	6.88	76.70	22.21	1.38	0.003

* Significant at 5 per cent level
** Significant at 1 per cent level

Appendix 13. Analyses of variance for the effect of shade on nitrogen contents of coleus leaf, stem + petiole and tuber

Source	df	Mean squares: Nitrogen content of leaf (days after planting) 35	65	95	125 (harvest)	Stem + petiole nitrogen content (days after planting) 35	65	95	125 (harvest)	Tuber nitrogen content (days after planting) 35	65	95	125 (harvest)
Block	4	0.01**	0.04	0.03*	0.003	0.006	0.004	0.002	0.002**	-	-	0.005	0.004
Treatment	3	0.73**	2.30**	1.85**	0.407**	0.579**	0.554**	0.664**	0.152**	-	-	0.004	0.118**
Error	12	0.002	0.02	0.01	0.003	0.003	0.003	0.001	0.0003	-	-	0.008	0.002

* Significant at 5 per cent level
** Significant at 1 per cent level

Appendix 14. Analyses of variance for the effect of shade on total uptake of nitrogen by coleus and for the content of phosphorus in coleus leaf and stem + petiole

Source	df	Mean squares											
		Total uptake of nitrogen (days after planting)				Phosphorus content of leaf (days after planting)				Stem + petiole phosphorus content (days after planting)			
		35	65	95	125 (harvest)	35	65	95	125 (harvest)	35	65	95	125 (harvest)
Block	4	269.50**	63.22	71.41	37.58*	0.005*	0.0004	0.001	0.0002	0.0003	0.0011	0.0003	0.0004*
Treatment	3	115.72	51.68	97.02	117.19	0.003**	0.0233**	0.0002	0.0021**	0.0021	0.0059**	0.0046**	0.0005*
Error	12	42.55	53.39	86.52	69.39	0.0001	0.0003	0.0006	0.0002	0.0008	0.0008	0.0001	0.0001

* Significant at 5 per cent level
** Significant at 1 per cent level

Appendix 15. Analyses of variance for the effect of shade on phosphorus content of coleus tuber, total uptake of phosphorus by coleus and potassium content in coleus leaf

Source	df	Mean squares									
		Tuber phosphorus content (days after planting)		Total uptake of phosphorus (days after planting)				Leaf potassium content (days after planting)			
		95	125 (harvest)	35	65	95	125 (harvest)	35	65	95	125 (harvest)
Block	4	0.001	0.0007*	3.09**	1.63	2.24	1.30	0.04*	0.02	0.02	0.03
Treatment	3	0.001	0.0025**	2.04*	4.38	17.90**	13.34*	0.74**	2.05**	1.18**	0.29**
Error	12	0.001	0.0001	0.52	1.56	2.23	2.46	0.01	0.01	0.04	0.01

* Significant at 5 per cent level
** Significant at 1 per cent level

Appendix 16. Analyses of variance for the effect of shade on potassium content of coleus stem + petiole and tuber; and for the total uptake of potassium by coleus

Source	df	Mean squares									
		Stem + petiole potassium content (days after planting)				Tuber potassium content (days after planting)		Total uptake of potassium (days after planting)			
		35	65	95	125 (harvest)	95	125 (harvest)	35	65	95	125 (harvest)
Block	4	0.03	0.04*	0.05	0.14*	0.12	0.02	479.58**	397.15	1703.84	350.60
Treatment	3	1.39**	6.36**	2.82**	2.82**	0.01	0.01	297.15*	708.96	3309.50*	1629.78
Error	12	0.01	0.01	0.23	0.04	0.06	0.04	84.61	290.21	819.60	468.16

* Significant at 5 per cent level
** Significant at 1 per cent level

Appendix 17. Analysis of variance for the effect of shade on soil nutrient status after the crop of coleus

Source	df	Nutrient		
		Total nitrogen	Available phosphorus	Available potassium
Block	4	0.0001	2.23	87.84
Treatment	3	0.0011**	4.81	1211.98**
Error	12	0.00005	1.96	29.38

** Significant at 1 per cent level

Appendix 18. Analyses of variance for the effect of shade on plant height and collar girth of colocasia

Source	df	Mean squares									
		Plant height (days after sprouting)					Girth at collar (days after sprouting)				
		30	60	90	120	150	30	60	90	120	150
Block	4	463.99*	32.33	33.05	55.53	47.54	17.53*	1.42	0.18	4.29	0.73
Treatment	3	159.17	859.74**	446.01**	49.49	46.55	4.30	46.40**	0.49	6.26	1.10
Error	12	93.82	127.39	59.40	49.62	46.39	4.23	4.62	0.91	2.69	0.93

* Significant at 5 per cent level
** Significant at 1 per cent level

Appendix 19. Analyses of variance for the effect of shade on number of tillers and leaf area index of colocasia

Source	df	Mean squares									
		Number of tillers plant^{-1} (days after sprouting)					Leaf area index (days after sprouting)				
		30	60	90	120	150	30	60	90	120	150
Block	4	0.65	1.30	9.16	7.32	1.33	0.21*	0.13	0.02	0.14*	0.02
Treatment	3	2.88	55.28**	40.12**	64.48**	50.57*	0.01	0.93	0.25	0.29**	0.02
Error	12	2.34	5.22	5.22	8.15	10.46	0.05	0.44	0.09	0.04	0.02

* Significant at 5 per cent level
** Significant at 1 per cent level

Appendix 20. Analyses of variance for the effect of shade on content of chlorophyll 'a' and 'b' of colocasia leaves

Source	df	Mean squares							
		Chlorophyll 'a' (days after sprouting)				Chlorophyll 'b' (days after sprouting)			
		80	110	140	170	80	110	140	170
Block	4	0.002	0.005	0.007	0.017*	0.024	0.023	-0.010	0.057
Treatment	3	0.093**	0.043*	0.072**	0.138**	0.117	0.111**	0.153**	0.193**
Error	12	0.008	0.009	0.005	0.005	0.060	0.021	0.016	0.018

* Significant at 5 per cent level
** Significant at 1 per cent level

Appendix 21. Analyses of variance for the effect of shade on total chlorophyll content and ratio of chlorophyll a-b of colocasia leaves

Source	df	Mean squares							
		Total chlorophyll content (days after planting)				Chlorophyll a:b (days after planting)			
		80	110	140	170	80	110	140	170
Block	4	0.047	0.046	0.032	0.135*	0.004*	0.0008*	0.0004	0.023
Treatment	3	0.588**	0.290*	0.434**	0.653**	0.002	0.0009*	0.0003	0.032
Error	12	0.051	0.057	0.037	0.025	0.001	0.0002	0.0004	0.014

* Significant at 5 per cent level
** Significant at 1 per cent level

Appendix 22. Analyses of variance for the effect of shade on total dry matter production, yield of total tubers, side tubers and haulm for harvest index of colocasia

Source	df	Mean squares: total dry weight (days after sprouting) 30	60	90	120	150	180 (Harvest)	Yield: Total tuber	Side tuber	Haulm	Harvest index
Block	4	109.93**	115.14	297.15	536.67	589.67	285.75	17.27	8.56	0.033	0.001
Treatment	3	14.03	1976.13**	2460.32**	5375.29**	3980.57**	4495.43*	112.93**	79.53**	0.047	0.006**
Error	12	13.53	237.96	205.01	291.07	501.22	828.89	16.39	8.93	0.023	0.0008

* Significant at 5 per cent level
** Significant at 1 per cent level

Appendix 23. Analyses of variance for the effect of shade on nitrogen content of leaf and pseudostem of colocasia

Source	df	Mean squares: Leaf nitrogen content (days after sprouting) 30	60	90	120	150	180 (harvest)	Pseudostem nitrogen content (days after sprouting) 30	60	90	120	150	180 (harvest)
Block	4	0.04**	0.05	0.07	0.03	0.04	0.01	0.01	0.08	0.01	0.01	0.02*	0.004
Treatment	3	0.22**	0.83**	0.63**	0.31**	0.27**	0.06**	0.13**	0.13	0.05**	0.45**	0.23**	0.118**
Error	12	0.01	0.03	0.06	0.02	0.02	0.01	0.005	0.05	0.004	0.003	0.004	0.005

* Significant at 5 per cent level
** Significant at 1 per cent level

Appendix 24. Analyses of variance for the effect of shade on nitrogen content of tuber and for total uptake of nitrogen by colocasia

Source	df	Mean squares: Tuber nitrogen content (days after sprouting) 60	90	120	150	180 (harvest)	Total uptake of nitrogen (days after sprouting) 30	60	90	120	150	180 (harvest)
Block	4	0.002	0.0007	0.006	0.0001	0.005	165.33**	18.77	76.95	140.06	129.99	63.72
Treatment	3	0.034**	0.0015*	0.734**	0.013**	0.163**	22.62	742.41*	376.74*	1869.85**	741.88*	752.59
Error	12	0.0012	0.0004	0.004	0.001	0.003	18.82	145.55	81.22	90.49	135.42	234.67

* Signifieant at 5 per cent level
** Significant at 1 per cent level

Appendix 25. Analyses of variance for the effect of shade on phosphorus content of leaf and pseudostem of colocasia

Source	df	Mean squares: Leaf phosphorus content (days after sprouting) 30	60	90	120	150	180 (harvest)	Pseudostem phosphorus content (days after sprouting) 30	60	90	120	150	180 (harvest)
Block	4	0.002	0.002**	0.002	0.001	0.001	0.0002	0.0025**	0.014*	0.001	0.001*	0.001	0.001
Treatment	3	0.012**	0.025**	0.003	0.008**	0.001	0.0022*	0.0248**	0.049**	0.008**	0.010**	0.018**	0.011**
Error	12	0.001	0.0003	0.001	0.001	0.001	0.0005	0.0004	0.004	0.0005	0.0002	0.001	0.001

* Significant at 5 per cent level
** Significant at 1 per cent level

Appendix 26. Analyses of variance for the effect of shade on tuber phosphorus content of colocasia and for the total uptake of phosphorus by colocasia

Source	df	Mean squares										
		Tuber phosphorus content (days after sprouting)					Total phosphorus uptake (days after sprouting)					
		60	90	120	150	180 (harvest)	30	60	90	120	150	180 (harvest)
Block	4	0.003	0.001	0.005**	0.002	0.003	5.26**	1.62	2.79	2.58	3.57	2.69
Treatment	3	0.002	0.021**	0.010**	0.025*	0.033**	0.27	39.19**	35.24**	35.94**	24.07*	144.27**
Error	12	0.003	0.0004	0.0006	0.004	0.002	0.46	5.77	2.65	6.15	6.51	6.46

* Significant at 5 per cent level
** Significant at 1 per cent level

Appendix 27. Analyses of variance for the effect of shade on potassium content of leaf and pseudostem of colocasia

Source	df	Mean squares											
		Leaf potassium content (days after sprouting)						Pseudostem potassium content (days after sprouting)					
		30	60	90	120	150	180 (harvest)	30	60	90	120	150	180 (harvest)
Block	4	0.16	0.27**	0.01	0.12	0.07	0.06	0.29**	0.25**	0.19**	0.13*	0.05	0.08
Treatment	3	0.92**	0.23**	0.54**	0.74**	0.92**	0.58**	0.77**	0.18*	1.77**	1.25**	0.98**	1.68**
Error	12	0.06	0.03	0.02	0.04	0.03	0.05	0.05	0.03	0.03	0.02	0.04	0.12

* Significant at 5 per cent level
** Significant at 1 per cent level

Appendix 28. Analyses of variance for the effect of shade on potassium content of colocasia tuber and for the total uptake of potassium by colocasia

Source	df	Mean squares										
		Tuber potassium content (days after sprouting)					Total uptake of potassium (days after sprouting)					
		60	90	120	150	180 (harvest)	30	60	90	120	150	180 (harvest)
Block	4	0.05**	0.025	0.09**	0.05	0.07*	967.21**	346.11	610.18	667.02	474.36	137.19
Treatment	3	0.09**	0.143*	0.11**	0.02	0.12**	182.07	6830.64**	3833.71**	5970.77**	2934.60**	6117.59**
Error	12	0.006	0.027	0.015	0.02	0.02	119.57	1017.70	523.00	491.43	475.79	720.04

* Significant at 5 per cent level
** Significant at 1 per cent level

Appendix 29. Analyses of variance for the effect of shade on soil nutrient status after the crop of colocasia

Source	df	Mean squares		
		Total nitrogen	Available phosphorus	Available potassium
Block	4	0.000002	3.99**	84.67*
Treatment	3	0.00044**	11.28**	848.79**
Error	12	0.00003	0.43	25.69

* Significant at 5 per cent level
** Significant at 1 per cent level

Appendix 30. Analyses of variance for the effect of shade on plant height, number of tillers and leaf area index of turmeric

Source	df	Mean squares						Leaf		
		Plant height (days after sprouting)			Number of tillers plant^{-1} (days after sprouting)			Leaf area index (days after sprouting)		
		60	120	180	60	120	180	60	120	180
Block	4	152.5	1103.8**	124.7	1.34	1.01	3.17*	1.47*	25.08*	411.11
Treatment	3	122.5	215.4	730.3**	8.94*	1.58	5.34**	2.94**	6.28	33.47
Error	12	61.2	68.0	61.7	1.66	0.79	0.62	0.35	6.99	20.04

* Significant at 5 per cent level
** Significant at 1 per cent level

Appendix 31. Analyses of variance for the effect of shade on content of chlorophyll 'a', 'b' and total chlorophyll; chlorophyll a-b ratio of turmeric leaves

Source	df	Mean squares							
		Chlorophyll 'a' content (days after sprouting)		Chlorophyll 'b' content (days after sprouting)		Total chlorophyll content (days after sprouting)		Chlorophyll a:b (days after sprouting)	
		100	160	100	160	100	160	100	160
Block	4	0.04*	0.02	0.09**	0.04	0.23**	0.10	0.002	0.0036
Treatment	3	0.17**	0.13**	0.18**	0.18**	0.71**	0.61**	0.007**	0.0001
Error	12	0.01	0.01	0.01	0.02	0.03	0.06	0.001	0.0043

* Significant at 5 per cent level
** Significant at 1 per cent level

Appendix 32. Analyses of variance for the effect of shade on total dry matter production, net assimilation rate, rhizome yield, haulm yield, and harvest index of turmeric

Source	df	Mean squares									
		Total dry weight($g\ plant^{-1}$) (days after sprouting)					Net assimilation rate		Rhizome yield	Haulm yield	Harvest index
		60	120	180	220 (harvest)	220 (harvest) $t\ ha^{-1}$	Between 60 & 120 days	Between 120 & 180 days			
Block	4	17.11*	230.65	1301.71	619.87	6.8	0.08	0.19	95.32	0.98	0.003
Treatment	3	55.32**	203.61	902.54	1481.67*	18.43**	0.08	0.32	594.08**	6.26**	0.009
Error	12	4.38	79.70	607.39	248.64	2.85	0.15	1.10	54.73	0.96	0.003

* Significant at 5 per cent level
** Significant at 1 per cent level

Appendix 33. Analyses of variance for the effect of shade on nitrogen content of leaf and pseudostem of turmeric

Source	df	Mean squares							
		Leaf nitrogen content (days after sprouting)				Pseudostem nitrogen content (days after sprouting)			
		60	120	180	220	60	120	180	220
Block	4	0.012**	0.008*	0.003**	0.001	0.003	0.00003	0.0002	0.001*
Treatment	3	0.162**	0.108**	0.174**	0.077**	0.200**	0.057**	0.016**	0.026**
Error	12	0.002	0.002	0.0004	0.007	0.003	0.001	0.0002	0.0002

* Significant at 5 per cent level
** Significant at 1 per cent level

Appendix 34. Analyses of variance for the effect of shade on nitrogen content of turmeric rhizome and for the total uptake of nitrogen by turmeric

Source	df	Mean squares							
		Rhizome nitrogen content (days after sprouting)				Total uptake of nitrogen (days after sprouting)			
		60	120	180	220 (harvest)	60	120	180	220 (Harvest)
Block	4	0.005	0.0001	0.002	0.005	391.38	2470.18*	6618.29	3605.94
Treatment	3	0.252**	0.052**	0.029**	0.030**	710.87**	1287.94	1027.58	6493.52*
Error	12	0.010	0.001	0.003	0.002	96.30	546.12	3066.65	1531.21

* Significant at 5 per cent level
** Significant at 1 per cent level

Appendix 35. Analyses of variance for the effect of shade on phosphorus content of leaf and pseudostem of turmeric

Source	df	Mean squares							
		Leaf phosphorus content (days after sprouting)				Pseudostem phosphorus content (days after sprouting)			
		60	120	180	220 (harvest)	60	120	180	220 (harvest)
Block	4	0.001	0.0003	0.0003	0.0002	0.0001	0.0001	0.003	0.0004
Treatment	3	0.002	0.003**	0.006**	0.0013**	0.0116**	0.0015*	0.006	0.0008*
Error	12	0.001	0.0002	0.0008	0.0001	0.0003	0.0004	0.005	0.0002

* Significant at 5 per cent level
** Significant at 1 per cent level

Appendix 36. Analyses of variance for the effect of shade on phosphorus content of turmeric rhizomes and for the total uptake of phosphorus by turmeric

Source	df	Mean squares							
		Rhizome phosphorus content (days after sprouting)				Total uptake of phosphorus (days after sprouting)			
		60	120	180	220 (harvest)	60	120	180	220 (harvest)
Block	4	0.0003	0.0007	0.001	0.015	7.75*	63.08*	238.34	145.91
Treatment	3	0.0029*	0.0091**	0.015**	0.013	12.47**	36.18	175.20	450.39*
Error	12	0.0006	0.0009	0.007	0.017	2.02	17.57	186.47	80.32

* Significant at 5 per cent level
** Significant at 1 per cent level

Appendix 37. Analyses of variance for the effect of shade on potassium content in leaf and pseudostem of turmeric

Source	df	Mean squares							
		Leaf potassium content (days after sprouting)				Pseudostem potassium content (days after sprouting)			
		60	120	180	220 (harvest)	60	120	180	220 (harvest)
Block	4	0.018	0.100	0.119	0.015	0.021	0.027	0.174**	0.029
Treatment	3	0.161**	0.501**	0.384*	1.808**	2.020**	2.977**	1.341**	2.306**
Error	12	0.019	0.036	0.069	0.026	0.072	0.019	0.026	0.038

* Significant at 5 per cent level
** Significant at 1 per cent level

Appendix 38. Analyses of variance for the effect of shade on potassium content of turmeric rhizome and for the total uptake of potassium by turmeric

Source	df	Mean squares							
		Rhizome potassium content (days after sprouting)				Total uptake of potassium (days after sprouting)			
		60	120	180	220 (harvest)	60	120	180	220 (harvest)
Block	4	0.036	0.045	0.013	0.013	3039.02*	42892.4*	98760.6	39894.0
Treatment	3	0.409**	1.040	1.028**	0.170**	6898.93**	22212.2	12021.3	63093.8*
Error	12	0.033	0.016	0.038	0.024	884.03	9107.4	42925.3	14124.1

* Significant at 5 per cent level
** Significant at 1 per cent level

Appendix 39. Analyses of variance for the effect of shade on soil nutrient status after the crop of turmeric

Source	df	Mean squares		
		Total nitrogen	Available phosphorus	Available potassium
Block	4	0.00001	0.106	52.76
Treatment	3	0.0048**	2.775*	1055.23**
Error	12	0.00001	0.711	24.19

* Significant at 5 per cent level
** Significant at 1 per cent level

Appendix 40. Analyses of variance for the effect of shade on plant height, number of tillers and leaf area index of ginger

Source	df	Mean squares: Plant height (days after sprouting) 60	120	180	Number of tillers plant^{-1} (days after sprouting) 60	120	180	Leaf area index (days after sprouting) 60	120	180
Block	4	17.90	61.55*	15.17	4.06	21.13	22.11*	0.02	0.68	2.80
Treatment	3	8.93	125.01**	387.74**	13.13*	56.51	7.74	0.06	2.10	2.53
Error	12	24.57	17.84	29.23	3.54	21.87	5.89	0.06	1.13	2.24

* Significant at 5 per cent level
** Significant at 1 per cent level

Appendix 41. Analyses of variance for the effect of shade on content of chlorophyll 'a', 'b' and total chlorophyll; chlorophyll a:b of ginger leaves

Source	df	Mean squares: Chlorophyll 'a' (days after sprouting) 100	160	Chlorophyll 'b' (days after sprouting) 100	160	Total chlorophyll (days after sprouting) 100	160	Chlorophyll a:b (days after sprouting) 100	160
Block	4	0.04*	0.07*	0.07	0.23**	0.19	0.51**	0.006	0.025*
Treatment	3	0.26**	0.46**	0.40**	0.66**	1.31**	2.19**	0.002	0.006
Error	12	0.01	0.02	0.03	0.02	0.06	0.06	0.005	0.005

* Significant at 5 per cent level
** Significant at 1 per cent level

Appendix 42. Analyses of variance for the effect of shade on total dry matter production, net assimilation rate, rhizome yield, haulm yield and harvest index of ginger

Source	df	Mean squares								
		Total dry weight (days after sprouting)				Net assimilation rate		Rhizome yield	Haulm yield	Harvest index
		60	120	180	225 (harvest)	Between 60 & 120 days	between 120 & 180 days			
Block	4	0.82	25.32	153.61	245.49	0.14	0.11	2.73	0.22	0.00
Treatment	3	3.66	152.05*	582.38	1741.18	0.87	0.65	65.59*	1.01	0.020*
Error	12	1.58	36.95	184.12	149.97	0.28	0.83	9.84	0.72	0.005

* Significant at 5 per cent level

Appendix 43. Analyses of variance for the effect of shade on content of nitrogen in leaf, pseudostem and rhizome of ginger

Source	df	Mean squares									
		Leaf nitrogen content (days after sprouting)			Pseudostem nitrogen content (days after sprouting)			Rhizome nitrogen content (days after sprouting)			
		60	120	180	60	120	180	60	120	180	225 (harvest)
Block	4	0.10*	0.007**	0.018	0.007	0.006	0.036	0.421	0.006	0.012	0.008*
Treatment	3	0.06	0.919**	0.207**	0.176**	0.083**	0.027	0.733	0.007	0.039	0.211**
Error	12	0.02	0.001	0.006	0.021	0.006	0.043	0.541	0.004	0.015	0.002

* Significant at 5 per cent level
** Significant at 1 per cent level

Appendix 44. Analyses of variance for the effect of shade in total uptake of nitrogen by ginger and for the content of phosphorus on ginger leaf and pseudostem

Source	df	Mean squares									
		Total uptake of nitrogen (days after sprouting)				Leaf phosphorus content (days after sprouting)			Pseudostem phosphorus content (days after sprouting)		
		60	120	180	225 (harvest)	60	120	180	60	120	180
Block	4	30.32	175.79	612.11	1694.12	0.001	0.0001	0.0009	0.0006	0.002	0.0003
Treatment	3	137.02	876.52	2056.26	419.22	0.001	0.0045**	0.0037**	0.0021	0.015**	0.0027
Error	12	46.35	260.17	1021.03	1084.77	0.001	0.0007	0.0003	0.0007	0.001	0.000

** Significant at 1 per cent level

Appendix 45. Analyses of variance for the effect of shade on phosphorus content of ginger rhizome and for total uptake of phosphorus by ginger

Source	df	Mean squares							
		Rhizome phosphorus content (days after sprouting)				Total uptake of phosphorus (days after sprouting)			
		60	120	180	225 (harvest)	60	120	180	225 (harvest)
Block	4	0.001	0.003	0.0001	0.1500	0.33	4.29	12.82	132.29
Treatment	3	0.015**	0.003	0.0029**	0.0030**	1.52	26.17*	91.59*	166.04
Error	12	0.002	0.001	0.0003	0.0002	0.58	6.31	24.24	63.01

* Significant at 5 per cent level
** Significant at 1 per cent level

Appendix 46. Analyses of variance for the effect of shade on potassium content in leaf, pseudostem and rhizome of ginger

Source	df	Mean squares									
		Leaf potassium content (days after sprouting)			Pseudostem potassium content (days after sprouting)			Rhizome potassium content (days after sprouting)			
		60	120	180	60	120	180	60	120	180	225 (harvest)
Block	4	0.03	0.25*	0.10	0.19**	0.04	0.01	0.03	0.03	0.01	0.001
Treatment	3	0.88**	0.59**	0.60**	1.07**	1.00**	0.63**	0.18*	0.26**	0.53**	0.231**
Error	12	0.03	0.07	0.03	0.02	0.04	0.04	0.05	0.03	0.02	0.016

* Significant at 5 per cent level
** Significant at 1 per cent level

Appendix 47. Analyses of variance for the effect of shade on total uptake of potassium by ginger and for the soil nutrient status after the crop of ginger

Source	df	Mean squares						
		Total potassium uptake (days after sprouting)				Soil nutrient status		
		60	120	180	225 (harvest)	Total nitrogen	Available phosphorus	Available potassium
Block	4	96.75	1378.13	2576.78	6447.87	0.00004*	0.21	13.25
Treatment	3	327.69	7531.54	6195.45	2787.95	0.0024**	0.99	1133.8**
Error	12	177.33	2381.29	4909.63	3251.08	0.00001	0.46	11.55

* Significant at 5 per cent level
** Significant at 1 per cent level

Appendix 48. Analyses of variance for the yield response of different crops to varying intensities of shade

Source	df	Sweet potato ($\log_{10}(y + 1)$) sum of squares	Sweet potato mean squares	Coleus (y) sum of squares	Coleus mean squares	Colocasia ($\log_{10} y$) sum of squares	Colocasia mean squares	Turmeric ($\log_{10} y$) sum of squares	Turmeric mean squares	Ginger ($\log_{10} y$) sum of squares	Ginger mean squares
Treatment	3	2.7966	0.9322	1576.44	525.48	0.4865	0.1622	0.2144	0.714	0.1217	0.0406
i) Linear	1	2.5241	2.5241**	1562.62	1562.62**	0.3037	0.3037**	0.0995	0.0995**	0.0817	0.0817**
ii) Quadratic	1	0.2670	0.2670**	8.33	8.33	0.1630	0.1630*	0.0850	0.0850**	0.0400	0.0400*
iii) Cubic	1	0.0055	0.0055	5.49	5.49	0.0198	0.0198	0.0299	0.0299**	0.0000	0.0000
Error	12	0.1736	0.0145	266.57	22.21	0.2264	0.0189	0.0585	0.0049	0.0619	0.0052

y = actual yields
* Significant at 5 per cent level
** Significant at 1 per cent level

SHADE RESPONSE OF COMMON RAINFED INTERCROPS OF COCONUT

BY

LALITHA BAI, E. K.

ABSTRACT OF A THESIS

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for the degree

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ABSTRACT

An experiment was conducted at the College of Horticulture, Vellanikkara during 1980-81 to study the shade response of five common rainfed intercrops of coconut garden.

The experiment was laid out in randomised block design with four levels of shade and five replications.

The study revealed that sweet potato cannot be cultivated under shade as it is a 'shade-sensitive' crop, while coleus is suitable only where light infiltration is high. Colocasia, turmeric and ginger were found suitable for intercropped situations. Colocasia appears to be 'shade-tolerant' while ginger and turmeric are indicated as 'shade-loving'. These two shade-loving crops are best suited under shaded situations upto 25 and 50 per cent shade, respectively. Photosynthetic mechanism appears to have a decisive role on the shade response of all these crops excepting sweet potato. Excepting colocasia, plant height (length of vine) in all the crops increased with increasing shade intensities. Number of branches (tillers) in all the crops significantly decreased with increasing intensities of shade. The content of total chlorophyll and

its components were significantly influenced by shading in all the crops.

The contents of nitrogen, phosphorus and potassium in all the plant components of all the crops increased because of shading. The uptake of all the nutrients followed an identical pattern as that of dry matter accumulation in all the crops.