PHYSIOLOGY OF GROWTH AND PRODUCTIVITY OF TURMERIC (*Curcuma domestica* Val.) IN MONOCULTURE AND AS AN INTERCROP IN COCONUT GARDEN

Thesis Submitted to the
University of Calicut
For the Award of the Degree of

DOCTOR OF PHILOSOPHY

BY

K. V. SATHEESAN

February, 1984

Division of Plant Physiology,
Central Plantation Crops Research Institute,
Kasaragod, Kerala, India.

CERTIFICATE

This is to certify that this is an authentic record of the work carried out by Shri. K.V. Satheesan, M.Sc., from December 1977 to February 1984, under my supervision and guidance and that no part thereof has been presented before for any other degree, and also that he has passed the Ph.D. Preliminary and Final Qualifying Examinations of the University of Calicut held in September 1979 and February 1981, respectively.

A Ramadasan

A. Ramadasan,
Head,
Division of Plant Physiology.

Central Plantation Crops
Research Institute,
Kasaragod, Kerala.

Date: 15 Feb. 1984.

ACKNOWLEDGEMENTS

It is with a deep sense of gratitude and pleasure I express my sincere thanks to my Research Supervisor, Dr. A. Ramadasan, M.A., M.Sc., Ph.D., Senior Scientist, for suggesting the problem, for invaluable guidance and constant encouragement during the course of the study.

I am specially grateful to Dr. K.V. Ahamed Bavappa, Director, CPCRI for providing facilities and encouragement.

To Dr. M.R. Sethuraj, Director; Dr. A.S. Raghavendra, Deputy Director; Dr. G. Gururaja Rao, Assistant Plant Physiologist, RRII, Kottayam, I express my gratitude for their valuable suggestions and timely help.

My sincere thanks are also due to Shri. K. Vijayakumar, Shri. M.V. George and Shri. Jacob Mathew, Scientists, Statistics Division of CPCRI, for their assistance in analysing the data.

To Mrs. K.V. Kasturi Bai and Mr. S. Shivashankar, Scientists and other technical staff of Plant Physiology Division, CPCRI, I express my sincere thanks for their help at times of need.

The supply of seed material by the authorities of All India Co-Ordinated Spices and Cashewnut Improvement Project, CPCRI is gratefully acknowledged.

CONTENTS

Page

INTRODUCTION .. .. 1 - 27

MATERIALS AND METHODS .. .. 28 - 48

RESULTS

Leaf area development .. .. 49 - 57

Dry matter production .. .. 58 - 79

Efficiency of solar energy conversion and environmental factors .. 80 - 91

Photosynthetic efficiency .. .. 92 - 98

Carbohydrates .. .. 99 - 111

Partitioning of assimilates and yield 112 - 120

Uptake of nutrients .. .. 121 - 141

Curcumin and essential oil .. 142 - 150

Effect of CCC or nitrogen application on growth and productivity .. 151 - 154

An analysis of yield—and growth components .. .. 155 - 160

DISCUSSION .. .. 161 - 209

SUMMARY .. .. 210 - 218

REFERENCES .. .. 219 - 259

INTRODUCTION

Turmeric, *Curcuma domestica* Val. Syn. *Curcuma longa* L. is an important spice crop of India. It is an erect perennial herb, but mostly cultivated as an annual. The rhizomes are extensively used as a very common spice in countries like India, South East Asia and Indonesia. It is used directly either as a spice for culinary purposes or as a colouring agent after grinding, and also for the preparation of the solvent extracted oleoresin containing a major pigment, curcumin and essential oil. Curcumin is the principal colouring constituent which imparts the typical yellow colour to the turmeric rhizome. The dried rhizome contains nearly 4 to 7 percent of curcumin and 3 to 6 percent of the essential oil.

1. The crop, area and production

Besides India, the world's largest producer and exporter, it is cultivated in other Asian countries like China, Pakistan and Taiwan. In India, the area under cultivation as well as the production is steadily increasing every year because of its high export value. The area and production of turmeric in the country were about 39,000 hectares and 105,000 tonnes respectively for the year 1960-61. This had increased to 81,000 hectares and 151,000 tonnes respectively for the year 1970-71 and 99,000 hectares and 210,000 tonnes respectively for the year 1980-81. Thus, between the period of 1960-61 and 1980-81, the area and production of turmeric went up by 151 per cent and 100 per cent respectively, while its productivity declined by 20 per cent. Nearly 90 per cent of India's total turmeric production was used for local consumption and only 10 per cent had been exported. During the year of 1980-81 India exported 11,000 tonnes of turmeric valued at Rs. 63.1 million. Exports were mainly to USA, UK, Canada and Middle East countries.

In India, the main turmeric growing states are Andhra Pradesh, Orissa, Tamil Nadu, Maharashtra, Assam, Bihar and Kerala. Among these states, Andhra Pradesh is the largest producer having 26 per cent of the total turmeric growing area accounting for 36 per cent of the total production. The average productivity for the states like Tamil Nadu, Karnataka and Andhra Pradesh were about 3 to 4 tonnes per hectare, while for the other states including Kerala it is only about 1 tonne per hectare or lower. Although the productivity in Kerala is not very high, a major part of the turmeric produced here (Alleppey finger turmeric) is preferred for export due to its high curcumin content. In the major turmeric producing states in India like Andhra Pradesh and Tamil Nadu it is traditionally cultivated as a monocrop. But due to pressure on cultivable land, this crop is now being cultivated as an intercrop along with other tree and plantation crops, particularly in Kerala, Tamil Nadu and Karnataka.

2. Multiple cropping system

The shortage of cultivable land and the need for maximising food production per unit land area, renewed the interest in the multiple cropping systems (Beets, 1976 and Crookston, 1976). Multiple cropping, growing of more than one crop simultaneously (intercropping) or sequentially (relay-cropping) on the same land is an ancient farming practice in the rainfed areas of many tropical countries in Africa, Asia and Latin America. However, the modern concepts of multiple cropping are of recent origin (Papendick *et al*., 1976). Andrews and Kassam (1976) defined it as "the intensification of cropping in space and time dimensions - growing two or more crops on the same field in a year". Several research programmes are underway to evaluate different multiple cropping systems in countries such as Malaysia, Philippines, India, Taiwan, Nigeria, Rhodesia and Columbia. With a rapidly increasing population and exhausting area of cultivable land, multiple cropping practice is getting more importance in many Asian countries. Intercropping or other systems of multiple cropping improve productivity and increase net income per hectare, compared with their respective monocultures (Andrews, 1972; Willey and Osiru, 1972; Enyi, 1973a; Fisher, 1977a; Santa-Cecilia and Vieira, 1978; Cordero and Mc Collum, 1979; and Rao and Willey, 1980). Apart from this yield advantage, the most important factor for the preference of multiple cropping to sole cropping among the small scale farmers is that intercropping imparts greater stability of yields over different seasons (Francis and Sanders, 1978; and Rao and Willey, 1980).

3. Yield advantage of intercropping system

The yield advantages of different intercropping systems have to be assessed by different criteria. A very well recognised situation in India including the coconut based intercropping systems is that the intercropping must give full yield of the main crop and some yield of a second crop. Under such a situation, an additional profit is guaranteed even if there is nominal yield of a second crop. Most of the Indian intercropping trials had therefore aimed at maximising yield of the second crop without reducing yield of the main crop (Willey, 1981). The yield advantage for an intercropping combination originates either due to higher yields of individual crops or due to higher plant population densities or both (Andrews and Kassam, 1976). An index to identify a crop combination that maximises productivity per unit area of land is the land equivalent ratio (LER) which may be defined as the relative land area under sole crops that is required to produce the yields achieved under the intercropping (Mead and Willey, 1980). The LER compares the productivity in intercropping with that in monoculture, with values more than unity indicating the advantage of intercropping. For eg., under coconut based intercropping systems, LER values will be more than unity if the normal yield of coconut is unaffected, even with minimal yields from second crop.

An yield advantage from an intercropping systems is achieved also due to better use of the growth resources. Generally the component crops will have varied requirement of growth resources and when they are cultivated together they are able to compliment each other so as to achieve a better overall use of environmental resources than when grown separately. The best exploitation of an intercropping system can therefore be through maximising the degree of complementarity between the component crops and minimising the inter-crop competition (Willey, 1979a,b). The component crops with diverse growth habits have been demonstrated to be able to absorb plant nutrients or moisture at different layers of soil and to intercept light, more effectively under the intercropped situation, than under the monoculture (Donald, 1963; Loomis et al., 1971; Kassam and Stockinger, 1973; Dalal, 1974; and Trenbath, 1974). An effective utilisation of nitrogen can be noticed in legume/non-legume crop combinations (Agboola and Fayemi, 1972; and Searle et al., 1981). The different factors which can influence the intercrop competition and 'complementarity', thereby affecting the yield advantage of intercropping combinations were widely investigated in recent years. These include population densities and planting pattern (Evans, 1960;

Tarhalkar and Rao, 1975; Beets, 1977; Fisher, 1977b; Freyman and Venkateswarlu, 1977; Natarajan and Willey, 1980; and Lima and Lopes, 1981), relative sowing time (Baker, 1981; and Francis et al., 1982), and genotype evaluation (Andrews, 1972, 1974; Francis et al., 1976; Hamblin et al., 1976; Wien and Smithson, 1981; and Rao and Willey, 1983).

4. Coconut based intercropping systems

The importance of intercropping for increasing agricultural productivity in India was highlighted as early as 1949 by Aiyer. Further work had indeed stressed its importance in the Indian farming systems (Kanwar, 1970; Swaminathan, 1970; and Mahapatra et al., 1973). Although considerable work has been done on annual crop combinations only meagre information is available about cropping systems involving perennials. There are many advantages for the intercropping systems involving perennials. Most of the perennials are planted with wide spacing, transmitting enough light to the ground thereby allowing the growth of fast maturing annuals as intercrops. Species such as cacao, coffee and black pepper require shade for their proper growth and can be successfully intercropped with a tall perennial tree like coconut. Bavappa and Jacob (1982) developed multiple cropping models involving many species of perennial crops. Bananas, chillies, pineapples, vegetables, cassava, peanuts, maize, and cocoa are commonly intercropped with rubber or coconut in Malaysia (Dunsmore and Ngui, 1970; and Pushparajah and Wong, 1970). Root crops such as cassava, yams, sweet potato; rhizomatous crops like ginger and turmeric; banana, pineapple, and different grain legumes are cultivated extensively as intercrops in the coconut plantations in India. Nair (1979) had made a comprehensive review about the intensive multiple cropping with coconuts in India. Gomez and Gomez (1983) had discussed several aspects of the coconut based intercropping systems in Philippines.

The coconut palm (*Cocos nucifera* L.) has an erect, cylindrical stem with an apical crown of 30 to 40 feathery leaves. The crown attains full diameter by about eight years after planting after which the crown size does not change appreciably untill the palm is very old. Due to its large crown size and to avoid overlapping of leaves of adjacent palms, recommended spacing for the coconut in India is 7.5 x 7.5 m. Under normal management conditions the root zone of an adult coconut palm is confined laterally within a radius of 2 m from the base. Vertically, top 30 cm layer of the soil is devoid of functional roots and 85 per cent of the functional roots are concentrated between 30 and 120 cm depth from the surface. The area occupied by the palm following the spacing of 7.5 x 7.5 m is 56.25 m^2, out of which the area of active root zone is only about 12.57 m^2 which constitute only 22.3 per cent of the total area occupied by the palm. Thus, in a conventional plantation of coconut alone, as much as 77.7 per cent of the total area is not effectively utilized by the roots.

The amount of the radiation transmitted by the coconut canopy depends upon the age of the palm. When the palms are about 8 to 10 years old, the light transmission by the coconut canopy is about 20 per cent of the incident light, and this value remains almost constant upto 20 years of age. In subsequent years, light transmission steadily increases due to a decrease in canopy coverage. For eg., when the palms are about 35 to 40 years old, the light transmission rises upto 50 per cent (Nelliat et al., 1974). The reflectance of the coconut leaf can reasonably be expected to be high owing to the thick cuticle. Apart from reflecting the light back into the atmosphere, the drooping leaves at the lower levels of the canopy can also reflect the light in all directions thereby contributing to the light availability inside the plantation when the palm is getting matured.

5. Efficiency of solar energy conversion

It becomes evident from the above description that solar energy as well as the soil surface are not fully utilised in a pure stand of coconut. The quantity of solar radiation which penetrates the coconut canopy is an important factor affecting the microenvironment inside the plantation. Establishing the canopy light relationship and the quantification of the photosynthetically active radiation (PAR) available during the development of each crop within an intercrop system is very important in evolving ideal intercrop combination. Basically all agricultural systems are photosynthetic systems for harvesting solar energy and their efficiency can be assessed in terms of the efficiency of solar energy conversion into biomass which includes useful end products. Blackman and Black (1959b) stated: 'under conditions where growth is not restricted by temperature or by supply of nutrients or water, maximum production of dry matter per unit area will be limited by leaf area index and the amount of solar radiation'. The efficiency of solar energy conversion can be evaluated on different ways considering total available radiation over the year, energy input during the growing season or based on the radiation available during the period when photosynthesis is directly contributing towards the economic yield, i.e. bulking period in tubers and grain filling period in cereals (Sibma, 1968, 1970; Cooper, 1970; Stewart, 1970; and Loomis *et al*., 1971). Further, the performance of each crop can be analysed in terms of variation from season to season in the incoming solar radiation, proportion of this radiation intercepted and the efficiency of use of this intercepted radiation (Monteith, 1977). It had been established that the rate at which crop plants accumulate dry matter is almost proportional to the radiation intercepted by its canopy especially during the early periods of growth (Williams *et al*., 1968; Monteith, 1977; and Gallagher and Biscoe, 1978).

Generally in a closed crop canopy, provided water and nutrients are not limiting, most of the C_3-plants can convert 3 to 4 per cent of incident PAR and C_4-plants about 5 to 6 per cent or more (Loomis and Gerakis, 1975). Duncan *et al*. (1967) predicted that present agricultural systems can convert upto a maximum of 5 to 10 per cent of the incident PAR. However, normal efficiencies recorded even in intensive agricultural systems are only about half of this prediction, which points out immense possibilities for further improvement by breeding or innovative management practices. The high daily conversion efficiency cannot be maintained throughout the whole year since the duration of the growth period and maintenance of a closed canopy for a prolonged period are the main factors which determine the total photosynthetic production. Many plantation crops growing in the tropical environments, with a favourable temperature and sufficient water availability, can maintain a closed canopy throughout the year, such crop stands can allocate a fairly good proportion of their assimilates towards the economically important sinks (Cooper, 1975). The efficiency in terms of economic yield is determined by the proportion of the assimilates transferred to the economically important sinks and the duration of such transfer. Thorne (1971) reported that a grain yield of 6 t ha^{-1} converts only about 0.7 per cent of the annual energy input, but 2 per cent of the energy received during the period from ear emergence to ripening for a cereal crop in Britain. In tuber, root or rhizomatous crops the transfer of assimilates to the economically important organs can continue for a much longer period than that in the determinate cereal crops, which means a better annual energy conversion. It was reported that in case of a potato crop in north-west Europe, an yield of 12 to 15 t dry matter in the tubers gave a conversion efficiency of 1 per cent of the annual energy input, but this efficiency was as high as 2.5 per cent during the bulking period (Thorne, 1971; Watson, 1971). Thus the energy conversion by agricultural systems is considerably lower on an annual basis compared to the peak values noted for daily production rates. Only a few crops are known to exceed 3 per cent conversion efficiency during the growing season. The possibilities for increasing production do therefore exist, either by extending growth duration or by effective utilization of seasonal input of solar energy or both.

Several physiological and morphological features influence the efficiency of solar energy conversion and potential productivity of a crop. The genetic variations available in these parameters can be successfully exploited in breeding programmes for increased productivity. Such genetic variations can occur in crop photosynthesis, distribution of assimilates, and response of genotypes to environmental stresses (Cooper, 1975).

When the tallest component of an intercropping combination shows complete domination over the system, it effectively behaves as a sole crop. In these types of intercropping systems the understorey components intercept the light that was not otherwise utilized (Fisher, 1975). Since the coconut based intercropping systems behave like this, greater care should be taken in the selection of the genotypes of the dominated component which can grow well in an environment modified by the dominant crop, coconut. The restricted amount of solar radiation reaching the plantation floor may limit the growth of such intercrops which are shade-intolerant in nature. Since the degree of shade tolerance of component crops is an important factor determining the productivity of intercrops in the coconut plantation, a thorough understanding of the inherent responses of different genotypes to low light levels and the quantitative assessment of light climate within the coconut plantation are essential, for evolving ideal crop combinations for coconut based intercropping systems.

6. Growth analysis as a tool for analysing crop yield

Apart from the analysis of various microenvironmental factors which contribute towards the benefits of intercropping, a thorough knowledge of the growth rhythm of the component crops as influenced by the environmental variables would be instrumental in analysing intercropping systems. Crop physiologists had employed the technique of 'growth analysis' for approximately sixty years and the results made substantial contribution towards understanding the concept of the physiological basis of crop yield. The first step in bringing out a procedure for analysing the growth in terms of dry weight change was made by Blackman (1919) when he proposed the concept of 'relative growth rate' (RGR) which represents the efficiency of the plant as a producer of new material. Watson (1952) pointed out that dry weight increase per unit leaf area was a measure of the excess of the rate of photosynthesis over the dry matter loss by respiration. Gregory (1917) was the first to suggest the use of this function in growth analysis and called it 'net assimilation rate' (NAR). Briggs *et al.* (1920) brought together these two concepts and pointed out that RGR was the product of NAR and the ratio of leaf area to total dry weight, the leaf area ratio (LAR). Therefore, the analysis of change in dry weight can be divided into two parts, first, the calculation of RGR, and second, further analysis of RGR in terms of NAR and LAR (Watson, 1952). Blackman and his associates (1951, 1954, 1955, 1959a, b) had discussed the effects of environmental factors on RGR, NAR and LAR in their series of papers on physiological and ecological studies in the analysis of plant environment.

The rate of dry matter production in a stand (crop growth rate, CGR) depends on NAR as well as leaf area index (LAI), CGR being the product of LAI and NAR. Watson (1947) pointed out that it is appropriate to express the leaf area of a crop on the same basis as yield i.e. leaf area per unit land area rather than total leaf area of individual plant, and proposed the term leaf area index (LAI) for this measure. Watson (1952) reported that an assessment of relative importance of variation in leaf area and in NAR as determinants of dry matter yield must take into account of the different lengths of the growing period. He stated that the appropriate measure for this purpose was the integral of LAI over the growth period. Since this had dimensions of time, it was termed leaf area duration (LAD).

The calculation of the various growth analysis quantities as mean values over the period between the two harvest intervals has been the standard approach (classical approach) for most of the studies in this field. More recently, workers have taken the advantage of high-speed computing facilities to fit mathematical functions to experimental data (functional approach). From these functions fitted values are taken to derive various growth analytical quantities (Hughes and Freeman, 1967; Hunt and Evans, 1980; and Hunt, 1982). Buttery (1969) got similar results with the classical and regression techniques of growth analysis. Eventhough the regression technique revealed additional treatment effects due to reduced sampling error, it concealed growth fluctuations as influenced by environmental factors in some circumstances. Koller et al. (1970) and Mc Collum (1978) had applied both techniques to analyse the growth of the soybean and potato respectively, while Sivakumar and Shaw (1978) evaluated the suitability of the two methods for analysing the growth of the field grown soybeans. Growth analysis was extensively used to examine the effects of various agronomic treatments like irrigation, nutrient supply, and population density (Power et al., 1967; Buttery, 1969; Dyson and Watson, 1971; Clarke and Simpson, 1978; and Scott and Batchelor, 1979), to assess the response of a genotype to a particular environment (Hearn, 1969; Cooper, 1972), and to evaluate the varietal differences (Wallace and Munger, 1965; Hesse, 1965; 1968; Buttery and Buzzell, 1972; Constable and Gleeson, 1977; and Pandey et al., 1978). The classical approach of growth analysis had been found to be valid to assess the growth and productivity of even crops with underground storage organs e.g. potato (Bremner and Radley, 1966; Bremner and Taha, 1966; Dyson and Watson, 1971; Sale 1973a, b; Collins, 1977a, b; and Mc Collum 1978), sugar beet (Watson and Witts, 1959; Loach, 1970; and Olech and Bieganski, 1978), cassava (Williams, 1972; Enyi, 1973b; Hunt et al., 1977; and San Jose and Mayobre, 1982), and sweet potato (Tsuno and Fujise, 1965a; Tsuno, 1971; Hoett and O'neil, 1976; and Agata, 1982).

Watson (1952, 1968) and Blackman (1968) reviewed the application of growth analysis for understanding the physiological basis of variation in crop yield. Radford (1967) presented a review of growth analysis formulae, their derivation and necessary condition for use. He also discussed the functional approach of the growth analysis and narrated the merits and demerits associated with the two methods. Kvet et al. (1971) reviewed the concepts of the both classical and functional approaches of growth analysis. Evans (1972) discussed the principles underlying various growth analytical formulae and their behaviour with changes in the environment and ontogeny. While reviewing the applicability of growth analysis for assessing the plant photosynthetic production, Hunt (1978) stated: 'the great advantage of many of the quantities involved in plant growth analysis is that they provide accurate measurements of the sum performance of the plant integrated both throughout the whole plant and across substantial intervals of time. To predict this from the starting point of purely physiological observations would involve many dangerous assumptions'.

Donald (1963) identified some of the limitations of the classical growth analysis when he stated that while NAR can be used as a criteria of the efficiency of an individual leaf or plant, for the crop as a whole, it is only an average value for all the leaves which differ in their contribution from strongly positive to negative values. So, a thorough understanding of the light relationship and foliar environment of various layers of the canopy is necessary. Under conditions where there is no limitation for water and nutrients and there are enough plants per unit area, the yield will be governed by the ability of the plants to intercept and use the light. At early stage of crop growth, with a small LAI, and when production is limited by the amount of light intercepted by the crop, horizontal leaves seem to be advantageous than the inclined leaves (de Wit, 1965; Duncan et al., 1967; Trenbath and Angus, 1975; and Monteith, 1981). But at large leaf area indices, canopies with strongly vertical leaves had a marked advantage. Monteith (1977) suggested a new approach for growth analysis which will help to avoid some of the difficulties confronted with the classical growth analysis especially the nonindependent nature of the LAI and NAR.

He suggested that a more rational basis would be provided by two variables : the fraction of the radiation which a canopy intercepts and the efficiency with which the absorbed radiation is used for the photosynthesis. Adopting this method, Allen and Scott (1980) got a linear relationship between both total and tuber dry matter yields and the amount of the radiation intercepted for the potato crop.

7. Photosynthesis and yield

Apart from the total area and orientation of the leaves, the crop photosynthesis is strongly related to the photosynthetic capacity of the individual leaves. Several reports have described cultivar differences in the photosynthetic rate, but correlation between the leaf-apparent photosynthesis and yields was found to be low (Evans, 1975a; Irvine, 1975; Bhagsari *et al.*, 1977; Mauney *et al.*, 1978; and Kueneman *et al.*, 1979). However, the photosynthetic rate during the period of development of economically important 'sinks' could be related to yield (Moorby, 1970; Krishnamoorthy *et al.*, 1973 and Peet *et al.*, 1977). Harison *et al.* (1981) found that seed yield and canopy apparent photosynthesis was significantly correlated in soybeans. Nasyrov (1978) stated that the absence of a direct relation between the photosynthetic rate and crop yield could be explained by the dependence of crop yield on the net assimilation value which in turn is determined not only by the unit rate of photosynthesis but also by leaf surface, duration of vegetative period, canopy structure, dark and light respiration, translocation and partitioning of assimilates.

The photosynthetic rate of a leaf can vary according to the conditions towards which it is more acclimatised. The degree of shade tolerance by crop species depends strongly on their native habitat (Maestri and Barros, 1977). Plants are classified into 'sun' and 'shade' plants depending on their adaptability to a selected light intensity (Bjorkman, 1968). The 'sun' ecotypes photosynthesise more efficiently in intense radiation, whereas the 'shade' ecotypes showed higher rate of photosynthesis in weak radiation. This type of photosynthetic adaptation to 'sun' and 'shade' environments had been reported for a number of species (Bjorkman and Holmgren, 1963, 1966; Gauhl, 1976; Clough *et al*., 1979; and Armitage and Vines, 1982). Boardman (1977) discussed the comparative photosynthetic efficiency of 'sun' and 'shade' plants and described their adaptive features for the growth at different light intensities. Adaptability within a given genotype can be considerable, but range of adjustment varies depending on the condition prevailing in its native habitats. Adaptation for high photosynthetic efficiency under one extreme of light may impede high efficiency at the other extreme. Bunce (1983) showed that leaves with highest values of the photosynthetic parameters for each species were often developed in environments with irradiance levels below saturation for photosynthesis, and lower air temperatures during growth increased photosynthetic characteristics for a given irradiance regime. Allen *et al.* (1976) reported that, due to the differential absorption of solar radiation by leaves, the spectral qualities of radiation will change with depth of penetration and become poor in photosynthetically active wave lengths. Apart from the light quantity, the tolerance in terms of spectral quality of radiation has also to be taken into consideration while screening different genotypes for shade tolerance. Allen *et al.* (1974) reported that the ratio of near infra red radiation to photosynthetically active radiation (NIR/PAR) in a tropical rain forest increased with cumulative leaf area index which became greater with the depth of the penetration of the radiation into the canopy. Smith (1981) stated that the ratio of the red photons to the far-red photons decreased proportionately with the increasing depth of shade and demonstrated that the light quality in terms of the ratio of the red photons to the far-red photons and light quantity (PAR) affected the development of plants in quite different ways.

8. Partitioning of assimilates

Although the dry weight increase is directly related to the photosynthesis, the most important determinant of the economic yield of many crop plants is not the total crop photosynthesis, but the manner in which assimilates are partitioned among various plant parts, either for the continued vegetative growth or for accumulation in the economically important 'sinks' (Donald, 1968; and Nichiporovich, 1969, 1970). The accumulation of assimilates in economically important parts is limited either by the supply of assimilates ('source' strength) or the ability of the 'sink' to make use of them ('sink' strength). In cereals, the ear is the dominant sink after anthesis. In the case of root, tuber and rhizomatous crops, the underground storage organs are the predominant 'sink' during the storage period, although shoot growth itself is an important sink in the earlier life cycle of these crops. There are several reports suggesting that distribution of assimilates within the plant is limited by the supply of assimilates, the utilisation by the 'sink' or by the rate of translocation (Rawson and Evans, 1971; Wardlaw, 1971; Duncan, 1972; Jones *et al*., 1974; Evans, 1975b; Wareing and Patrick, 1975; Hahn, 1977; and Gifford and Evans, 1981). Bingham (1969) suggested that grain yield might be limited due to both assimilate supply and factors within the grain itself, but under some circumstances of genotype and environment, either of them may predominate. The rate as well as the duration of storage will determine the accumulation of photosynthetic assimilates in the economically important 'sinks'. Evans and Dunstone (1970) found that enhanced rate of storage resulted in a greater allocation of assimilates to the grain in the case of wheat. Daynard *et al*. (1971) reported that length of grain filling period rather than rate of filling was the important determinant of varietal differences in grain yield. Comparing wheat, barley, potatoes and sugar beet, Watson (1971) found differences in the rate of storage, but final yields were most clearly related to differences in duration of storage. Spiertz (1974) observed that low temperature together with hih light intensity resulted in a surplus of available carbohydrate leading to a favourable effect of a greater ear capacity on grain yield. Gibson and Schertz (1977) found that in sorghum, hybrids achieved most of the yield advantage by combining the higher rate of dry matter production of one parent with the effective translocation of dry matter to the grain of the other. Gifford and Evans (1981) concluded that the phenomena in the 'sinks' largely determined the distribution of assimilates, and factors determining the setting up and relative activity of 'sinks' will determine the pattern of assimilate distribution, thereby showing the importance of factors affecting photosynthetic assimilate production during the early stages of crop growth. Improvement in harvest index will be the most effective route for increased yield potential until it is at the expense of light intercepting leaf surface.

In the case of root and tuberous crops, the source-sink relationship had been widely investigated especially for potato, sugar beet and sweet potato. In most cases, the interrelation between 'source' and 'sink' showed a pronounced feedback effect. Burt (1964) found that removing potato tubers 21 days after the initiation slowed the NAR, and suggested that assimilation by leaves under bright light may be restricted by the ability to use or store photosynthetic products. Nosberger and Humphries (1965) also found that removal of tubers depressed NAR and increased carbohydrate contents of stems and leaves. Burt (1966) showed that when the tubers were developed slowly in a cold season, NAR was less than that when tubers grew fast. Moorby (1968, 1970) and Collins (1977b) reported that photosynthetic rate of leaves increased and proportion of assimilates exported to tubers increased as soon as the tubers were initiated. In the case of potato, the gain in weight of the crop was dependent primarily on the strength of the photosynthetic 'sink' offered by the developing tubers, which was determined at the time of tuber initiation (Milthorpe and Moorby, 1967; and Moorby, 1970). The short-term fluctuations in the incident solar energy and rainfall occurring in the later periods had little effect. Sale (1973a, b) and Sale (1976) got more or less same results and stated that the day to day changes in the NAR was largely controlled by the 'sink' strength, although the amount of solar energy received apparently affected the number of tubers formed. Thorne and Evans (1964) found that leaves of spinach beet grafted to the sugar beet roots (which has got a large sink than the spinach root) had a higher NAR than spinach beet leaves grafted to spinach beet roots showing that assimilate accumulation was limited by 'sink' demand. Higher yields were obtained when sugar beet seedlings were grown in the continuous light rather than in the field eventhough the two crops had similar LAI and LAD (Humphries and French, 1969). Such seedlings were capable of maintaining a high root:shoot ratio at the time of transplanting and maintained active sink resulting in high yields. Loach (1970) found that the differences in root and sugar yield in the sugar beet was mainly determined by the NAR in the late season which in turn is controlled by two factors: retention of relatively old leaves and the ability of roots to receive the assimilate i.e. the 'sink strength'. French and Humphries (1977) found that removing the mature leaves of sugar beet plants decreased the yields considerably, but removing all leaves except 6 to 20 did not decrease total dry matter yield and in one trial increased it by 7 per cent and root weight by 15 per cent. In the case of sweet potato, Tsuno and Fujise (1965b) concluded that sufficient translocation of assimilates from the leaves into tuberous roots was necessary in order to maintain high photosynthetic activity. Hozyo and Park (1971) also got a positive relationship between tuberous root growth and photosynthetic activity in sweet potato. Spence and Humphries (1972) reported that increased tuberous root growth of sweet potato had been associated with an increase in NAR, and when the tubers did not form, there was an increased accumulation of dry matter in the laminae and petioles. Hahn (1977) observed that sweet potato varieties with large sink responded to increase in 'source' as the 'sink' demand increased, and as the 'sink' capacity increased more production and supply by the 'source' occurred. In such cases, genotypes with large 'sink' capacity should be selected primarily in breeding programmes with subsequent improvement by incorporating large 'source' potential. While selecting for an active 'source' coupled with a large 'sink' capacity, it must be remembered that the 'source' component should not be too active as a competitive 'sink'.

In the case of root, tuber and rhizomatous crops, where the period in which storage capacity is determined overlaps the period of storage itself, the mutual adjustment between 'source' and 'sink' components can be more easily achieved than in cereal crops. In such crops, after the establishment of a closed canopy, further leaf growth is required only to maintain that canopy and maximum amount of assimilates should be translocated to the economic 'sink'. In the case of potato, Moorby and Milthorpe (1975) reported that encouragement of haulm growth retarded tuber initiation, but after the initiation, a large haulm surface maintained a higher tuber growth rate for a longer time.

9. Present work

Turmeric is presently cultivated in different agro-ecological conditions and under different cropping systems. Due to the long duration nature of the crop, taking seven to eight months for maturity, small farmers cannot afford to grow it as a monocrop. In most of the southern states of India it is now often cultivated along with other perennial and plantation crops. But, most of the investigations designed to increase the productivity of the crop were mainly on nutritional requirements and standardising the pest and disease control measures which had been recently reviewed by Sivaraman Nair (1982), Nair (1982), and Joshi and Sharma (1982). Little information is available about the growth and productivity of the crop as influenced by varied environmental conditions. Kundu and Chatterjee (1982) reported that when turmeric was intercropped with cereals and legumes, the yield of turmeric was considerably reduced which caused a marked reduction in the monetary advantages accrued from intercropping.

The foregoing review on the various aspects of growth and productivity of crop plants also points out that in the case of turmeric there has not been any systematic investigations on growth and yield components under monoculture as well as intercropping systems. A thorough evaluation of the different genotypes of turmeric for their adaptability to grow well in an environment determined by the dominant perennial crop without substantial reduction in yield is an important prerequisite for getting intercropping advantage from a coconut + turmeric intercropping system.

The present study was undertaken with the following major objectives:

(i) Evaluation of growth and productivity of three cultivars of turmeric in the monoculture and in association with coconut.

(ii) Systematic analysis of growth components under the above experiment.

(iii) Understanding the genotypic variations, if any, in the photosynthetic solar energy conversion efficiency, the growth rhythm, and the partitioning of assimilates as influenced by the environmental variables in the field.

(iv) Examination of nutrient uptake, changes in the carbohydrate fractions, curcumin and essential oil content of the three cultivars as influenced by the environment.

(v) Assessment of the efficacy of chlorocholine chloride (CCC) treatment and nitrogen amendments to increase dry matter production and partitioning of assimilates in the three cultivars.

MATERIALS AND METHODS

1. Raising the crop

The study was conducted with three turmeric cultivars viz., Cls.No.24 (C_1), Cll.328 Sugandham (C_2) and Duggirala (C_3). The seed rhizomes were obtained from the germplasm collection of the Project Coordinator, All India Coordinated Spices and Cashewnut Improvement Project, Central Plantation Crops Research Institute (CPCRI), Kasaragod, Kerala. The three cultivars were selected based on the rhizome characters. The size of the mother rhizome (length x breadth) was in the range of 17 to 22 cm^2 for cultivar C_1, and in the range of 23 to 28 cm^2 for the other two cultivars. Cultivar C_1 produce a total number of about 17 to 23 fingers, while cultivars C_2 and C_3 produce about 7 to 12 and 10 to 15 fingers respectively. The length of the first order fingers was in the range of 4.3 to 4.8 cm for the cultivar C_1, but for the other two cultivars it was in the range of 4.7 to 5.3 cm. The breadth of the first order fingers was in the range of 2.0 to 2.5 cm for the cultivar C_1 as against 2.4 to 2.9 cm for the other two cultivars. The morphological nature of the entire plant as well as their appearance in the field at the time of maximum leaf area of the three cultivars can be seen in plates 1-3. The morphological nature of rhizome at maturity is presented in plate 4.

Plate 1. Morphological nature (a) and the appearance in the field (b) at the time of maximum leaf area of the cultivar Cls. No.34.

a

b

PLATE 1

Plate 2 . Morphological nature (a) and appearance in the field (b) at the time of maximum leaf area of the cultivar C11.328 Sugandham.

a

b

PLATE 2

Plate 3 . Morphological nature (a) and appearance in the field (b) at the time of maximum leaf area of the cultivar Duggirala.

a

b

PLATE 3

Plate 4 . Morphological nature of rhizome of three turmeric cultivars at the time of maturity.

a. Cls. No.24

b. Cll.326 Sugandham

c. Duggirala

PLATE 4

The three cultivars were raised under monoculture (pure stand) or in association with coconut of West Coast Tall (WCT) variety of 30 years of age (intercropped stand) adopting a completely randomised design with five replicates. The study was conducted for two years 1977 and 1978. The experimental data were subjected to analysis of variance, so as to split up the total variation into between cropping systems, cultivars and their interactions. The turmeric was planted in association with coconut leaving a circular area of 2 m radius at the base of the palms (representing the active root zone of coconut) so as to facilitate the opening of basins around the palm for the application of fertilisers and to minimise the competition between roots of the intercrop and coconut. Monoculture check plots of coconut are not included since previous studies conducted at this Institute had shown that the association of tuberous crops following the planting pattern described above did not affect the coconut yield when both the intercrop and coconut were manured as per the recommended package of practices (Varghese *et al.*, 1978). The turmeric crop raised in monoculture and in association with coconut can be seen in plate 5.

The field was the experimental farm of CPCRI, Kasaragod. The two experimental plots, for monoculture or intercropping with coconut, were adjacent. Care was taken that the shade cast by the coconut trees would not interfere with the monoculture plots of turmeric throughout

Plate 5 . Turmeric crop raised in monoculture (a)
and as an intercrop in coconut garden (b).

a

b

PLATE 5

the crop growth period. The soil was red sandy loam, with a pH of 4.5, about 1 per cent organic carbon, 31.2 ppm available P and 25.1 ppm available K. The soil did not reveal any significant difference in the nutrient status between these two experimental sites. The turmeric crop was raised during the cropping season from June to December. Three weeks before planting, the sites were ploughed and fumigated. At the time of planting, beds of approximately 1 m width and 30 cm height were formed and the plots were peg-marked. Five beds each with an area of 3.3. m^2 constituted a plot. Mature rhizome fingers free of visible nematode or fungal infection, each weighing 25 to 30 g, were used as seed material. Before planting, the seed rhizomes were treated with hot water to kill any nematode present and then dipped in 0.3 per cent Benomyl (fungicide) suspension. The seed rhizomes were placed at a depth of about 10 cm by hand to ensure the uniform spacing. There were four rows in each bed. The distance between plants along the row was 30 cm and the distance between the rows was 25 cm. The monoculture as well as intercrop of turmeric had received fertiliser at the rate of 30:30:60 kg N, P & K/ha of which full dose of P_2O_5 and half of K_2O were applied as basal dressing, half of nitrogen was applied six weeks after planting, and the rest halves of potassium and nitrogen were applied ten weeks after planting.

Cattle manure was applied as basal dressing at a rate of 20-25 t/ha. All plots were mulched with green leaves at a rate of 15 t/ha. Coconut was manured as per the package of practices recommended by the Institute.

2. Sampling pattern

Nine samples were taken for growth analytical studies at 4th, 6th, 8th, 11th, 14th, 18th, 22nd, 26th, and 30th weeks after planting. Harvest was done immediately after the last sampling. At each interval, eight plants, representing an area of 0.6 m^2 of land (i.e. four plants randomly selected from each of two inner rows) were taken from each replication. Border strips were kept in between the sample rows. The plants were separated into shoots, rhizomes and roots. Dry weights of various plant parts were obtained by drying in paper bags in a hot air oven at 70° C upto constant weight. The leaf area was obtained using an electronic leaf area meter (LI-COR, Nebraska, USA).

3. Growth analytical technique

The following abbreviations and units are used during the calculation of different growth indices:

W (g/plant) = Dry weight of the whole plant (shoot + rhizome + root)

W_l (g/plant) = Dry weight of leaves

W_s (g/plant) = Dry weight of the shoot which includes flowers, if present.

W_r (g/plant) = Dry weight of rhizome.

A (cm^2/plant) = Leaf area.

T (weeks) = Time after 4th week.

CGR (g m^{-2} of ground area $week^{-1}$) = Crop growth rate.

SGR (g m^{-2} of ground area $week^{-1}$) = Crop growth rate of shoot (shoot growth rate).

RhGR (g m^{-2} ground area $week^{-1}$) = Crop growth rate of rhizome (rhizome growth rate).

LGR (cm^2 $plant^{-1}$ $week^{-1}$) = Growth rate of leaf area.

RGR (g g^{-1} $week^{-1}$) = Relative growth rate.

RRhGR (g g^{-1} $week^{-1}$) = Relative growth rate of rhizome.

RLGR (cm^2 cm^{-2} $plant^{-1}$) = Relative growth rate of leaf area.

NAR (g m^{-2} of leaf area $week^{-1}$) = Net assimilation rate.

EAR (g m^{-2} of leaf area $week^{-1}$) = Economic assimilation rate.

LAR (cm^2/g) = Leaf area ratio.

SLA (cm^2/g) = Specific leaf area, cm^2 of leaf laminae (one side) per g of dry laminar tissue.

LWR (g/g) = Leaf weight ratio.

LAI (no units) = Leaf area index.

LAD (weeks) = Leaf area duration.

PC (%) = Partition coefficient.

HI (no units) = Harvest index.

Classical methods of growth analysis were used as adopted by Kvet *et al.* (1971) from the description of Watson (1952). The mean values of different growth indices were calculated as follows.

$$\mathrm{CGR} = \frac{{}_2W - {}_1W}{P({}_2T - {}_1T)}$$

$$\mathrm{SGR} = \frac{{}_2W_s - {}_1W_s}{P({}_2T - {}_1T)}$$

$$\mathrm{RhGR} = \frac{{}_2W_r - {}_1W_r}{P({}_2T - {}_1T)}$$

The ground area on which W, W_s and W_r are estimated is represented by P.

$$\mathrm{LGR} = \frac{{}_2A - {}_1A}{{}_2T - {}_1T}$$

$$\text{RGR} = \frac{\ln_2 W - \ln_1 W}{{}_2T - {}_1T}$$

$$\text{SRGR} = \frac{\ln_2 W_S - \ln_1 W_S}{{}_2T - {}_1T}$$

$$\text{RLWGR} = \frac{\ln_2 W_L - \ln_1 W_L}{{}_2T - {}_1T}$$

$$\text{RLGR} = \frac{\ln_2 A - \ln_1 A}{{}_2T - {}_1T}$$

$$\text{NAR} = \frac{{}_2W - {}_1W}{{}_2A - {}_1A} \cdot \frac{\ln_2 A - \ln_1 A}{{}_2T - {}_1T}$$

$$\text{EAR} = \frac{{}_2W_L - {}_1W_L}{{}_2A - {}_1A} \cdot \frac{\ln_2 A - \ln_1 A}{{}_2T - {}_1T}$$

In case of LAR, SLA, LWR and LAI instantaneous values at the time of each sampling were calculated as follows:

$$\text{LAR} = \frac{A}{W}$$

$$\text{SLA} = \frac{A}{W_L}$$

$$\text{LWR} = \frac{W_L}{W}$$

$$\text{LAI} = \frac{A}{P} = \frac{A \times 0.0008}{0.6}$$

(Eight plants per 0.6 m^2 of land)

$$ {}_{1-2}LAD = \frac{{}_1LAI + {}_2LAI}{2} ({}_2T - {}_1T) $$

$$ \text{Total LAD} = \sum \frac{{}_1LAI + {}_2LAI}{2} ({}_2T - {}_1T) \ldots \frac{{}_8LAI + {}_9LAI}{2} ({}_9T - {}_8T) $$

LAD was calculated for the period of 4th to 30th week after planting.

$$ PC = \frac{CGR \times 100}{RBGR} $$

$$ HI = \frac{\text{Rhizome yield}}{\text{Biological yield}} $$

In the calculation of NAR, a linear relationship between W and A was assumed. This assumption was practically correct until 22nd week after planting when senescence of leaves became rapid under the monoculture system. The sampling intervals were so adjusted that the increase in A between two consecutive samplings, i.e. ${}_2A/{}_1A$ would not exceed appreciably beyond a range of 2.0 to 2.5.

4. Measurement of light and other environmental factors

4.1. PAR Measurement

Photosynthetically active radiation (PAR) was measured by LI-COR Instruments (Nebraska, USA), daily in the open as well as in the coconut garden during June to December of the year 1977 and 1978. A LI-190S quantum sensor was used in combination with either a LI-510B quantum integrator (for 24-h integrated values) or a LI-185A quantum meter (for instantaneous values). In coconut garden a series of readings were taken at equal distances of one meter apart, along the sides and diagonals of a square area occupied by four palms. Light interception by the pure and intercropped stands of turmeric was calculated by measuring the PAR above, below and within the canopy. The measurements were monitored between 10.00 h and 15.00 h. The incident PAR was measured by holding the sensor 10 cm above the turmeric canopy. The amount of light reaching the soil surface was measured by placing the sensor 5 cm above the ground level. Alternate measurements were made within and in between the rows at an interval of two minutes. The interception efficiency of the pure stands of turmeric or coconut and their canopies under intercropping are calculated as follows:

$$\text{Interception efficiency (\%)} = \frac{I_0 - I \times 100}{I_0}$$

where I and I_0 were the transmitted and incident PAR respectively.

The transmission efficiency of the coconut canopy during different months as well as its diurnal trend was calculated as follows:

$$\text{Transmission efficiency (\%)} = \frac{I \times 100}{I_0}$$

where I was the transmitted PAR by the coconut canopy measured 1.0 m above the ground level and I_0 was the incident PAR in the open.

The efficiency of solar energy conversion for the pure and intercropped stands of turmeric were calculated for two periods, from germination to harvest and for the bulking period (8th to 22nd week after planting) following the formula given below:

$$\text{Efficiency of solar energy conversion (\%)} = \frac{P_n \times 100}{I_0}$$

where P_n was the net photosynthesis expressed in energetic terms, assuming that 4.2 Kcal are required for the production of 1 g of dry matter, and I_0 was the incident photosynthetically active energy.

4.2. Measurement of optical properties of coconut leaf

The reflectance, absorptance and transmittance of single leaf-lets of coconut of WCT variety were measured using a LI-1800 Portable Spectroradiometric Research System (LI-COR, Nebraska, USA).

4.3. Measurement of other environmental variables

The monthly values of meteorological parameters like temperature, humidity, vapour pressure, sunshine, rainfall, evaporation (USWB pan), soil moisture and soil temperature during the turmeric growing season in the years 1977 and 1978 were collected from the agro-meteorological observatory of CPCRI, Kasaragod. Different microclimatic parameters like evaporation, air temperature, soil temperature, humidity, vapour pressure and soil moisture under pure and intercropped stands of turmeric were measured for five clear days having more than six hours of sunshine in each month of the crop growth during the year 1977. The details of observations are given below:

Evaporation, air temperature, maximum and minimum temperatures, relative humidity and vapour pressure were measured at a height of 100 cm above ground level. The soil temperature and soil moisture were measured at a depth of 15 cm from ground level. The evaporation was measured at 14.30 h, while relative humidity, vapour pressure, air temperature, soil temperature and soil moisture were measured twice daily, at 8.00 and 14.30 h. The evaporation was measured using a cup evaporimeter (Balakrishnan *et al*., 1976). Relative humidity and vapour pressure were measured using an Assman's psychrometer. Air and soil temperatures were measured using meteorological and soil thermometers respectively and maximum minimum temperature using a max.-mini. thermometer. Soil moisture was determined by the gravimetric method. Other procedures followed were as described by Nair and Balakrishnan (1977).

5. Apparent photosynthesis and photosynthetic characteristics of turmeric leaves

5.1. Measurement of apparent photosynthesis in turmeric by gasometric method

Twenty plants of each cultivar, at the stage of attainment of maximum leaf area, were selected for the determination of rate of apparent photosynthesis. From each plant, the youngest fully unfolded leaf was sampled for the study. From the mid region of each leaf, small discs (7 mm diameter) were cut and used for the determination of the rate of apparent photosynthesis, following the method described by Forsyth and Hall (1965) using a Warburg apparatus.

Desired number of leaf discs were placed in the main compartment of manometer reaction flask with their upper surface facing the light source. The side arm of the reaction flask contained 0.4 ml distilled water, to prevent desiccation of the leaf discs. The centre well of the flask contained 0.6 ml Pardee's CO_2 buffer (Umbreit *et al.*, 1964). A folded filter paper was placed in the centre well to increase the surface area of the buffer, exposed to flask atmosphere. The light source was tungsten lamps of different light intensities for standardization and further measurements were made at saturating light intensities. The reaction flasks were not shaken as the discs were not suspended in the fluid. Ten to 15 min equilibration, after switching on the lights, preceded the commencement of gas output measurements. Throughout the study, the reaction flasks were immersed upto the neck in water in the water bath of the equipment. Other manometric procedures followed were as described by Umbreit _et al._ (1964). Manometric readings were recorded at 10 min. intervals and results were expressed as μl O_2 evolved/cm^2 leaf tissue/h. For each sample 3 replicates were run simultaneously and the mean of the nearest two values were taken for the calculation of O_2 evolved.

3.2. Photosynthetic characteristics of turmeric leaves

3.2.1. Chlorophyll content

The youngest fully unfolded leaves of twenty plants of each cultivar of which the rate of apparent photosynthesis was determined were sampled for the estimation of chlorophyll. Twenty discs (1 cm diameter) were punched from the middle portion of the leaf nearer to the areas from which samples were drawn for the determination of the rate of apparent photosynthesis. Chlorophylls _a_ and _b_ were estimated according to the method described by Sestak (1971). The chlorophyll pigments were extracted using 80 per cent acetone. The absorbance of the extract was measured at 663 and 645 nm on a Spectrophotometer and the chlorophyll content was estimated using the equations given below (Arnon, 1949).

$$\text{Chlorophyll } \underline{a} = 12.7\, A_{663} - 2.69\, A_{645}$$

$$\text{Chlorophyll } \underline{b} = 22.9\, A_{645} - 4.68\, A_{663}$$

$$\text{Chlorophyll } (\underline{a} + \underline{b}) = 8.02\, A_{663} + 20.20\, A_{645}$$

The values were expressed as mg g^{-1} fresh weight of leaf tissue.

3.2.2. Leaf air space volume

Twenty plants of each cultivar at the stage of attainment of maximum leaf area were selected for the determination of leaf air space volume. The air space volume was determined following the infiltration method using water as solvent (Byott, 1976). Five segments each with an area of 1 cm^2 were cut from the middle portion of the youngest fully unfolded leaf. The segments were quickly weighed and put in 50 ml of water in a 100 ml beaker. The beaker was then placed in a vacuum desiccator and evacuated for two minutes. The vacuum was then replaced quickly allowing the air to enter the desiccator.

Ten to 15 such infiltrations were done for each set of 5 segments. The segments were thereafter removed, blotted between filter paper folds and quickly weighed. The volume of air space was then estimated assuming that 1 g of water occupied 1 cm^3 space in the leaf.

Hand sections of leaf laminae were cut, leaf thickness was measured at random intervals using an ocular micrometer and an average of ten readings was taken. The total leaf volume was calculated and the air space volume was expressed as percentage of total leaf volume.

6. Estimation of carbohydrates

Total sugars and starch were extracted according to the method of Highkin and Frenkel (1962). Hundred mg of dried and powdered samples were extracted in 80 per cent ethyl alcohol. The total sugar content was then estimated by the phenol-sulphuric method (Dubois <u>et al</u>., 1956). Two ml of the extract were mixed with 1 ml of 5% (w/v) phenol. Five ml of con. H_2SO_4 were added with a wide mouthed pipette and mixed thoroughly. Optical density of the solution was read after 30 minutes at 490 nm.

The residue obtained from the original alcoholic extract was used for starch estimation. The residue was kept suspended in 52 per cent perchloric acid for 30 minutes with intermittent shaking. The solution was filtered and five ml aliquots of the filtrate were digested with 2.5 N. HCl in a water bath at 100° C for 30 minutes and neutralised with 30% NaOH. Two ml of the hydrolysate were taken for the estimation of starch content by the phenol-sulphuric acid method (Dubois et al., 1956) as described above.

7. Analysis of nutrients

The major nutrients N, P and K in the leaves, rhizomes and roots were estimated for each sampling date according to the method described by Jackson (1958).

Nitrogen:

Total N was determined adopting microkjeldahl distillation technique. Hundred mg of oven dried and finely powdered plant sample were taken in a microkjeldahl digestion flask and digested with 2 ml con. H_2SO_4 introducing 1 g of K_2SO_4:$CuSO_4$ (10:1 w/w) digestion mixture. The whole digest was then transferred to a microkjeldahl distillation unit and 10 ml of 40% NaOH was added. The ammonia released was steam-distilled into 5 ml of 2% boric acid solution containing 2 to 3 drops of methyl red-bromocresol green indicator. The distillate was titrated with 0.02 N H_2SO_4. The values are expressed as percentage of dry weight of plant tissue.

Preparation of sample solution for P and K estimation:

One g of oven dried and finely powdered plant tissue was taken in a 100 ml standard flask and digested with 10 ml of diacid mixture ($HClO_4$: HNO_3, 1:2 v/v) over a sand bath untill the solution was clear. The whole digest was made upto the volume and filtered. Aliquots were taken from the clear filtrate for P and K estimation.

Phosphorus:

Phosphorus in plant tissue was determined by vanadomolybdate colorimetric procedure. Five ml of aliquot were taken in a 25 ml standard flask and added 10 ml of Barton's HNO_3 - vanadate - molybdate reagent (Jackson, 1958) and made upto volume. The vanado molybdo phosphoric yellow colour was measured at 470 nm on a Spectronic 20. The P content of the plant tissue was then calculated by referring to the standard curve developed for the known concentrations of P.

Potassium:

Potassium in plant tissue was determined by flame photometry. One ml of aliquot was diluted to 25 ml and read directly in EEL flame photometer. The K content in plant tissue was then computed by referring to the standard graph for known concentrations of K.

Nitrogen, P and K accumulation were calculated on an oven-dry weight basis as the total amount of each element in different plant parts and the total amount per plant.

Since there was no physical loss of leaves during the period of senescence, the nutrients lost from the shoot was assumed to be redistributed to rhizome and was calculated by the following formula:

$$\text{Redistribution (\%)} = \left[\frac{X_{max} - X_{maturity}}{X_{max}}\right] 100$$

where X_{max} = Amount of nutrient in the shoot at a stage when it was maximum and $X_{maturity}$ = Amount of nutrient in the fully senesced shoot.

8. Estimation of curcumin and essential oil

8.1. Curcumin:

Curcumin content was estimated spectrophotometrically (American Spice Trade Association, 1968). Dried and finely ground rhizome sample (100 mg) was refluxed in 30 ml of 95% ethyl alcohol for 3 h. The extract was cooled, filtered and made upto 100 ml. One ml of this was diluted to 25 ml with 95% ethyl alcohol.

Standards of 0.5 to 5.0 µg/ml of curcumin (BDH, England) in 95% ethyl alcohol were employed for the preparation of standard curve. The absorbance of the standard or test solutions was measured at 425 nm against an alcohol blank.

8.2. Essential oil

Essential oil was estimated gravimetrically. Ten g of dried and finely ground rhizome sample were extracted for 24 h in petroleum ether (60-80° C) in a Soxhlet extractor.

9. CCC treatments

Two experiments were conducted, under the monoculture and under the intercropping systems during the cropping season in 1978 adopting a completely randomised design with five replications. The cultivar Cls. No.24 was selected for the study since it had shown maximum response to changes in environment.

Treatments were as follows:

H_0 - No CCC, control

H_1 - 2000 ppm CCC

H_2 - 4000 ppm CCC

H_3 - 6000 ppm CCC

Three foliar sprayings were conducted at 4th, 6th and 10th weeks after planting at the rate of one litre for

4 beds of 44 plants each. Five beds each with an area of 3.3 m^2 constituted a plot. Nine samples were taken for the growth analysis, at 4, 6, 8, 11, 14, 18, 22, 26 and 30th weeks after planting. Harvesting was done immediately after the last sampling. At each sampling date, eight plants (i.e. four from each of the two central rows, representing an area of 0.6 m^2) were taken from each replication. Border strips were kept in between the sample rows. The growth analytical techniques were adopted to assess the leaf area development and dry matter production as influenced by the CCC treatments.

10. Nitrogen amendments

Two experiments were conducted, under the monoculture and under the intercropping systems during the cropping season in 1978 adopting a completely randomised design with five replications. The cultivar Clo. No.24 was selected for the study. The treatments were as follows:

N_0 - No nitrogen.

N_1 - 30 kg/ha, equally split doses were applied during 6th and 10th weeks after planting (early application).

N_2 - 60 kg/ha, equally split doses were applied during 6th and 10th weeks after planting (early application).

N_3 - 60 kg/ha; 30 kg were applied during 6th and 10th weeks after planting in equally split doses and the rest 30 kg were applied during 16th week after planting (early + late application).

N_4 - 60 kg/ha; applied during 16th week after planting (late application).

Five beds each with an area of 3.3 m^2 constituted a plot. Nine samples were taken for leaf area measurements, at 4, 6, 8, 11, 14, 18, 22, 26 and 30th weeks after planting. Dry weight determination was done only at harvest. At each sampling date, eight plants (i.e. four from each of the two central rows, representing an area of 0.6 m^2) were taken from each replication. There were border strips in between the sample rows.

RESULTS

1. Leaf area development

Four parameters - leaf area index, leaf growth rate, relative leaf growth rate and leaf area duration - were used to examine the leaf area development in three turmeric cultivars under two cropping systems, viz., monoculture (pure stand) and associated with coconut (intercropped stand). On one hand, variation among cultivars was studied as influenced by the cropping system, while on the other the differences, if any, were assessed between first and second year of planting.

1.1. Leaf area and leaf area index

I Year. The total amount of leaf area produced per plant (LA) and leaf area index (LAI) during the cropping season in the year 1977 are presented in Tables 1a and 2a respectively. The trend in the time course of LAI is shown in Fig. 1. The LAI was considerably higher under the pure stand of turmeric than under the intercropped stand upto 11th week after planting for all the three cultivars. Cultivars C_1 and C_3 had significantly higher LAI values than those at C_2 during the experimental period. The LAI increased upto 22nd week under the intercropped stand, while under the pure stand the maximum LAI (LAI_{max}) values were attained

Table 1a. Leaf area per plant (cm^2) of three turmeric cultivars at different stages of growth under pure and intercropped stands during the year 1977

Cropping systems	Cultivars	Weeks after planting							
		4	6	8	11	14	18	22	26
Pure	C_1	237	524	1241	2814	4083	4733	3605	446
	C_2	244	433	751	2053	3028	3087	2164	366
	C_3	290	650	1250	3156	3847	3963	2829	355
Intercropped	C_1	240	482	1082	1924	2757	4033	4198	1671
	C_2	209	418	587	1411	2882	2960	3079	986
	C_3	331	476	915	2072	3128	4754	4775	1390
Mean Cultivars									
C_1		239	503	1162	2369	3420	4383	3901	1059
C_2		227	426	669	1732	2955	3024	2621	676
C_3		311	563	1083	2615	3488	4359	3802	873
Mean Systems									
Pure		257	536	1080	2674	3653	3928	2866	389
Intercropped		260	459	861	1803	2922	3916	4017	1349
CD (P = 0.05) Cultivars (C)		38	60	212	254	424	535	441	258
Systems (S)		NS	49	174	208	346	NS	360	220
C x S		NS	85	NS	NS	599	757	624	NS
CV (%)		16.1	13.1	14.9	12.1	14.0	14.8	13.9	32.1

Table 15. Leaf area per plant (cm^2) of three turmeric cultivars at different stages of growth under pure and intercropped stands during the year 1978

Cropping systems	Cultivars	Weeks after planting							
		4	6	8	11	14	18	22	26
Pure	C_1	238	441	715	1838	3131	3871	2651	443
	C_2	240	421	753	2024	2968	3027	2184	372
	C_3	284	638	1232	3127	3787	3903	2847	361
Intercropped	C_1	209	360	590	1167	2476	2934	3300	1373
	C_2	203	406	569	1381	2822	2910	3016	1004
	C_3	325	464	877	2042	3068	4722	4715	1406
Mean									
Cultivars									
C_1		223	400	653	1502	2803	3403	2975	908
C_2		222	414	661	1703	2895	2969	2600	688
C_3		305	551	1055	2585	3428	4313	3781	884
Mean									
Systems									
Pure		254	500	900	2330	3295	3600	2560	392
Intercropped		246	410	679	1530	2789	3522	3677	1261
CD (P = 0.05)									
Cultivars (C)		40	63	85	221	355	412	380	NS
Systems (S)		NS	52	69	180	289	NS	310	198
C x S		NS	89	120	NS	NS	583	537	NS
CV (%)		17.1	15.1	11.6	12.2	12.6	12.6	13.1	31.8

Table 2a. Leaf area index of three turmeric cultivars at different stages of growth under pure and intercropped stands during the year 1977

Cropping systems	Cultivars	Weeks after planting							
		4	6	8	11	14	18	22	26
Pure	C_1	0.32	0.70	1.65	3.75	5.45	6.31	4.81	0.59
	C_2	0.32	0.58	1.00	2.74	4.04	4.12	2.09	0.49
	C_3	0.30	0.87	1.67	4.21	5.13	5.29	3.77	0.47
Intercropped	C_1	0.32	0.64	1.44	2.56	3.67	5.38	5.60	2.23
	C_2	0.28	0.56	0.78	1.88	3.84	3.93	4.10	1.31
	C_3	0.44	0.63	1.22	2.76	4.17	6.34	6.37	1.85
Mean Cultivars									
C_1		0.32	0.67	1.55	3.16	4.56	5.84	5.20	1.41
C_2		0.30	0.57	0.89	2.31	3.94	4.03	3.10	0.90
C_3		0.42	0.75	1.45	3.49	4.65	5.81	5.07	1.16
Mean Systems									
Pure		0.34	0.72	1.44	3.57	4.87	5.24	3.52	0.52
Intercropped		0.35	0.61	1.15	2.40	3.89	5.22	5.36	1.80
CD (P = 0.05) Cultivars (C)		0.05	0.08	0.18	0.34	0.57	0.71	0.59	0.34
Systems (S)		NS	0.07	0.15	0.28	0.46	NS	0.48	0.28
C x S		NS	0.12	NS	NS	0.80	1.01	0.83	NS
CV (%)		16.1	13.3	15.0	12.1	14.0	14.8	13.9	32.1

Table 3b. Leaf area index of three turmeric cultivars at different stages of growth under pure and intercropped stands during the year 1978

Cropping systems	Cultivars	Weeks after planting							
		4	6	8	11	14	18	22	26
Pure	C_1	0.33	0.60	0.96	2.45	4.17	5.16	3.54	0.59
	C_2	0.32	0.56	1.00	2.70	3.96	4.04	2.91	0.50
	C_3	0.38	0.85	1.64	4.17	5.06	5.20	3.80	0.48
Intercropped	C_1	0.28	0.48	0.79	1.55	3.30	3.91	4.40	1.83
	C_2	0.27	0.54	0.76	1.84	3.76	3.85	4.03	1.34
	C_3	0.43	0.62	1.17	2.72	4.09	6.30	6.29	1.87
Mean									
Cultivars									
C_1		0.30	0.54	0.87	2.00	3.74	4.53	3.97	1.21
C_2		0.30	0.55	0.88	2.27	3.86	3.94	3.47	0.92
C_3		0.41	0.73	1.41	3.45	4.57	5.75	5.04	1.18
Mean									
Systems									
Pure		0.34	0.67	1.20	3.11	4.40	4.80	3.42	0.52
Intercropped		0.33	0.55	0.91	2.04	3.72	4.69	4.91	1.68
CD (P = 0.05)									
Cultivars (C)		0.05	0.09	0.11	0.29	0.47	0.55	0.51	NS
Systems (S)		NS	0.07	0.09	0.24	0.39	NS	0.41	0.26
C x S		NS	0.12	0.16	NS	NS	0.78	0.72	0.46
CV (%)		16.9	15.3	11.3	12.2	12.6	12.7	13.1	31.6

Fig.1. Leaf area index (LAI) at different stages of growth in three turmeric cultivars under pure and intercropped stands.

●——● Cls. No.24 (1977)
●- - -● Cls. No.24 (1978)
×——× Cll.328 Sugandham (1977)
△——△ Duggirala (1977)

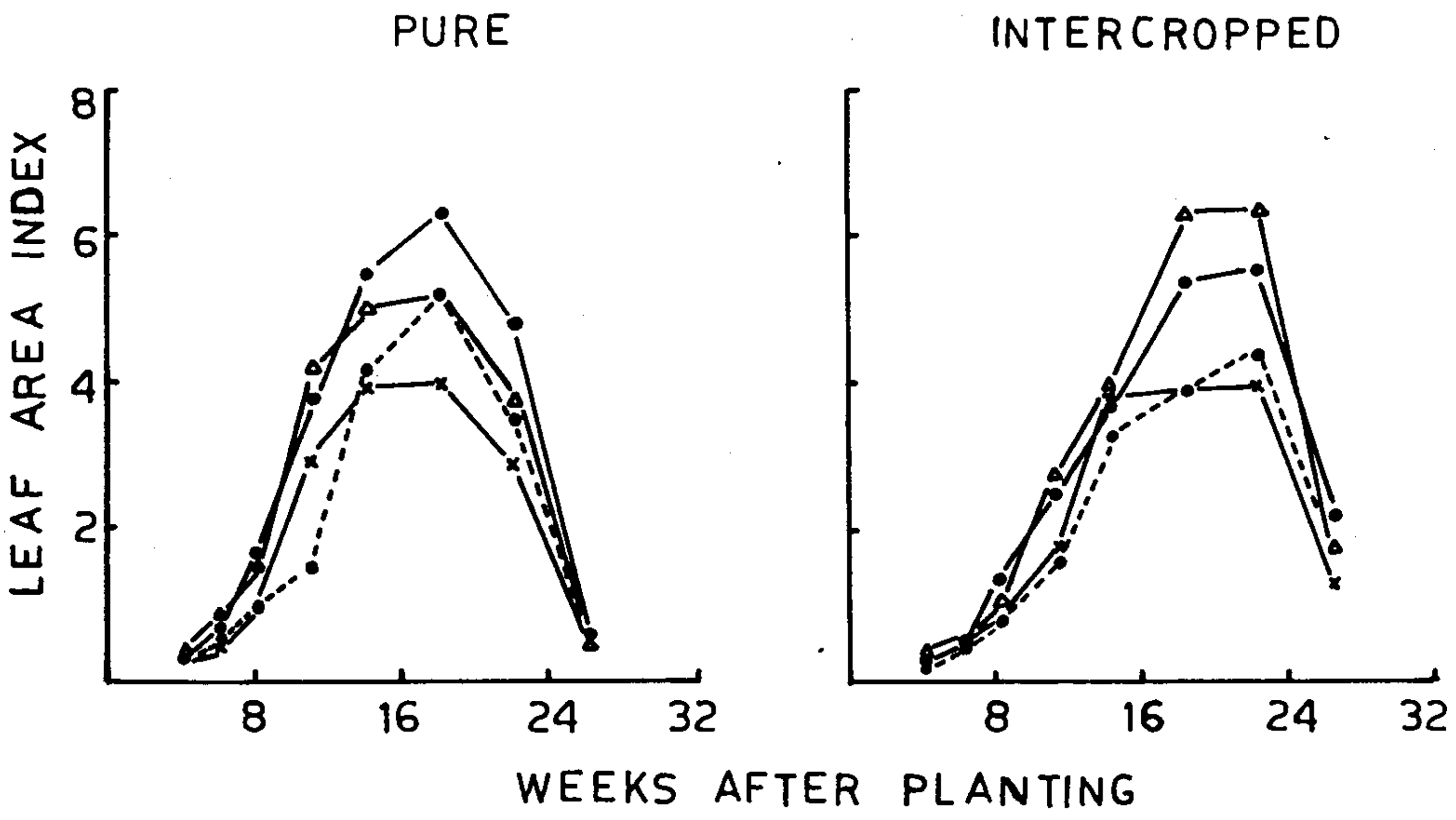

PURE
INTERCROPPED
LEAF AREA INDEX
8
6
4
2
8
16
24
32
8
16
24
32
WEEKS AFTER PLANTING

FIG.1

by 18th week itself. Thereafter, there was a steady decline in LAI upto harvest.

The LAI_{max} of the cultivar C_1 under the pure stand was considerably higher than that under the intercropped stand, while this trend was in reverse order for the cultivar C_3, intercropping resulting in significantly higher LAI_{max} value. Cultivar C_2 did not register any marked difference for the LAI_{max} values between the two cropping systems. Under the monoculture system, LAI_{max} of the three cultivars was in the order, $C_1 > C_3 > C_2$ with significant differences, whereas under the intercropping system, the highest LAI_{max} was for cultivar C_3 followed by C_1 and significantly less for C_2. During the period when LAI was decreasing, higher LAI was maintained by the cultivar C_1 followed by C_3 and C_2 under both the cropping systems.

II. Year. The total amount of leaf area produced per plant and leaf area index during the year 1978 are presented in Tables 1b and 2b respectively. The trend in the time course of LAI for the cultivar C_1 is depicted in Fig.1. The LAI values of the cultivars C_2 and C_3 did not register any considerable difference between the two years. However, in case of cultivar C_1, the LAI values during the early period of growth as well as the LAI_{max} attained were markedly reduced in the second year as compared to the first year under both the cropping systems.

Under the monoculture, in contrast to the first year, no significant difference was noticed between the cultivars C_1 and C_3 for the maximum LAI attained, eventhough these two had significantly higher LAI_{max} than the cultivar C_2. The other changes in the LAI of the three cultivars as influenced by the cropping system followed the same trend as that in the first year.

1.2. Leaf growth rate

I Year. The absolute growth rate of leaf area (LGR) during the cropping season in the year 1977 is presented in Table 3a and the trend of changes is depicted in Fig.2. Under the intercropped stand, maximum LGR was noticed between 14th and 18th weeks after planting for cultivars C_1 and C_3, and between 11th and 14th weeks for cultivar C_2. But under the pure stand, the maximum LGR was attained between 8th and 11th weeks for all the three cultivars. Under the monoculture, there was considerable leaf growth rate for cultivar C_1 upto 18th week, eventhough this was negligible beyond 14th week for the other two cultivars. Under the intercropped stand, there was a drastic reduction in the LGR after 14th week for cultivar C_2, but for the other two cultivars, this reduction was noticed only after

Table 2a. Growth rate of leaf area (cm^2 $week^{-1}$) of three turmeric cultivars at different stages of growth under pure and intercropped stands during the year 1977.

Cropping systems	Cultivars	Weeks after planting						
		4–6	6–8	8–11	11–14	14–18	18–21	21–25
Pure	C_1	143	358	525	423	163	-301	-790
	C_2	94	159	376	301	17	-203	-435
	C_3	180	300	580	220	30	-241	-641
Intercropped	C_1	122	300	281	278	319	41	-633
	C_2	105	84	275	429	20	30	-505
	C_3	72	220	386	321	421	5	-817
Mean Cultivars								
C_1		132	329	403	350	241	-130	-711
C_2		100	122	325	365	18	-87	-470
C_3		126	260	483	270	226	-118	-729
Mean Systems								
Pure		139	272	493	315	70	-248	-622
Intercropped		99	201	314	342	253	25	-652
CD (P = 0.05)								
Cultivars (C)		17	37	52	[illegible]	76	[illegible]	100
Systems (S)		14	47	43	[illegible]	62	90	[illegible]
C x S		24	[illegible]	74	121	107	[illegible]	153
CV (%)		15.3	26.1	14.0	28.2	51.0	-81.4	-88.4

Table 3b. Growth rate of leaf area (cm^2 week^{-1}) of three turmeric cultivars at different stages of growth under pure and intercropped stands during the year 1977

Cropping systems	Cultivars	Weeks after planting						
		4-6	6-8	8-11	11-14	14-18	18-22	22-26
Pure	C_1	104	126	345	391	193	-276	-587
	C_2	91	166	368	290	15	-185	-438
	C_3	177	297	576	210	57	-224	-644
Intercropped	C_1	76	115	215	375	136	110	-445
	C_2	102	81	271	420	23	27	-486
	C_3	69	207	388	312	429	00	-799
Mean Cultivars								
C_1		90	121	280	383	164	-83	-516
C_2		96	124	319	355	19	-79	-462
C_3		123	252	482	261	243	-112	-722
Mean Systems								
Pure		124	196	430	297	88	-228	-556
Intercropped		82	135	291	369	196	46	-577
CD (P = 0.05) Cultivars (C)		18	36	52	85	65	NS	107
Systems (S)		15	29	43	69	53	48	NS
C x S		26	NS	NS	NS	92	83	NS
CV (%)		19.0	23.6	15.7	27.7	51.5	30.8	20.3

Fig.2. Leaf growth rate (LGR) at different stages of growth in three turmeric cultivars under pure and intercropped stands.

●——●	Cls. No.24 (1977)
●- - -●	Cls. No.24 (1978)
×——×	Cll.328 Sugandham (1977)
△——△	Duggirala (1977)

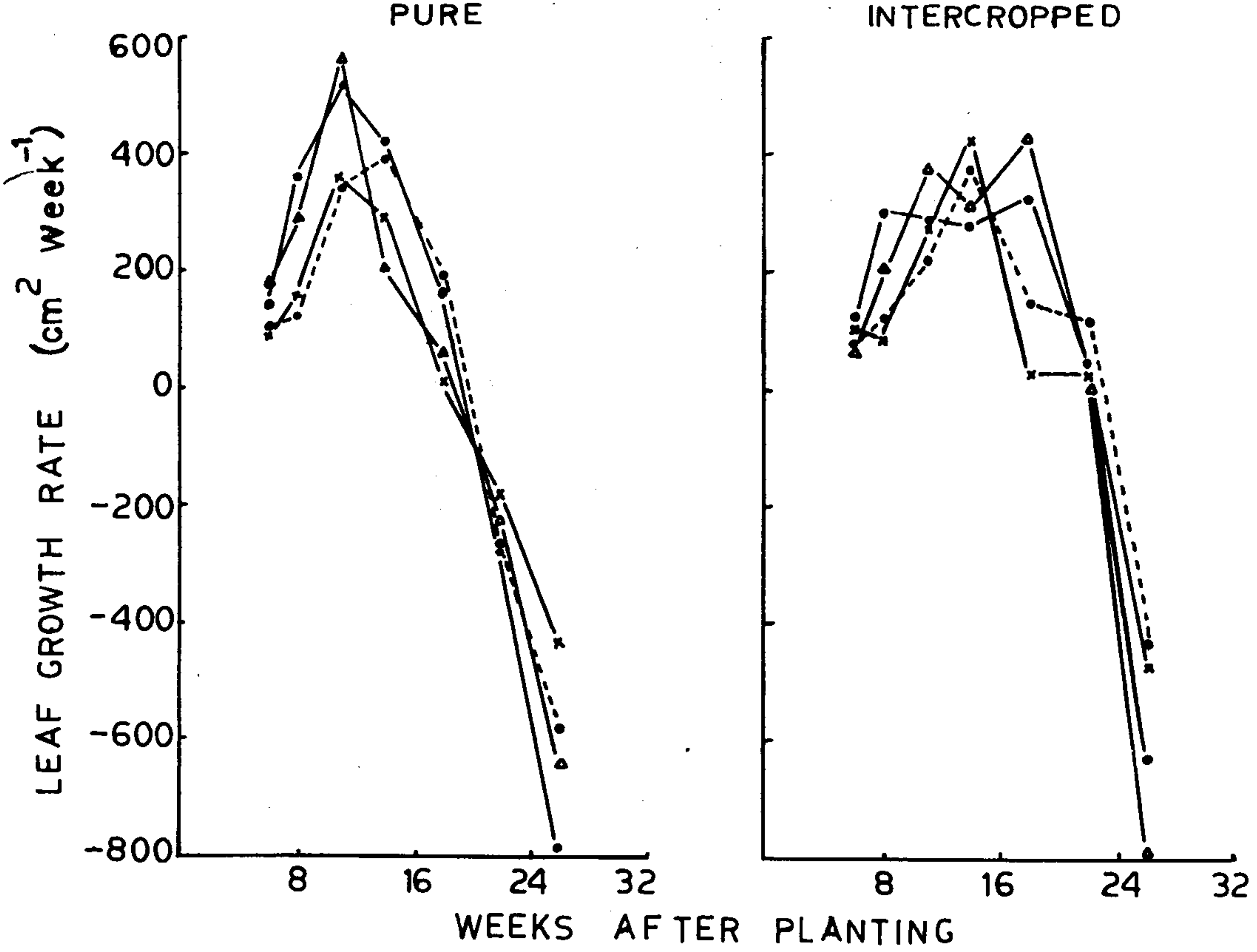
PURE
INTERCROPPED
LEAF GROWTH RATE (cm^2 week^{-1})
600
400
200
0
-200
-400
-600
-800
8
16
24
32
WEEKS AFTER PLANTING

FIG.2

18th week. The LGR values were positive upto 22nd week under the intercropped stand, but in the monoculture, negative values were obtained after 18th week of planting, for all the three cultivars.

Pure stand registered significantly higher LGR than the intercropped stand upto 11th week after planting. Cultivars C_1 and C_3 registered significantly higher LGR values than C_2 during this period. The maximum LGR values recorded for the three cultivars under the monoculture was in the order, $C_3 > C_1 > C_2$ with significant differences. Under the intercropping, the maximum LGR attained by cultivars C_2 and C_3 was considerably higher than in C_1. The maximum LGR values attained for cultivars C_1 and C_3 under the monoculture system was considerably higher than those attained under the intercropping system, while for C_2 this was higher under the intercropping system.

II Year. The absolute growth rate of leaf area during the cropping season in the year 1978 is presented in Table 3b. The trend in the time course of LGR for the cultivar C_1 is depicted in Fig.2. The LGR values of the cultivars C_2 and C_3 did not show any marked difference between the two years. In the case of cultivar C_1, the LGR values were considerably reduced in the second year as compared to the first year under both the cropping systems. In contrast to the first year, the attainment of the maximum LGR for the pure stand of the cultivar C_1 was postponed to the period of 11th to 14th week after planting. The maximum LGR attained by the cultivar C_1 in the second year was considerably low as compared to that attained in the first year, which was more pronounced under the monoculture system than under the intercropping system.

Under the monoculture, the maximum LGR for the cultivar C_3 was remarkably higher than those for C_1 or C_2. There was no considerable difference between pure and intercropped stands of the cultivar C_1 for the maximum LGR attained during the second year.

1.3. Relative leaf growth rate

I Year. The relative growth rate of leaf area (RLGR) during the cropping seasons in the year 1977 is given in Table 4a. The trend in the changes of RLGR during the crop growth period is shown in Fig.3. The heighest RLGR was in the early period of crop growth upto 8th week after planting. After 8th week, there was a considerable reduction in RLGR of the cultivar C_1 under both the cropping systems. In case of cultivars C_2 and C_3, such reduction was seen only after 11th week. The RLGR became negative during the period of 10th to

Table 4a. Relative growth rate of leaf area (cm^2 cm^{-2} week^{-1}) of three turmeric cultivars at different stages of growth under pure and intercropped stands during the year 1977

Cropping systems	Cultivars	Weeks after planting						
		2-5	5-8	8-11	11-14	14-18	18-22	22-26
Pure	C_1	0.397	0.428	0.274	0.124	0.037	-0.068	-0.524
	C_2	0.287	0.267	0.274	0.114	0.006	-0.077	-0.448
	C_3	0.407	0.331	0.280	0.064	0.008	-0.072	-0.578
Intercropped	C_1	0.349	0.397	0.195	0.118	0.094	0.011	-0.231
	C_2	0.347	0.180	0.292	0.204	0.007	0.013	-0.276
	C_3	0.184	0.325	0.275	0.125	0.108	0.002	-0.307
Mean								
Cultivars								
C_1		0.373	0.412	0.234	0.121	0.066	-0.029	-0.377
C_2		0.317	0.224	0.283	0.159	0.007	-0.032	-0.362
C_3		0.296	0.328	0.277	0.094	0.058	-0.035	-0.443
Means								
Systems								
Pure		0.364	0.342	0.276	0.100	0.017	-0.072	-0.517
Intercropped		0.294	0.301	0.254	0.149	0.070	0.009	-0.271
CD (P = 0.05)								
Cultivars (C)		0.030	0.063	0.023	0.024	0.016	NS	NS
Systems (S)		0.032	NS	0.019	0.020	0.013	0.014	0.067
C x S		0.055	NS	0.033	0.034	0.023	NS	NS
CV (%)		12.8	21.1	9.5	20.8	41.1	-37.6	-72.6

Table 4b. Relative growth rate of leaf area (cm^2 cm^{-2} week^{-1}) of three turmeric cultivars at different stages of growth under pure and intercropped stands during the year 1978

Cropping systems	Cultivars	Weeks after planting						
		4-6	6-8	8-11	11-14	14-18	18-22	22-26
Pure	C_1	0.324	0.219	0.288	0.161	0.056	-0.088	-0.501
	C_2	0.282	0.290	0.260	0.180	0.004	-0.070	-0.446
	C_3	0.409	0.334	0.281	0.062	0.008	-0.056	-0.574
Intercropped	C_1	0.272	0.238	0.258	0.216	0.040	0.036	-0.202
	C_2	0.347	0.180	0.296	0.204	0.007	0.013	-0.288
	C_3	0.181	0.318	0.281	0.123	0.111	0.000	-0.302
Mean								
Cultivars								
C_1		0.298	0.228	0.273	0.189	0.052	-0.026	-0.352
C_2		0.314	0.235	0.283	0.156	0.007	-0.029	-0.357
C_3		0.295	0.326	0.281	0.093	0.059	-0.028	-0.438
Means								
Systems								
Pure		0.338	0.281	0.280	0.111	0.023	-0.071	-0.507
Intercropped		0.267	0.245	0.270	0.181	0.055	0.016	-0.257
CD (P = 0.05)								
Cultivars (C)		NS	0.062	NS	0.030	0.017	NS	NS
Systems (S)		0.035	NS	NS	0.025	0.014	0.014	0.069
C x S		0.060	NS	NS	NS	0.024	0.025	NS
CV (%)		15.3	25.4	9.4	22.4	40.7	-82.1	-23.8

Fig.3. Relative leaf growth rate (RLGR) at different stages of growth in three turmeric cultivars under pure and intercropped stands.

●——●	Cls. No.24 (1977)
●- - -●	Cls. No.24 (1978)
×——×	Cll.328 sugandham (1977)
△——△	Duggirala (1977)

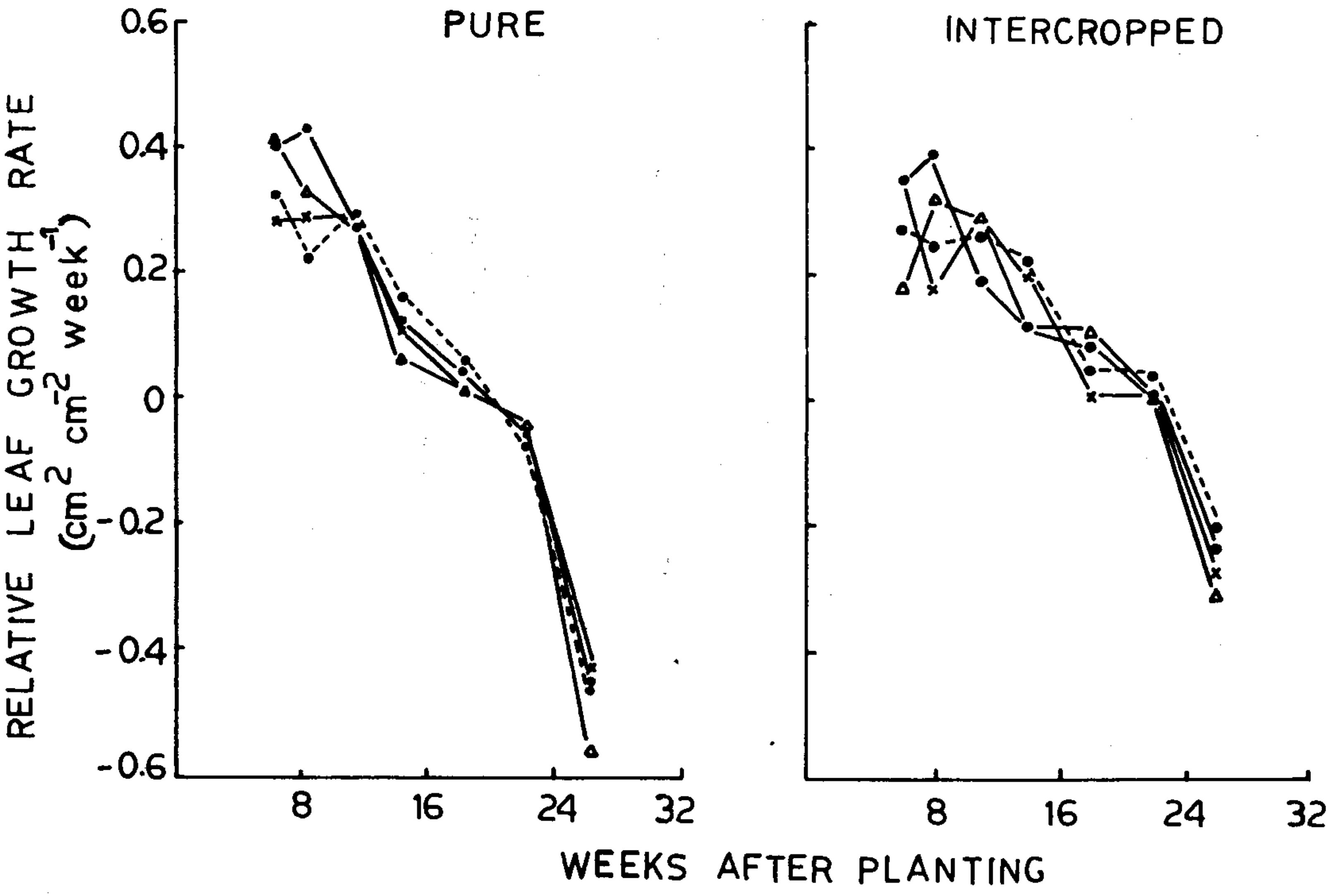

PURE
INTERCROPPED
RELATIVE LEAF GROWTH RATE
(cm^2 cm^{-2} $week^{-1}$)
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
8
16
24
32
8
16
24
32
WEEKS AFTER PLANTING

FIG.3

22nd week under the pure stand, while under intercropped stand, this was postponed to the period of 22nd to 26th week.

During the early period upto 11th week, the RLGR of cultivars C_1 and C_3 under the pure stand were higher than those under the intercropped stand, while for cultivar C_2, this superiority under pure stand was seen only during the period of 6th to 8th week. Under the monoculture, the RLGR was considerably higher for the cultivars C_1 and C_3 than for C_2 during the period of 4th to 8th week. Under the intercropped stand also, the cultivar C_1 was superior to C_2 or C_3 in RLGR registered during this early period of crop growth.

II Year. The relative growth rate of leaf area during the crop growth period in the year 1978 is presented in Table 4b. The trend in the changes of RLGR for the cultivar C_1 during this year is depicted in Fig.3. There was not much difference in RLGR of cultivars C_1 and C_2 between the two years. In the early period of crop growth upto 8th week after planing, the RLGR of cultivar C_1 was considerably low during the second year as compared to the first year. Unlike in the first year, the marked reduction in the RLGR values of the cultivar C_1 was postponed to after 11th and 14th weeks under pure and intercropped stands respectively.

The superiority of cultivar C_1 in RLGR, which was prominent in the first year of planting was not observed in the second year. Under the intercropped stand, the higher RLGR values were recorded for the cultivars C_2 and C_3 than those of C_1, while under the pure stand, the highest RLGR was registered by cultivar C_3.

1.4. Leaf area duration

I Year. The leaf area duration (LAD) calculated for different periods of sampling and the cumulative values during the crop growth period in the year 1977 are given in Tables 5a and 6a respectively. The cumulative increase in LAD of the three cultivars are presented in Fig.4. The cultivars C_1 and C_3 recorded significantly higher LAD than that of C_2 during most of the growth stages under both the cropping systems. The LAD of cultivar C_1 was higher under the pure stand than that under the intercropped stand during the period between 8th and 18th weeks. For the cultivar C_3, a similar trend was noticed upto 14th week, while for C_2, the LAD values did not show much difference between the two cropping systems. Beyond 18th week, following a rapid senescence of leaves under the monoculture, the LAD was maintained high only under the intercropping system. In the case of cultivar C_3, this trend was noticed between 18th and

Table 5a. Leaf area duration (weeks) of three turmeric cultivars at different stages of growth under pure and intercropped stands during the year 1977

Cropping systems	Cultivars	Weeks after planting							
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Pure	C_1	1.02	2.35	8.11	13.80	23.44	22.24	10.80	1.19
	C_2	0.90	1.57	6.17	10.51	15.74	15.07	6.99	1.34
	C_3	1.25	2.53	10.17	15.14	20.11	19.48	8.20	1.26
Intercropped	C_1	0.96	2.09	6.02	9.36	18.10	21.95	15.65	4.84
	C_2	0.84	1.34	4.80	9.81	15.01	16.07	10.88	4.15
	C_3	1.08	1.86	5.98	11.41	20.28	25.42	17.35	5.84
Mean Cultivars									
C_1		0.99	2.22	7.06	11.58	20.77	22.09	13.23	3.01
C_2		0.87	1.46	5.49	10.16	15.38	15.57	8.94	2.74
C_3		1.17	2.20	8.08	13.28	20.19	22.45	12.78	3.55
Mean Systems									
Pure		1.06	2.15	8.15	13.15	19.77	18.93	8.67	1.26
Intercropped		0.96	1.76	5.39	10.19	17.80	21.15	14.63	4.94
CD (P = 0.05) Cultivars (C)		0.11	0.23	0.86	1.31	2.41	2.50	1.48	NS
Systems (S)		NS	0.19	0.69	1.07	1.97	1.07	1.21	0.80
C x S		NS	NS	1.30	1.86	NS	NS	2.09	NS
CV (%)		13.8	12.9	13.1	12.4	11.9	13.6	13.8	14.4

Table 30. Leaf area duration (weeks) of three turmeric cultivars at different stages of growth under pure and intercropped stands during the year 1978

Cropping systems	Cultivars	Weeks after planting 2–5	5–8	8–11	11–14	14–18	18–22	22–26	26–30
Pure	C_1	0.93	1.63	5.54	11.00	17.88	19.18	7.94	1.49
	C_2	0.88	1.56	6.11	10.32	15.43	14.94	7.06	1.56
	C_3	1.23	2.50	10.76	15.62	19.79	19.35	8.26	1.56
Intercropped	C_1	0.76	1.27	3.17	8.47	12.69	14.15	13.49	4.87
	C_2	0.81	1.30	3.90	9.61	14.81	15.74	11.09	4.17
	C_3	1.05	1.79	5.84	11.21	20.05	25.16	16.89	5.97
Mean Cultivars									
C_1		0.85	1.45	4.35	9.74	15.28	16.67	10.72	3.18
C_2		0.84	1.43	5.01	9.97	15.12	15.34	9.08	2.87
C_3		1.14	2.14	8.30	13.42	19.92	22.26	12.57	3.77
Mean Systems									
Pure		1.01	1.90	7.47	12.31	17.70	17.82	7.75	1.54
Intercropped		0.87	1.45	4.30	9.77	15.85	18.35	13.82	5.00
CD (P = 0.05)									
Cultivars (C)		0.13	0.17	0.72	1.19	1.01	2.12	1.25	NS
Systems (S)		0.11	0.14	0.59	0.97	1.48	NS	1.02	0.89
C x S		NS	0.24	1.01	1.68	2.56	2.90	1.77	NS
CV (%)		15.3	11.0	12.5	11.9	11.7	12.3	12.5	26.2

Table 6a. Leaf area duration - cumulative (weeks) of three turmeric cultivars at different stages of growth under pure and intercropped stands during the year 1977

Cropping systems	Cultivars	Weeks after planting						
		8	11	14	18	22	26	30
Pure	C_1	3.37	11.48	25.28	48.73	70.97	81.77	86.95
	C_2	2.47	8.64	19.15	34.89	49.96	56.95	58.29
	C_3	3.79	13.96	29.10	49.21	68.69	76.89	78.15
Intercropped	C_1	3.05	9.07	18.43	36.53	58.48	74.13	78.97
	C_2	2.18	6.18	15.99	31.00	47.07	57.95	62.09
	C_3	2.93	8.91	20.32	40.60	66.02	83.37	89.22
Mean Cultivars								
C_1		3.21	10.27	21.86	42.63	64.72	77.95	82.96
C_2		2.33	7.41	17.57	32.95	48.52	57.45	60.19
C_3		3.36	11.44	24.71	44.91	67.36	80.13	83.69
Mean Systems								
Pure		3.21	11.36	24.51	44.28	63.21	71.87	74.46
Intercropped		2.72	8.05	18.25	36.04	57.19	71.82	76.76
CD (P = 0.05)								
Cultivars (C)		0.34	1.15	2.38	4.52	6.80	8.08	8.69
Systems (S)		0.28	0.94	1.95	3.69	5.55	NS	NS
C x S		NS	NS	NS	NS	NS	NS	NS
CV (%)		12.5	12.4	12.0	12.2	12.1	12.1	12.4

Table [illegible]. Leaf area duration - cumulative (weeks) of three turmeric cultivars at different stages of growth under pure and intercropped stands during the year 1978

Cropping systems	Cultivars	Weeks after planting						
		8	11	14	18	22	26	30
Pure	C_1	2.55	8.05	19.07	36.94	56.12	64.06	65.55
	C_2	2.44	8.55	18.87	34.30	49.24	56.30	57.86
	C_3	3.73	14.48	30.10	49.92	69.24	77.50	79.06
Intercropped	C_1	2.03	5.19	13.67	26.35	40.50	54.00	58.87
	C_2	2.11	6.01	15.62	30.32	46.06	57.15	61.32
	C_3	2.84	8.68	19.88	39.94	65.10	81.99	87.96
Mean Cultivars								
C_1		2.29	6.62	16.37	31.65	48.31	59.03	62.21
C_2		2.27	7.28	17.25	32.31	47.65	56.73	59.59
C_3		3.28	11.58	24.99	44.93	67.17	79.75	83.51
Mean Systems								
Pure		2.91	10.36	22.68	40.38	58.20	65.95	67.49
Intercropped		2.32	6.63	16.39	32.20	50.55	64.38	69.38
CD (P = 0.05) Cultivars (C)		0.29	0.95	1.99	3.53	5.20	6.12	6.46
System (S)		0.23	0.77	1.63	2.88	4.34	NS	NS
C x S		NS	1.34	2.82	NS	NS	NS	NS
CV (%)		11.8	11.6	11.0	10.5	10.3	10.1	10.1

Fig.4. Cumulative leaf area duration (LAD) in three turmeric cultivars under pure and intercropped stands.

●——● Cls. No.24 (1977)
●- - -● Cls. No.24 (1978)
×——× Cll.328 Sugandham (1977)
△——△ Duggirala (1977)

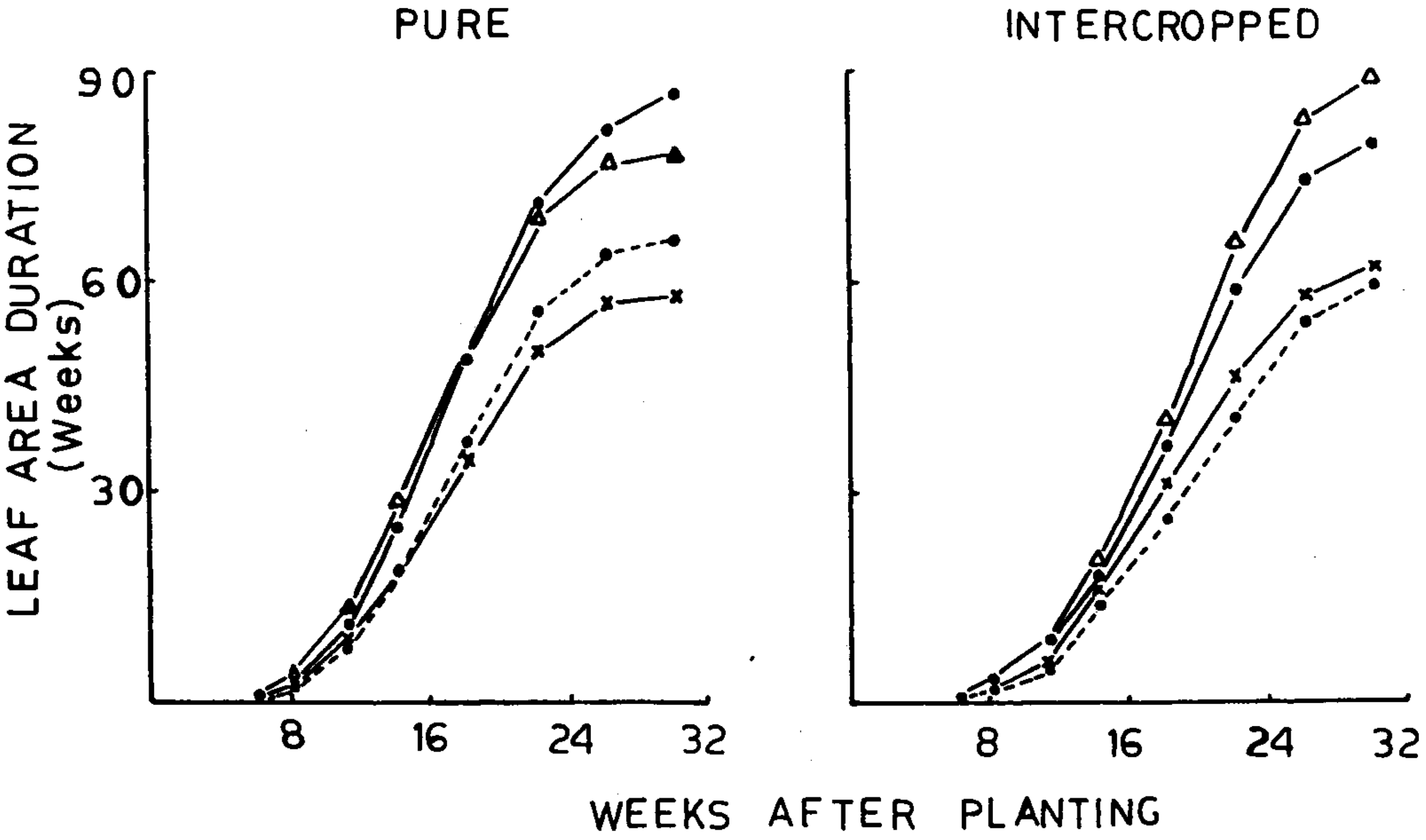

PURE
INTERCROPPED
LEAF AREA DURATION (Weeks)
90
60
30
8
16
24
32
8
16
24
32
WEEKS AFTER PLANTING

FIG.4

22nd weeks itself, whereas for the other two cultivars, this was seen beyond 22nd week only. The LAD values of the three cultivars during this period of leaf senescence were in the orders, $C_1 > C_3 > C_2$ and $C_3 > C_1 > C_2$ under pure and intercropped stands respectively.

The cumulative values of LAD were found to be significantly higher under the pure stand than under the intercropped stand upto 22nd week, but no significant differences was noticed for the total LAD values between the two cropping systems. Maximum values of the total LAD were recorded under the pure stand for the cultivar C_1 and under the intercropped stand for the other two cultivars. The total LAD for the three cultivars was in the orders, $C_1 > C_3 > C_2$ and $C_3 > C_1 > C_2$, under pure and intercropped stands respectively.

<u>II Year</u>. The LAD values calculated for different periods of sampling and the cumulative values for the year 1978 are presented in Tables 5b and 6b respectively. The cumulative increase in LAD for cultivar C_1 is depicted in Fig.4. The LAD of cultivar C_1 was considerably reduced in the second year as compared to the first year under both the cropping systems, while for the other two cultivars, such difference was not apparent. Eventhough there was no marked difference in

the total LAD of the cultivars C_2 and C_3 between the two years, a marked reduction was noticed for the cultivar C_1 in the second year as compared to the first year. The total LAD in the first year was about thirty per cent higher than in the second year for this cultivar under both the cropping systems.

In contrast to first year, cultivar C_3 had significantly higher LAD values than the other two cultivars upto 18th week, whereas after 18th week, cultivars C_1 and C_3 registered higher LAD values than those of C_2. In the second year, total LAD of cultivar C_3 was significantly higher than those of C_1 and C_2 under both the cropping systems.

2. Dry matter production

The dry matter production of three turmeric cultivars under the two cropping systems was studied adopting the technique of growth analysis. The seasonal pattern of dry matter accumulation in different plant parts was examined. Growth indices like crop growth rate, relative growth rate, and leaf area ratio and its components, specific leaf area and leaf weight ratio were computed.

2.1. Accumulation of dry matter

2.1.1. Shoot

<u>I Year</u>. The dry matter of the shoot at different periods during the cropping season in the year 1977 is presented in Table 7a and its pattern of accumulation is depicted in Fig.5. Cultivar C_1 attained the maximum shoot dry weight by 18th week under the pure stand, and at 22nd week under the intercropped stand. Beyond 22nd week, there was a reduction in shoot dry weight of this cultivar under the intercropped stand, although such reduction was not pronounced under the pure stand. For the cultivars C_2 and C_3, the shoot continued to accumulate dry matter upto 26th week under the intercropped stand. Under the pure stand,

Table 7a. Accumulation of dry matter in the shoot ($g\ m^{-2}$) of three turmeric cultivars at different stages of growth under pure and intercropped stands during the year 1977

Cropping systems	Cultivars	Weeks after planting								
		4	6	8	11	14	18	22	26	30
Pure	C_1	13.7	37.3	92.5	224.8	349.6	421.3	420.1	416.5	412.0
	C_2	13.0	28.9	54.0	162.9	268.6	326.3	301.2	285.1	283.5
	C_3	14.3	40.9	92.5	245.3	304.8	397.1	411.6	417.7	415.8
Intercropped	C_1	12.9	29.1	71.0	129.0	201.7	312.3	338.9	325.5	320.7
	C_2	10.5	22.7	33.0	93.4	242.0	254.3	260.6	263.5	263.7
	C_3	17.3	28.9	53.9	120.1	262.4	395.1	415.4	416.3	416.1
Mean										
Cultivars										
C_1		13.3	33.2	81.8	176.9	275.6	366.8	379.5	371.0	366.4
C_2		11.7	25.8	43.5	128.2	255.3	290.3	280.9	274.3	273.6
C_3		15.8	34.9	73.2	182.7	283.6	396.1	413.5	417.0	416.0
Mean										
Systems										
Pure		13.7	35.7	79.7	211.0	307.6	381.6	377.6	373.1	370.4
Intercropped		13.6	26.9	52.6	114.2	235.4	320.6	338.3	335.1	333.5
CD (P = 0.05)										
Cultivars (C)		3.0	4.5	9.2	22.4	NS	45.4	47.5	45.9	47.7
System (S)		NS	3.7	7.5	17.5	32.2	37.1	NS	37.5	NS
C x S		NS	NS	NS	NS	55.7	NS	NS	NS	NS
CV (%)		23.4	15.6	15.1	14.0	15.7	14.0	14.5	14.0	14.7

Table 7b. Accumulation of dry matter in the shoot ($g\ m^{-2}$) of three turmeric cultivars at different stages of growth under pure and intercropped stands during the year 1978

Cropping systems	Cultivars	Weeks after planting								
		4	6	8	11	14	18	22	26	30
Pure	C_1	14.1	28.1	47.1	154.3	248.0	357.6	340.5	336.8	332.4
	C_2	12.8	27.7	53.6	162.1	265.1	318.2	293.2	279.8	275.5
	C_3	15.1	39.7	91.1	244.4	301.5	389.0	405.6	409.6	407.8
Intercropped	C_1	11.8	22.2	36.2	69.1	175.6	204.9	236.2	257.3	259.9
	C_2	10.2	21.5	32.6	92.6	238.8	246.3	252.0	255.5	255.0
	C_3	16.2	27.6	52.5	119.3	259.1	389.8	407.3	408.3	406.5
Mean										
Cultivars										
C_1		13.0	25.2	41.7	111.7	211.8	281.2	288.4	297.1	296.2
C_2		11.5	24.6	43.1	127.4	252.0	282.3	272.6	267.6	265.2
C_3		15.7	33.7	71.8	181.9	280.3	389.4	406.5	408.9	407.1
Mean										
Systems										
Pure		14.0	31.8	63.9	186.9	271.6	355.0	346.4	342.1	338.6
Intercropped		12.7	23.8	40.4	93.6	224.5	280.3	298.5	307.0	307.1
CD (P = 0.05)										
Cultivars (C)		3.0	4.6	6.1	20.1	34.4	37.8	39.5	41.5	45.0
Systems (S)		NS	3.7	5.0	16.4	20.1	30.9	32.3	33.9	NS
C x S		NS	NS	8.6	NS	NS	53.5	55.9	NS	NS
CV (%)		23.7	17.3	12.5	15.2	15.0	13.0	13.4	13.9	15.1

Fig.5. Accumulation of dry matter in various plant parts of three turmeric cultivars under pure and intercropped stands.

A. Cls. No.24 (1977)

B. Cls. No.24 (1978)

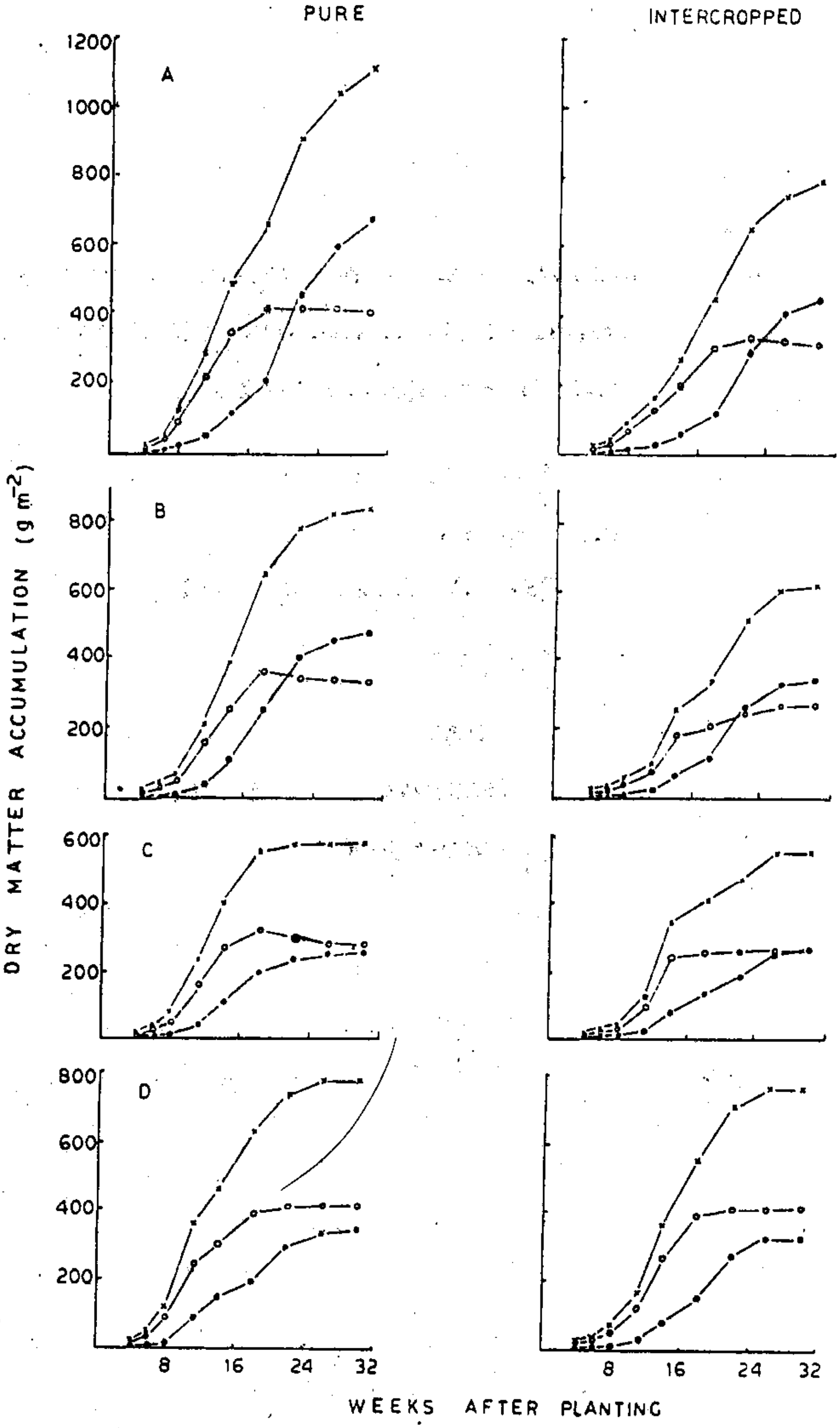
C. Cll.326 Sugandham (1977)

D. Duggirala (1977)

o——o Leaf

●——● Rhizome

×——× Whole plant



PURE
INTERCROPPED
A
B
C
D
1200
1000
800
600
400
200
DRY MATTER ACCUMULATION (g m^{-2})
8
16
24
32
WEEKS AFTER PLANTING

FIG. 5

a similar trend was noticed for the cultivar C_3, while for the cultivar C_2, there was a reduction in shoot dry weight beyond 18th week.

The shoot dry weight of the cultivars C_1 and C_3 was considerably higher than that of the cultivar C_2 throughout the growth cycle. Except at 14th week, the three cultivars showed similar response towards the two cropping systems, the monoculture cropping system accumulating significantly higher shoot dry matter than the intercropping system. In the 14th week, the shoot dry weight of the cultivar C_1 under the pure stand was significantly higher than that under the intercropped stand, but for the other two cultivars this difference was not significant. At maturity (30th week) the dry weight of the shoot for the three cultivars were in the order, $C_3 > C_1 > C_2$, the differences being significant. The dry matter accumulation in the shoot of the cultivar C_1 under the pure stand was remarkably higher than that under the intercropped stand, while this difference was not much pronounced for the other two cultivars.

II Year. The amount of dry matter accumulated in the shoot at different periods during the cropping season in the year 1978 is shown in Table 7b. The pattern of accumulation of shoot dry matter for the cultivar C_1 is depicted in Fig.5b. The cultivars C_2 and C_3 did not register any considerable difference in the amount of dry matter accumulated in the shoot as well as in the pattern of accumulation between the first and second years of planting. Dry matter accumulation in the shoot of the cultivar C_1 was remarkably reduced in the second year as compared to the first year under both the cropping systems. Under intercropping, in contrast to the first year, the shoot dry weight of the cultivar steadily increased upto 26th week and did not show any reduction at maturity. Under the monoculture, this cultivar registered a reduction in shoot dry weight beyond 18th week. Cultivar C_3 had significantly higher dry matter accumulation in the shoot throughout the growth period than the other two cultivars.

2.1.2. Rhizome

I Year. The extent of dry matter accumulation in the rhizome at different periods during the cropping season in 1977 is shown in Table 8a and its pattern of accumulation is depicted in Fig.5. The dry matter accumulation in the rhizome of the cultivar C_1 continued upto harvest especially under the pure stand, but for the other two cultivars, this was negligible beyond 26th week. The rhizome dry weight of the cultivars C_1 and C_3 was significantly higher than that of C_2 during most of the growth stages. In general, the dry matter accumulation in the rhizome of all the three cultivars was considerably higher under the pure stand than that under the intercropped stand.

Table 6a. Accumulation of dry matter in the rhizome (g m^{-2}) of three turmeric cultivars at different stages of growth under pure and intercropped stands during the year 1977

Cropping systems	Cultivars	Weeks after planting								
		4	6	8	11	14	17	20	23	26
Pure	C_1	2.9	7.8	15.3	51.1	135.3	209.7	401.3	601.2	677.9
	C_2	1.8	2.9	12.3	45.0	120.5	190.6	237.3	254.6	298.6
	C_3	2.3	6.1	18.8	88.4	125.4	196.6	295.7	331.8	343.8
Intercropped	C_1	2.6	6.7	11.8	26.7	58.1	122.7	235.7	411.2	449.9
	C_2	1.6	2.6	5.1	20.3	75.6	134.2	184.2	257.2	264.9
	C_3	2.1	3.7	9.1	29.1	81.4	148.9	270.1	321.6	327.4
Mean Cultivars										
C_1		2.8	7.3	13.6	38.9	96.7	166.2	317.5	506.2	563.9
C_2		1.7	2.8	8.7	32.7	98.0	162.4	210.7	255.9	281.8
C_3		2.2	4.9	14.0	58.8	103.4	172.7	282.9	326.7	335.6
Mean Systems										
Pure		2.4	5.6	15.5	61.5	127.1	201.3	311.4	395.9	436.8
Intercropped		2.1	4.3	8.7	25.4	71.7	135.6	230.0	330.0	347.4
CD (P = 0.05)										
Cultivars (C)		0.5	1.2	2.3	9.3	NS	NS	27.1	31.6	35.4
Systems (S)		NS	1.0	2.9	7.6	11.3	18.1	22.1	25.8	28.9
C x S		NS	NS	3.2	13.2	NS	NS	38.3	44.7	50.0
CV (%)		34.7	25.3	20.3	22.3	16.2	14.3	10.0	9.4	9.9

Table [illegible]. Accumulation of dry matter in the rhizome (g m^{-2}) of three turmeric cultivars at different stages of growth under pure and intercropped stands during the year 1978

Cropping systems	Cultivars	Weeks after planting								
		4	6	8	11	14	18	22	26	30
Pure	C_1	1.7	4.3	9.0	39.6	109.7	254.2	400.0	453.7	473.3
	C_2	1.7	2.8	14.1	44.6	109.7	194.5	231.6	249.0	253.0
	C_3	2.1	5.9	18.6	88.0	124.6	191.6	290.1	326.2	338.2
Intercropped	C_1	1.5	3.4	5.5	16.5	60.4	109.8	250.8	314.9	324.4
	C_2	1.7	2.4	4.8	19.9	74.8	130.1	170.6	251.5	259.2
	C_3	2.0	3.6	8.9	28.9	80.6	145.9	264.5	313.3	319.7
Mean Cultivars										
C_1		1.6	3.9	7.3	28.0	85.1	182.0	325.4	384.3	398.9
C_2		1.7	2.6	9.5	32.3	92.2	162.3	201.1	250.3	256.1
C_3		2.0	4.7	13.7	58.4	102.6	168.7	277.3	319.7	329.0
Mean Systems										
Pure		1.8	4.3	13.9	57.4	114.7	213.5	307.2	343.0	354.8
Intercropped		1.7	3.1	6.4	21.7	71.9	128.6	221.3	293.2	301.1
CD (P = 0.05)										
Cultivars (C)		NS	1.1	2.0	9.8	NS	NS	30.9	25.4	33.5
Systems (S)		NS	0.9	1.6	8.0	9.3	26.0	17.1	20.8	27.4
C x S		NS	NS	2.8	13.9	NS	27.7	29.6	36.0	47.4
CV (%)		27.4	30.9	30.8	25.9	13.3	12.4	8.3	6.6	11.2

The cultivar C_3 recorded significantly higher rhizome dry weight than the other two cultivars, viz., C_1 and C_2 during the period of 8th to 11th week after planting. In the subsequent periods of 14th and 18th weeks after planting there was no significant difference among the cultivars. But beyond 18th week, when the accumulation of dry matter in the shoot declined and that in the rhizome increased, the difference among the cultivars was again pronounced. By 26th week and at maturity, the dry matter accumulated in the rhizome for the three cultivars under both the cropping systems was in the orders, $C_1 > C_3 > C_2$ with significant differences.

II Year. The amount of dry matter accumulated in the rhizome at different stages during the cropping season in 1978 is shown in Table 8b. The pattern of accumulation of rhizome dry matter for the cultivar C_1 is depicted in Fig.8b. The cultivars C_2 and C_3 did not register any remarkable difference in the amount of rhizome dry matter produced as well as in its pattern of accumulation between first and second years of planting. Upto 11th week after planting, the cultivar C_1 recorded lesser amount of rhizome dry weight in the second year than in the first year under both the cropping systems. By 14th and 18th weeks, the intercropped stand of this cultivar did not show much difference in the rhizome dry weight between the two years of study, while the pure stand registered a marked increase during the second year. Beyond 18th week, the accumulation of dry matter in the rhizomes of the cultivar C_1 was considerably reduced in the second year under both the cropping systems.

Under the intercropping system, unlike in the first year, there was no significant difference between the cultivars C_1 and C_3 for the rhizome dry weight at maturity, eventhough these two had significantly higher dry weight in rhizome than the cultivar C_2. Under the monoculture, cultivar C_1 still maintained significantly higher rhizome dry weight than the other two cultivars.

2.1.3. Whole plant

I Year. The dry matter accumulation in the whole plant during the cropping season in the year 1977 is shown in Table 9a and its pattern of accumulation is depicted in Fig.5. Upto 18th week after planting, the trend in the changes of the whole plant dry weight followed the same pattern as that of the shoot dry weight. Beyond the 18th week the curve of the dry matter accumulation in the whole plant resembled that of the rhizome dry weight.

Under the monoculture, the dry matter accumulation for the cultivar C_2 was negligible beyond the 18th week, eventhough the rhizome dry weight increased. The total amount of dry matter produced by the cultivar C_1 under the pure stand was significantly higher than that produced

Table 9a. Accumulation of dry matter in the whole plant* (g m⁻²) of three turmeric cultivars at different stages of growth under pure and intercropped stands during the year 1977

Cropping systems	Cultivars	Weeks after planting								
		4	6	8	11	14	18	22	26	30
Pure	C_1	17.8	48.6	116.0	222.9	490.0	659.4	910.2	1046.3	1118.1
	C_2	16.1	35.4	74.0	224.7	402.8	559.5	574.3	573.8	573.9
	C_3	18.3	52.2	117.6	256.1	461.6	638.3	748.7	786.2	790.2
Intercropped	C_1	16.8	38.4	88.6	154.1	274.4	452.5	652.4	753.4	787.5
	C_2	13.4	27.9	43.1	134.5	339.7	410.9	472.1	550.7	550.5
	C_3	21.2	34.2	69.1	160.5	364.6	558.3	712.8	770.2	770.9
Mean										
Cultivars										
C_1		17.3	43.5	102.3	188.5	382.2	556.0	781.3	899.8	952.8
C_2		14.7	31.6	58.6	179.6	371.2	485.2	523.2	562.3	562.2
C_3		19.8	43.2	93.4	208.3	413.1	598.3	730.8	778.2	778.7
Mean										
Systems										
Pure		17.4	45.4	102.6	234.6	451.5	619.1	744.4	802.1	827.4
Intercropped		17.1	33.5	66.9	149.7	326.2	473.9	612.4	691.5	703.0
CD (P = 0.05)										
Cultivars (C)		3.6	5.9	11.6	32.1	NS	62.8	68.2	76.9	79.5
Systems (S)		NS	4.8	9.5	26.2	40.1	51.2	55.7	62.8	64.9
C x S		NS	NS	NS	NS	69.4	NS	96.4	108.8	112.4
CV (%)		22.4	16.2	14.9	15.3	13.7	12.4	10.9	11.2	11.3

* Includes dry weight of root also.

Table 9b. Accumulation of dry matter in the whole plant* (g m^{-2}) of three turmeric cultivars at different stages of growth under pure and intercropped stands during the year 1978

Cropping systems	Cultivars	Weeks after planting								
		4	6	8	11	14	18	22	26	30
Pure	C_1	17.6	36.8	62.2	207.9	381.0	644.6	778.8	820.0	834.7
	C_2	15.8	35.1	73.3	227.5	398.8	547.4	560.6	554.9	554.6
	C_3	19.0	51.9	117.0	354.8	457.5	626.2	734.8	772.5	776.5
Intercropped	C_1	14.8	28.3	46.1	93.7	282.0	330.8	509.8	597.8	607.8
	C_2	13.3	27.6	42.5	123.3	335.6	398.7	454.0	537.0	537.9
	C_3	19.9	33.9	68.6	159.3	360.0	548.9	699.1	756.5	754.9
Mean										
Cultivars										
C_1		16.2	32.6	54.1	150.8	326.5	487.7	644.3	708.9	721.2
C_2		14.5	31.3	57.9	175.4	367.2	473.0	507.3	546.0	546.3
C_3		19.0	42.9	92.8	257.1	408.1	587.5	724.5	764.5	765.7
Mean										
Systems										
Pure		17.5	41.3	84.2	263.4	409.8	606.0	691.4	715.8	721.9
Intercropped		16.0	29.9	52.4	125.4	315.9	426.1	554.3	630.4	633.5
CD (P = 0.05)										
Cultivars (C)		3.7	5.9	8.0	28.3	39.6	48.8	55.1	66.7	72.1
Systems (S)		NS	4.8	6.5	23.3	32.3	39.8	44.9	54.4	58.8
C x S		NS	NS	11.3	40.3	NS	69.0	77.9	94.3	101.9
CV (%)		23.4	18.0	12.6	15.5	11.7	10.3	9.6	10.7	11.5

* Includes dry weight of root also.

under the intercropped stand, while for the other two cultivars this difference was not significant. Under the monoculture, the dry matter accumulation at maturity for the three cultivars was in the order, $C_1 > C_3 > C_2$, with significant differences. Under the intercropping system, the dry matter accumulation of the cultivars C_1 and C_3 was significantly higher than that in cultivar C_2; there was no significant difference between the former two cultivars.

<u>II Year</u>. The dry matter accumulation in the whole plant during the cropping season in the year 1978 is shown in Table 9b. The pattern of dry matter accumulation for the cultivar C_1 is depicted in Fig.5b. The cultivars C_2 and C_3 did not register any significant difference in the extent of dry matter accumulation between first and second years of planting, whereas in case of cultivar C_1, the dry matter of the whole plant in the second year was considerably less than that in the first year under both the cropping systems. As in the case of first year, the pattern of changes in dry weight of whole plant was same as that of the shoot upto 18th week, beyond which the total dry weight closely followed the same trend as that of the rhizome.

Under the monoculture, unlike in the first year, there was no significant difference between the cultivars C_1 and C_3 for the total dry matter accumulation, although the dry weight of C_1 or C_3 was significantly higher than that of C_2. Under the intercropping system, the total dry matter accumulation for the three cultivars was in the order, $C_3 > C_1 > C_2$, the differences being significant.

2.2. Crop growth rate, relative growth rate and leaf area ratio

2.2.1. Crop growth rate (Whole plant)

<u>I Year</u>. The crop growth rate (CGR) at different periods during the cropping season in the year 1977 is shown in Table 10a and its trend of changes is depicted in Fig.6a. Under the monoculture, cultivar C_1 attained the maximum CGR during the period of 11th to 14th week and decreased between 14th and 18th week. This was followed by a further remarkable increase during 18th to 22nd week before falling again in the subsequent periods. Under intercropping, this cultivar showed a continued increase in CGR upto 22nd week and a decrease thereafter. Cultivar C_2 attained the maximum CGR during the period of 11th to 14th week under both the cropping systems. However, under intercropping, the CGR of this cultivar continued to be high upto 26th week, while under pure stand this was negligible beyond 18th week. Under the monoculture, CGR of cultivar C_3 reached the maximum during the period of 8th to 11th week itself and decreased between 11th and 14th week, followed by a further rise during 14th to 18th week. Under intercropping, this cultivar attained the maximum CGR between the period of 11th and 14th week and exhibited a decrease thereafter.

Table 10a. Crop growth rate (g m^{-2} week^{-1}) of three turmeric cultivars at different stages of growth under pure and intercropped stands during the year 1977

Cropping Systems	Cultivars	Weeks after planting						
		2-5	5-8	8-11	11-14	14-18	18-22	22-26
Pure	C_1	15.41	15.69	58.96	65.70	42.36	62.71	34.01
	C_2	9.65	18.69	46.18	56.10	40.56	5.29	0.00
	C_3	16.15	32.21	72.48	35.17	45.31	26.64	9.38
Intercropped	C_1	10.81	25.09	25.18	36.77	44.45	49.98	25.25
	C_2	7.27	7.63	27.11	62.74	18.45	14.31	19.66
	C_3	6.53	17.44	30.48	62.01	50.20	38.63	13.88
Mean								
Cultivars								
C_1		13.11	20.39	42.06	51.23	43.41	56.34	29.63
C_2		8.46	13.16	36.65	59.42	29.50	9.80	9.83
C_3		11.34	24.83	51.48	48.59	47.76	32.63	11.63
Mean								
Systems								
Pure		13.74	22.20	59.21	52.32	42.74	31.55	14.46
Intercropped		8.20	16.72	27.59	53.84	37.70	34.64	19.60
CD (P = 0.05)								
Cultivars (C)		1.74	4.40	6.62	NS	7.90	7.12	5.38
Systems (S)		1.42	3.59	5.41	NS	NS	NS	4.40
C x S		2.46	NS	NS	15.69	11.17	10.07	7.61
CV (%)		17.2	21.0	16.5	22.9	21.1	24.0	34.0

Table [illegible]. Crop growth rate (g m^{-2} week^{-1}) of three turmeric cultivars at different stages of growth under pure and intercropped stands during the year 1978

Cropping systems	Cultivars	Weeks after planting						
		4-6	6-8	8-11	11-14	14-18	18-22	22-26
Pure	C_1	9.65	12.17	44.82	53.11	68.80	33.24	9.50
	C_2	9.57	19.14	45.52	55.02	38.46	4.46	1.16
	C_3	16.95	32.55	71.32	34.23	43.26	26.26	9.43
Intercropped	C_1	6.79	9.04	17.29	46.36	22.26	50.32	22.19
	C_2	7.16	7.47	26.91	61.92	16.33	13.82	20.07
	C_3	6.84	17.37	30.23	61.16	48.82	37.55	13.88
Mean								
Cultivars								
C_1		8.22	10.61	31.06	49.73	45.53	41.78	15.85
C_2		8.37	13.30	36.22	58.47	27.40	9.14	10.62
C_3		11.90	24.96	50.77	47.70	46.04	31.90	11.66
Mean								
Systems								
Pure		12.06	21.28	53.89	47.45	50.17	21.32	6.70
Intercropped		6.93	11.30	24.81	56.48	29.14	33.90	18.71
CD (P = 0.05)								
Cultivars (C)		1.78	2.75	6.96	9.87	6.46	9.28	NS
Systems (S)		1.45	2.25	5.68	8.06	5.27	7.58	4.60
C x S		2.51	3.89	9.85	13.96	9.13	NS	NS
CV (%)		20.8	18.3	19.1	20.8	17.7	37.3	48.7

Fig.6. Crop growth rate (CGR) of shoot, rhizome and whole plant at different stages of growth in three turmeric cultivars under pure and intercropped stands.

A. CGR - Whole plant

B. CGR - Shoot

C. CGR - Rhizome

●——● Cls. No.24 (1977)

●----● Cls. No.24 (1978)

×——× Cll.328 Sugandham (1977)

△——△ Duggirala (1977)

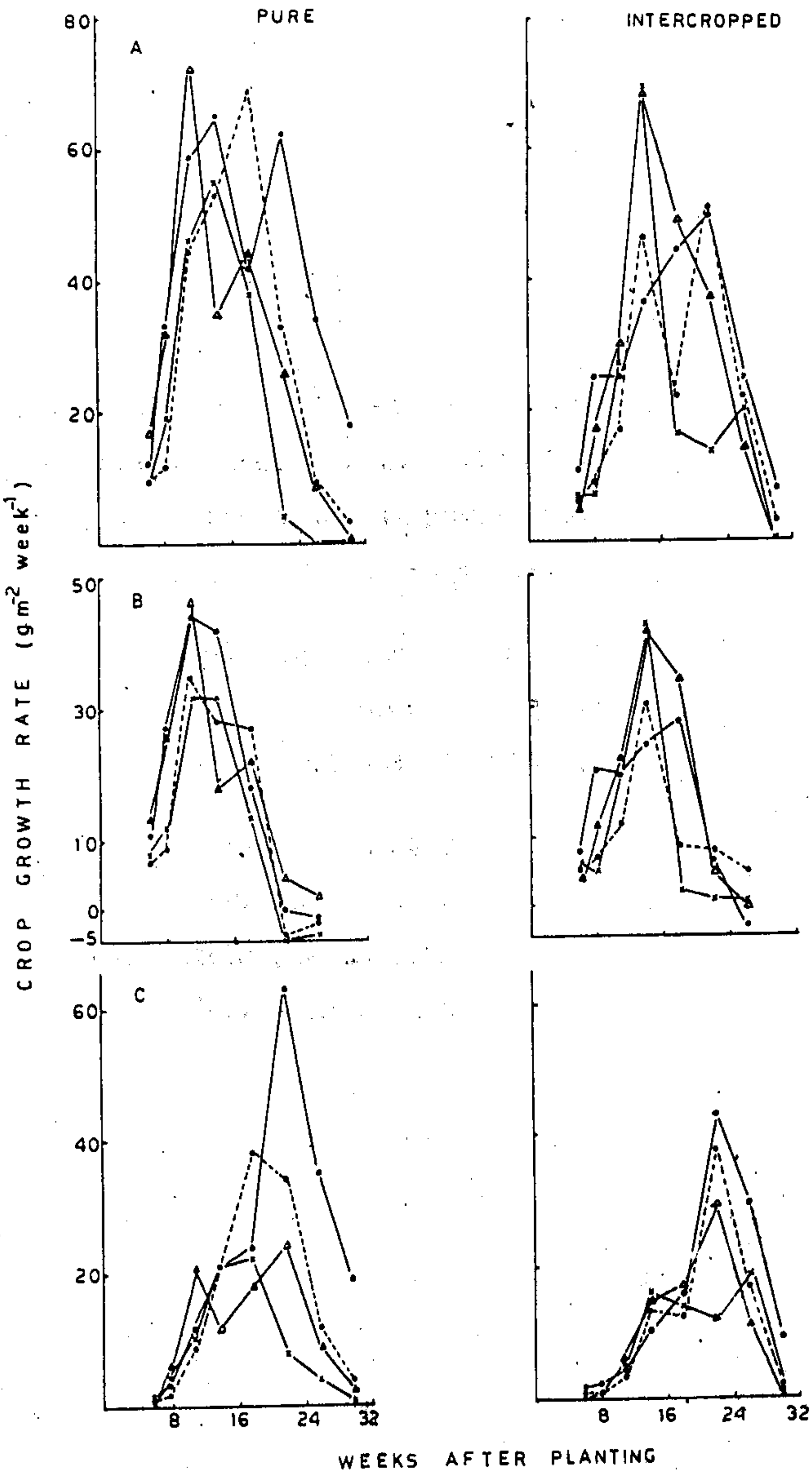

PURE
INTERCROPPED
A
B
C
80
60
40
20
50
30
10
0
-5
60
40
20
CROP GROWTH RATE (g m^{-2} week^{-1})
8
16
24
32
8
16
24
32
WEEKS AFTER PLANTING

FIG. 6

The maximum CGR attained by the cultivar C_1 under the pure stand was considerably higher than that attained under the intercropped stand, while for the other two cultivars there was no marked difference. Under the monoculture, the highest CGR was recorded by the cultivar C_3 followed by C_1 and C_2 in that order. Under intercropping, the maximum CGR attained by the cultivars C_2 and C_3 were considerably higher than that attained by C_1. The CGR values of cultivars C_1 and C_3 were remarkably higher than that of C_2 during most of the growth periods. During the period of 18th to 22nd week, when the accumulation of dry matter in the shoot declines, the CGR for the three cultivars under both the cropping systems were in the orders, $C_1 > C_3 > C_2$ with significant differences. Cultivar C_1 maintained significantly higher CGR values than the other two cultivars during the period of 22nd to 26th week also. Beyond 18th week, the CGR of the cultivar C_1 was under the pure stand was significantly higher than that under the intercropped stand, whereas for the other two cultivars, it was higher under the intercropped stand.

II Year. The crop growth rate at different periods during the cropping season in the year 1978 is presented in the Table 10b. The trend of changes in the CGR of the cultivar C_1 during this year is depicted in Fig.6a. The trend in CGR in the two years was similar for cultivars C_2 and C_3.

Under the monoculture, unlike in first year, the attainment of maximum CGR for the cultivar C_1 was delayed upto the period of 14th to 18th week and decreased thereafter. Under the intercropping, the CGR of this cultivar increased upto 14th week. A further rise in CGR occurred between 18th and 22nd week.

Upto 11th week after planting, the CGR of this cultivar during second year was less than that in first year under both the cropping systems. However, the CGR recorded by this cultivar in the second year was comparitively higher than that in its first year during the periods of 14th to 18th week under the pure stand and 11th to 14th week under intercropped stand. Beyond 18th week, under the monoculture system, CGR values of the cultivar C_1 were considerably reduced in the second year as compared to the first year, although such reduction was not pronounced under the intercropping system. During this period, unlike in first year, the cultivar C_1 registered higher CGR under the intercropped stand than under the pure stand. The CGR of the three cultivars during the period of 18th to 22nd week was in the order, $C_1 > C_3 > C_2$ with significant differences. But during the period of 22nd to 26th week, unlike in first year, the higher CGR of cultivar C_1 than those of the other two cultivars was not significant enough.

3.2.1.1. Crop growth rate (Shoot)

I Year. The shoot growth rate (SGR) at different periods during the cropping season in the year 1977 is presented in Table 11a and its trend of changes is depicted in Fig.6b. Under the monoculture, all the three cultivars attained the maximum SGR between 8th and 11th week. Under the intercropping, the attainment of the maximum SGR was in the period of 11th to 14th week for the cultivars C_2 and C_3 or between 14th and 18th week for the cultivar C_1. The values of SGR were positive upto 22nd week for all the cultivars under the intercropped stand. Under the monoculture, the SGR of the cultivars C_1 and C_2 were either ceased or became negative beyond 18th week, while that of the cultivar C_3 continued to be positive upto 26th week.

The maximum SGR attained by the cultivar C_1 under the pure stand was considerably higher than that under the intercropped stand, whereas this difference was not marked for the other two cultivars. Under the monoculture, the maximum values of SGR reached by cultivars C_1 and C_3 were significantly higher than that by the cultivar C_2, while under the intercropping, the values for the cultivars C_2 and C_3 were considerably higher than that for C_1. From 14th week onwards, the SGR of cultivar C_3 was the highest followed by C_1 and C_2 under both the cropping systems.

Table [illegible]. Shoot growth rate (g m^{-2} week^{-1}) of three turmeric cultivars at different stages of growth under pure and intercropped stands during the year 1977

Cropping systems	Cultivars	Weeks after planting					
		4-6	6-8	8-11	11-14	14-18	18-22
Pure	C_1	11.83	27.60	44.09	41.58	17.95	0.00
	C_2	7.94	12.59	32.51	33.34	14.94	-5.49
	C_3	13.31	25.76	47.45	19.94	23.91	4.00
Intercropped	C_1	8.09	20.94	19.33	24.24	27.66	6.65
	C_2	6.36	4.88	20.11	43.35	3.32	1.59
	C_3	5.83	13.16	22.55	43.22	34.36	5.63
Mean Cultivars							
C_1		9.96	24.27	31.71	32.91	22.81	3.32
C_2		7.15	8.74	26.31	38.35	9.13	-1.95
C_3		9.57	19.46	35.00	31.58	29.13	4.82
Mean Systems							
Pure		11.03	21.98	41.35	31.62	18.93	-0.50
Intercropped		6.76	12.99	20.66	36.94	21.78	4.62
CD (P = 0.05)							
Cultivars (C)		1.32	3.47	4.58	NS	5.06	3.52
Systems (S)		1.08	2.83	3.74	NS	NS	NS
C x S		1.87	NS	6.48	13.36	8.29	NS
CV (%)		16.5	21.6	16.2	30.0	31.2	117.8

Table 11b. Shoot growth rate (g m^{-2} $week^{-1}$) of three turmeric cultivars at different stages of growth under pure and intercropped stands during the year 1978

Cropping systems	Cultivars	Weeks after planting					
		4-6	6-8	8-11	11-14	14-18	18-22
Pure	C_1	7.01	9.00	35.01	28.41	27.40	-3.99
	C_2	7.94	12.47	31.09	32.43	13.69	-5.47
	C_3	13.22	26.49	46.28	18.21	21.65	4.81
Intercropped	C_1	5.20	6.97	12.11	30.44	6.67	7.80
	C_2	6.15	5.06	19.96	42.67	2.14	1.44
	C_3	6.03	12.45	21.92	42.48	33.78	4.96
Mean Cultivars							
C_1		6.10	7.99	23.56	29.43	17.04	1.91
C_2		7.04	8.77	25.53	37.55	7.92	-2.02
C_3		9.63	19.47	34.10	30.35	27.72	4.89
Mean Systems							
Pure		9.39	15.99	37.46	26.35	20.91	-1.55
Intercropped		5.79	8.16	18.00	38.53	14.20	4.73
CD (P = 0.05) Cultivars (C)		1.37	1.94	4.57	NS	3.92	4.22
Systems (S)		1.12	1.59	3.73	7.29	3.20	3.45
C x S		1.93	2.75	6.46	NS	5.54	5.97
CV (%)		20.1	17.6	17.0	29.0	23.6	119.3

The SGR followed more or less the same trend of changes as that of CGR upto 18th week after planting. In the case of cultivars C_2 and C_3, the periods of maximum SGR coincided with those of maximum CGR, while for the cultivar C_1, the period of maximum CGR followed that of maximum SGR.

II Year. The shoot growth rate at different periods during the cropping season in the year 1978 is presented in Table 11b. The trend of changes in the SGR of the cultivar C_1 during this year is depicted in Fig.6b. The values and trend of SGR were similar in both the years for cultivars C_2 and C_3. In the second year, the intercropped stand of the cultivar C_1 attained the maximum SGR comparatively early, i.e. during the period of 11th to 14th week, beyond which the values were considerably reduced. Under the monoculture, the reduction in SGR of this cultivar was postponed to beyond 18th week in the second year, while the decrease was noticed by 14th week itself in the first year. Shoot growth rate followed the same pattern as that of CGR upto 18th week after planting. The SGR of cultivar C_1 was considerably reduced in the second year as compared to the first year through most of the growth periods except during 14th to 18th week under pure stand and 11th to 14th week under the intercropped stand.

2.2.1.2. Crop growth rate (Rhizome)

I Year. The rhizome growth rate (RhGR) for different periods during the cropping season in the year 1977 is presented in Table 12a and its trend of changes is depicted in Fig.6a. Under the monoculture, all cultivars registered a marked increase in RhGR during the period of 8th to 11th week following the initiation of fingers, but under the intercropping, such an increase was delayed upto the period of 11th to 14th week. For the cultivar C_1, a further remarkable increase in RhGR during 18th to 22nd week under both the cropping systems resulted in its attaining maximum values, the values however, fell in subsequent periods. The RhGR of the cultivar C_2 under the pure stand increased upto the 18th week and decreased considerably after that. Under the intercropping, the RhGR of this cultivar which rose upto the 14th week, did not show much reduction upto 26th week after planting. Pure stand of the cultivar C_3 showed a steady rise in RhGR upto the 11th week which decreased thereafter. The maximum RhGR for the intercropped stand of this cultivar was during the period of 18th to 22nd week.

The highest RhGR was of cultivar C_1 followed by C_3 and C_2 in that order under both the cropping systems. The maximum RhGR attained by the cultivar C_1 under the pure stand was considerably higher than that under the intercropped stand, while there was no such difference for the other two cultivars. Upto 8th week after planting,

Table 12a. Rhizome growth rate (g m^{-2} week^{-1}) of three turmeric cultivars at different stages of growth under pure and intercropped stands during the year 1977

Cropping systems	Cultivars	Weeks after planting						
		4-6	6-8	8-11	11-14	14-18	18-22	22-26
Pure	C_1	2.44	3.76	11.92	21.39	23.61	62.89	34.99
	C_2	0.65	3.99	10.67	21.60	22.81	8.47	3.86
	C_3	1.70	5.87	21.15	12.33	18.00	24.45	9.03
Intercropped	C_1	2.07	2.57	4.94	10.49	16.14	43.25	28.87
	C_2	0.47	1.25	5.07	16.13	15.17	12.82	18.72
	C_3	0.80	2.70	6.71	15.85	17.74	30.06	12.43
Mean								
Cultivars								
C_1		2.25	3.17	8.43	15.94	19.87	53.07	31.93
C_2		0.56	2.62	7.87	18.86	18.99	10.65	11.29
C_3		1.25	4.29	13.93	14.09	17.87	27.26	10.73
Mean								
Systems								
Pure		1.60	4.54	14.58	18.44	21.47	31.94	15.96
Intercropped		1.11	2.18	5.57	14.16	16.35	28.71	20.01
CD (P = 0.05)								
Cultivars (C)		0.39	0.80	2.52	3.37	NS	5.30	3.87
Systems (S)		0.32	0.72	2.06	2.75	3.39	NS	3.16
C x S		0.55	1.25	3.57	4.76	NS	7.50	5.47
CV (%)		30.9	27.0	27.1	23.1	23.3	19.0	24.2

Table 12b. Rhizome growth rate (g m^{-2} $week^{-1}$) of three turmeric cultivars at different stages of growth under pure and intercropped stands during the year 1978

Cropping systems	Cultivars	Weeks after planting						
		4-6	6-8	8-11	11-14	14-18	18-22	22-26
Pure	C_1	1.32	2.32	9.31	21.09	37.78	34.01	12.28
	C_2	0.55	4.66	10.13	21.44	21.96	8.12	4.26
	C_3	1.90	6.33	20.10	12.20	17.18	23.61	8.60
Intercropped	C_1	0.96	1.12	3.90	13.65	12.74	37.77	16.93
	C_2	0.36	1.21	5.01	17.01	14.34	12.11	17.63
	C_3	0.80	2.67	7.16	15.73	16.92	29.65	11.79
Mean								
Cultivars								
C_1		1.14	1.72	6.61	17.37	25.26	35.89	14.61
C_2		0.45	2.94	7.57	19.23	18.15	10.12	10.94
C_3		1.35	4.50	13.63	13.97	17.05	26.63	10.20
Mean								
Systems								
Pure		1.25	4.44	13.18	18.24	25.64	21.91	8.38
Intercropped		0.71	1.67	5.36	15.46	14.67	26.51	15.45
CD (P = 0.05)								
Cultivars (C)		0.39	0.77	2.72	2.91	4.48	5.83	NS
Systems (S)		0.32	0.63	2.22	NS	3.66	NS	3.13
C x S		NS	1.10	3.85	4.12	6.34	NS	NS
CV (%)		43.0	27.5	31.2	19.9	23.7	26.0	36.4

cultivar C_1 and C_3 recorded higher RhGR than the cultivar C_2. The cultivars did not differ markedly in their RhGR values during the period of 8th to 18th week. The changes in RhGR beyond 18th week followed the same pattern as that of CGR.

II Year. The rhizome growth rate for different periods during the cropping season in the year 1978 is presented in the Table 12b. The trend of the RhGR during this year illustrated in Fig.6a is only of cultivar C_1 because the pattern of RhGR was similar in both the years for the other two cultivars. Under the monoculture, the maximum RhGR was attained by the cultivar C_1 comparitively early in this year, i.e. during the period of 14th to 18th week after planting. Unlike in first year, the RhGR of this cultivar under the monoculture system did not show any increase during the period of 18th to 22nd week. The maximum RhGR of this cultivar during second year was considerably less than that in the first year, particularly under the monoculture system. Such reduction in RhGR was more pronounced beyond 18th week. In spite of this reduction, the maximum RhGR attained by this cultivar was still higher than those by the other two cultivars under both the cropping systems.

3.2.2. Relative growth rate

I Year. The relative growth rate (RGR) at different periods during the cropping season in the year 1977 is shown in Table 13a and its trend of changes is illustrated in Fig.7a.

Table 11a. Relative growth rate (g g^{-1} $week^{-1}$) of three turmeric cultivars at different stages of growth under pure and intercropped stands during the year 1977

Cropping systems	Cultivars	Weeks after planting 4–6	6–8	8–11	11–14	14–18	18–22	22–26
Pure	C_1	0.502	0.432	0.311	0.170	0.074	0.082	0.035
	C_2	0.400	0.366	0.313	0.175	0.086	0.025	0.000
	C_3	0.534	0.414	0.336	0.092	0.084	0.038	0.012
Intercropped	C_1	0.414	0.411	0.208	0.168	0.127	0.093	0.036
	C_2	0.372	0.227	0.351	0.292	0.050	0.035	0.039
	C_3	0.204	0.354	0.292	0.248	0.111	0.061	0.019
Mean								
Cultivars								
C_1		0.458	0.421	0.260	0.169	0.100	0.087	0.036
C_2		0.386	0.296	0.332	0.234	0.068	0.030	0.019
C_3		0.369	0.384	0.314	0.170	0.098	0.049	0.016
Mean								
Systems								
Pure		0.479	0.404	0.320	0.146	0.081	0.048	0.016
Intercropped		0.330	0.331	0.284	0.236	0.096	0.063	0.031
CD (P = 0.05)								
Cultivars (C)		0.056	0.056	0.025	0.031	0.025	0.011	0.008
Systems (S)		0.046	0.046	0.021	0.025	0.013	0.009	0.006
C x S		0.080	NS	0.035	0.044	0.022	NS	0.011
CV (%)		15.9	16.6	9.0	17.7	18.6	24.3	24.9

Table 13b. Relative growth rate (g g^{-1} $week^{-1}$) of three turmeric cultivars at different stages of growth under pure and intercropped stands during the year 1978

Cropping systems	Cultivars	Weeks after planting						
		4-6	6-8	8-11	11-14	14-18	18-22	22-26
Pure	C_1	0.371	0.248	0.378	0.182	0.136	0.049	0.013
	C_2	0.406	0.366	0.318	0.173	0.083	0.005	0.002
	C_3	0.542	0.415	0.340	0.085	0.082	0.038	0.015
Intercropped	C_1	0.323	0.250	0.262	0.290	0.076	0.123	0.041
	C_2	0.371	0.226	0.353	0.291	0.045	0.033	0.041
	C_3	0.204	0.356	0.282	0.246	0.110	0.060	0.019
Mean								
Cultivars								
C_1		0.347	0.249	0.320	0.236	0.106	0.086	0.027
C_2		0.388	0.296	0.336	0.232	0.064	0.019	0.023
C_3		0.373	0.385	0.311	0.166	0.096	0.049	0.017
Mean								
Systems								
Pure		0.439	0.343	0.345	0.147	0.100	0.031	0.010
Intercropped		0.300	0.277	0.299	0.276	0.077	0.072	0.034
CD (P = 0.05)								
Cultivars (C)		NS	0.026	NS	0.034	0.015	0.019	NS
Systems (S)		0.040	0.048	0.025	0.020	0.012	0.016	0.007
C x S		0.034	NS	0.044	NS	0.022	0.027	0.012
CV (%)		17.5	20.4	10.5	17.7	18.8	40.7	42.3

Fig.7. Relative growth rate (RGR) of rhizome, shoot and whole plant at different stages of growth in three turmeric cultivars under pure and intercropped stands.

A. RGR - Whole plant

B. RGR - Shoot

C. RGR - Rhizome

●——● Cls. No.24 (1977)

●- - -● Cls. No.24 (1978)

×——× Cll.328 Sugandham (1977)

△——△ Duggirala (1977)

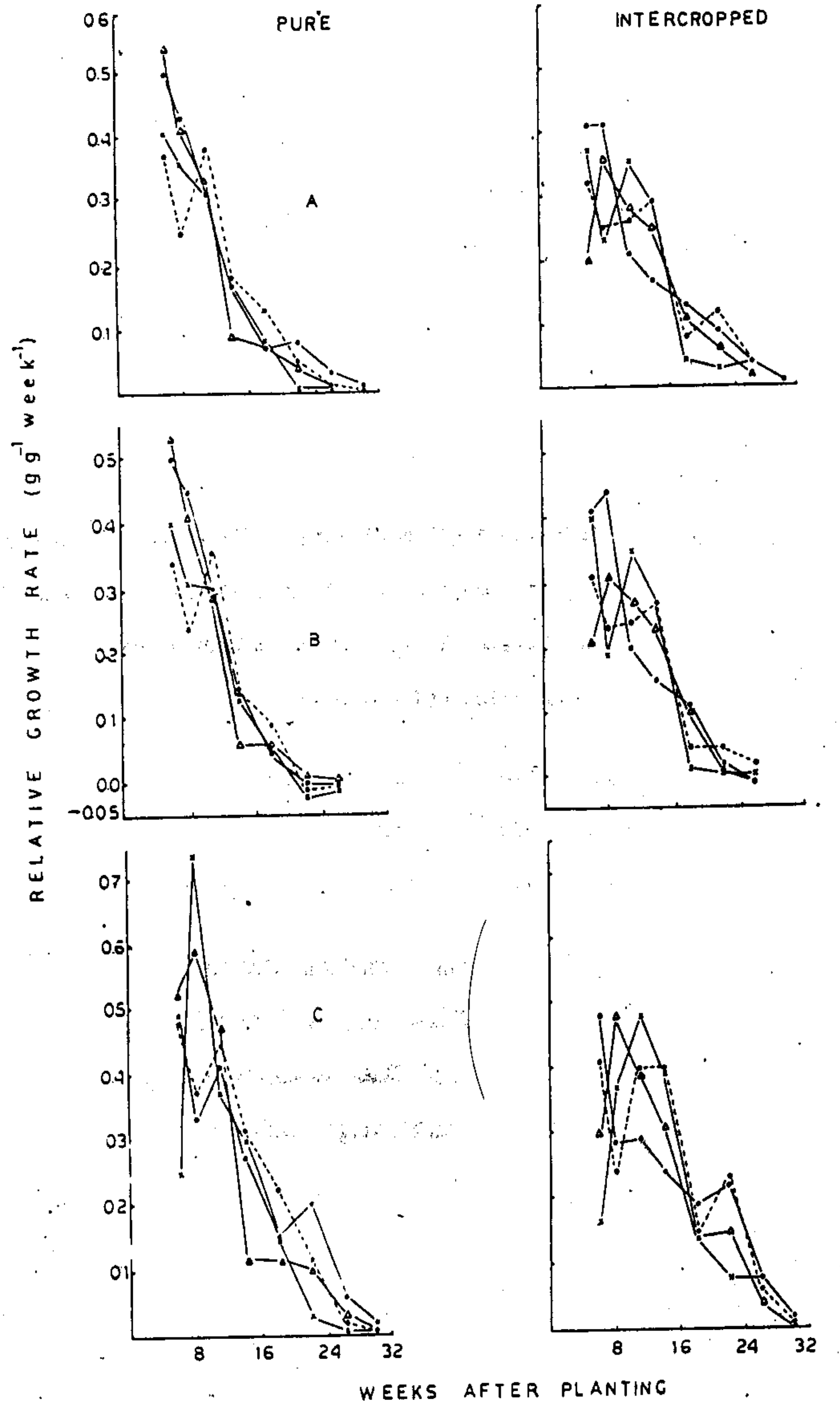

PURE
INTERCROPPED
RELATIVE GROWTH RATE (g g^{-1} week^{-1})
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.05
0.7
A
B
C
8
16
24
32
WEEKS AFTER PLANTING

FIG. 7

The maximum RGR was recorded in the early stages i.e. between 4th and 8th week after planting and RGR decreased thereafter. The RGR under the pure stand was considerably reduced after 11th week, while under the intercropped stand, a remarkable reduction was seen only after 14th week. The RGR values of cultivar C_1 levelled off during 14th to 22nd week under the monoculture system, while it continued to decrease under the intercropping system. The intercropped stand of cultivar C_2 registered a rise in RGR during the period of 8th to 11th week and the values levelled off during 18th to 26th week, while the RGR of pure stand steadily decreased throughout the growth cycle.

Under the monoculture, the maximum RGR attained by cultivars C_1 and C_3 were considerably higher than that attained by C_2, while under the intercropping, C_1 was superior to C_2 or C_3, however, the differences among the cultivars were not significant. All the cultivars registered higher values of RGR under the pure stand than under the intercropped stand at the early stages of crop growth although this difference was much pronounced for cultivars C_1 and C_3. The RGR of the cultivar C_1 under the pure stand was higher than that under the intercropped stand upto 14th week. For the cultivars C_2 and C_3, this superiority in RGR under pure stand was visible only upto 8th and 11th weeks respectively, beyond which it was generally higher under the intercropped stand. Beyond 18th week, RGR of the cultivar C_1 was markedly higher than those of the other two cultivars under both the cropping systems. During this period, the RGR values of this cultivar did not show any marked difference between the two cropping systems.

II Year. The relative growth rate at different periods of growth during the cropping season in the year 1978 is presented in Table 13b. The pattern of changes in the RGR of cultivar C_1 is depicted in Fig.7a. The RGR values of the cultivars C_2 and C_3 did not differ markedly between the two years of study. The RGR values of the cultivar C_1 during early period of 4th to 8th week in the second year were considerably less than that in the first year under both the cropping systems. A rise in the RGR values, coinciding with the initiation of fingers, was noticed for the cultivar C_1 during the period of 8th to 11th week under the pure stand and during 8th to 14th week under the intercropped stand. As a result, the RGR of this cultivar was higher in the second year than that in the first year during 8th to 18th week and during 8th to 14th week under pure and intercropped stands respectively, but in the subsequent periods the values were again comparitively low during the second year of study under both the cropping systems.

During the early period, the superiority of cultivar C_1 over the other two cultivars, as observed in the first year, was not noticed. Under the monoculture, the maximum RGR attained by the cultivar C_3 was significantly higher than those attained by the other two cultivars.

During the period of 18th to 22nd week, the RGR values of the three cultivars were in the order, $C_1 > C_3 > C_2$ with significant differences. All the cultivars registered higher RGR values under the intercropped stand than under the pure stand during last stages of crop growth, i.e. 18th to 26th week.

2.2.2.1. Relative growth rate (Shoot)

I Year. The relative growth rate of shoot (SRGR) at different periods during the cropping season in the year 1977 is presented in Table 14a and its trend of changes is depicted in Fig.7b. The course of SRGR of all the three cultivars under both the cropping systems followed the same pattern as that of RGR upto 18th week during which the shoot growth dominated over the rhizome growth. The maximum SRGR was noticed early in the growth cycle, during 4th to 8th week after planting. Under the monoculture, the SRGR of the cultivars C_1 and C_2 was either nil or negative by 22nd week, while for the cultivar C_3, the values were positive upto 26th week. Under the inter-cropping, the values were positive upto 22nd week for all the cultivars.

II Year. The relative growth rate of shoot at different periods during the cropping season in the year 1978 is presented in Table 14b. The trend of changes in the SRGR values of the cultivar C_1 during this year is depicted

Table 14a. Relative growth rate of shoot (g g^{-1} $week^{-1}$) of three turmeric cultivars at different stages of growth under pure and intercropped stands during the year 1977

Cropping systems	Cultivars	Weeks after planting					
		4–6	6–8	8–11	11–14	14–18	18–22
Pure	C_1	0.503	0.451	0.298	0.146	0.046	0.000
	C_2	0.415	0.310	0.303	0.149	0.053	-0.018
	C_3	0.529	0.413	0.296	0.070	0.068	0.011
Intercropped	C_1	0.406	0.438	0.203	0.145	0.110	0.021
	C_2	0.390	0.196	0.345	0.276	0.015	0.006
	C_3	0.220	0.315	0.268	0.231	0.109	0.015
Mean							
Cultivars							
C_1		0.455	0.445	0.250	0.146	0.078	0.011
C_2		0.402	0.253	0.324	0.212	0.034	-0.006
C_3		0.374	0.364	0.282	0.151	0.089	0.013
Mean							
Systems							
Pure		0.482	0.391	0.299	0.122	0.056	-0.002
Intercropped		0.339	0.316	0.272	0.217	0.078	0.014
CD (P = 0.05)							
Cultivars (C)		0.061	0.054	0.020	0.036	0.018	NS
Systems (S)		0.050	0.044	0.023	0.030	0.015	0.007
C x S		0.086	NS	0.040	0.061	0.026	NS
CV (%)		16.1	16.5	10.6	23.1	29.0	103.6

Table 14b. Relative growth rate of shoot (g g^{-1} $week^{-1}$) of three turmeric cultivars at different stages of growth under pure and intercropped stands during the year 1978

Cropping systems	Cultivars	Weeks after planting 4–6	6–8	8–11	11–14	14–18	18–22
Pure	C_1	0.344	0.242	0.366	0.143	0.095	–0.010
	C_2	0.408	0.309	0.304	0.139	0.048	–0.018
	C_3	0.539	0.417	0.296	0.068	0.066	0.011
Intercropped	C_1	0.314	0.233	0.243	0.269	0.046	0.043
	C_2	0.404	0.193	0.346	0.274	0.010	0.006
	C_3	0.212	0.314	0.269	0.229	0.109	0.013
Mean							
Cultivars							
C_1		0.329	0.237	0.304	0.206	0.070	0.017
C_2		0.406	0.251	0.325	0.207	0.029	–0.006
C_3		0.375	0.366	0.282	0.149	0.087	0.012
Mean							
Systems							
Pure		0.430	0.323	0.322	0.117	0.070	–0.006
Intercropped		0.310	0.247	0.286	0.257	0.055	0.021
CD (P = 0.05)							
Cultivars (C)		NS	0.055	0.030	0.039	0.016	0.015
Systems (S)		0.083	0.045	0.024	0.032	0.013	0.013
C x S		0.092	NS	0.042	NS	0.022	0.022
CV (%)		19.0	20.9	10.6	22.6	28.4	117.5

in Fig.7b. The cultivars C_2 and C_3 did not show any marked difference between the two years of study for this parameter. The pattern of SRGR was similar to that of RGR upto 18th week after planting by which shoot growth ceased.

2.2.2.2. Relative growth rate (Rhizome)

I Year. The relative growth rate of rhizome (RRhGR) at different periods during the cropping season in the year 1977 is presented in Table 15a and its trend of changes is depicted in Fig.7c. Maximum values of RRhGR were recorded early in the growth cycle, between 4th and 11th week after planting and the growth declined thereafter. Cultivar C_1 recorded rises in RRhGR during 8th to 11th week under the monoculture and between 18th and 22nd week under both the cropping systems. Such pattern was not recorded for the other two cultivars, since RRhGR decreased soon after attaining the maximum values.

The cultivar C_1 showed considerably higher RRhGR under the pure stand than under the intercropped stand upto 14th week after planting. The superiority of pure stands of cultivars C_2 and C_3 was noticeable upto only 8th and 11th weeks respectively. During the earlier periods, the RRhGR of the three cultivars under the pure stand were in the order, $C_2 > C_3 > C_1$, whereas the difference among the cultivars was not marked under the intercropped stand. Beyond 18th week RRhGR followed the pattern of RGR.

Table 33a. Relative growth rate of rhizome (g g^{-1} week^{-1}) of three turmeric cultivars at different stages of growth under pure and intercropped stands during the year 1977

Cropping systems	Cultivars	Weeks after planting						
		4–6	6–8	8–11	11–14	14–18	18–22	22–26
Pure	C_1	0.492	0.332	0.407	0.269	0.150	0.199	0.067
	C_2	0.231	0.720	0.370	0.280	0.153	0.040	0.017
	C_3	0.492	0.582	0.470	0.117	0.114	0.102	0.029
Intercropped	C_1	0.484	0.286	0.289	0.239	0.191	0.220	0.082
	C_2	0.205	0.367	0.455	0.393	0.146	0.080	0.082
	C_3	0.285	0.465	0.384	0.314	0.156	0.146	0.043
Mean								
Cultivars								
C_1		0.488	0.309	0.348	0.254	0.171	0.209	0.074
C_2		0.218	0.543	0.413	0.336	0.150	0.060	0.049
C_3		0.388	0.524	0.427	0.216	0.135	0.124	0.036
Mean								
Systems								
Pure		0.405	0.545	0.416	0.222	0.139	0.114	0.038
Intercropped		0.325	0.373	0.376	0.315	0.165	0.149	0.069
CD (P = 0.05)								
Cultivars (C)		0.073	0.101	0.059	0.056	NS	0.025	0.013
Systems (S)		0.059	0.082	NS	0.046	NS	0.020	0.011
C x S		0.108	0.143	0.083	0.079	NS	NS	0.019
CV (%)		21.6	23.8	16.1	23.0	20.3	20.3	28.0

Table 15b. Relative growth rate of rhizome (g g^{-1} $week^{-1}$) of three turmeric cultivars at different stages of growth under pure and intercropped stands during the year 1978

Cropping systems	Cultivars	Weeks after planting 4-6	6-8	8-11	11-14	14-18	18-22	22-26
Pure	C_1	0.480	0.370	0.447	0.313	0.217	0.116	0.029
	C_2	0.365	0.742	0.364	0.281	0.149	0.040	0.018
	C_3	0.521	0.591	0.464	0.116	0.110	0.100	0.029
Intercropped	C_1	0.411	0.244	0.400	0.398	0.149	0.232	0.062
	C_2	0.166	0.373	0.465	0.394	0.141	0.080	0.083
	C_3	0.302	0.484	0.388	0.315	0.152	0.148	0.041
Mean Cultivars								
C_1		0.446	0.307	0.423	0.355	0.183	0.174	0.045
C_2		0.265	0.557	0.415	0.337	0.145	0.060	0.050
C_3		0.412	0.538	0.426	0.216	0.131	0.124	0.035
Mean Systems								
Pure		0.416	0.568	0.425	0.237	0.159	0.085	0.025
Intercropped		0.293	0.367	0.418	0.369	0.147	0.153	0.062
CD (P = 0.05) Cultivars (C)		0.090	0.113	NS	0.065	0.031	0.033	NS
Systems (S)		0.074	0.092	NS	0.053	NS	0.027	0.011
C x S		NS	0.159	NS	NS	0.044	0.046	0.020
CV (%)		27.6	26.1	19.6	23.7	21.8	29.0	36.2

<u>II Year</u>. The relative growth rate of rhizome at different periods during the cropping seasons in the year 1978 is presented in Table 15b. The trend of changes in the RRhGR of the cultivar C_1 is depicted in Fig.7c. The cultivars C_2 and C_3 did not record any marked difference between the two years. A rise in the RRhGR was noticed for the cultivar C_1 during 8th to 11th week or 8th to 14th week under pure and intercropped stands respectively, coinsiding with the period of initiation of fingers. But unlike in first year, the RRhGR of this cultivar did not increase further during 18th to 22nd week under the monoculture system. During the second year, the pattern of changes in the RRhGR of the cultivar C_1 was similar to that of RGR even from 8th week onwards, while such similarity was pronounced only in later periods of growth during the first year.

2.2.3. Leaf area ratio

<u>I Year</u>. The values of leaf area ratio at different periods during the cropping season in the year 1977 are presented in Table 16a and the trend of changes is illustrated in Fig.8a. The LAR declined throughout the crop growth period under both the cropping systems. Under the monoculture, LAR of all the cultivars declined sharply beyond 4th week. Under the intercropping, a drastic reduction was observed only after 11th week for the cultivars C_1 and C_3 eventhough

Table 30a. Leaf area ratio (cm^2 g^{-1}) of three turmeric cultivars at different stages of growth under pure and intercropped stands during the year 1977

Cropping systems	Cultivars	Weeks after planting 4	6	8	11	14	18	22
Pure	C_1	178	144	143	128	111	96	69
	C_2	219	165	135	118	100	74	65
	C_3	217	168	142	118	111	83	72
Intercropped	C_1	192	168	163	157	135	119	85
	C_2	210	200	182	153	113	96	88
	C_3	212	186	176	172	115	113	89
Mean Cultivars								
C_1		185	156	153	142	123	107	77
C_2		215	183	159	135	107	85	77
C_3		215	177	159	145	113	98	81
Mean Systems								
Pure		204	159	140	121	107	84	69
Intercropped		205	185	174	161	121	109	88
CD (P = 0.05)								
Cultivars (C)		22	13	NS	NS	6	5	NS
Systems (S)		NS	11	8	8	5	4	4
C x S		NS	NS	13	14	8	NS	NS
CV (%)		12.0	8.3	6.6	7.6	5.2	5.5	6.8

Fig.8. Leaf area ratio (LAR), specific leaf area (SLA) and leaf weight ratio (LWR) at different stages of growth in three turmeric cultivars under pure and intercropped stands.

a. LAR

b. SLA

c. LWR

●——● Cls. No.24 (1977)

●- - -● Cls. No.24 (1978)

×——× Cll.328 Sugandham (1977)

Δ——Δ Duggirala (1977)

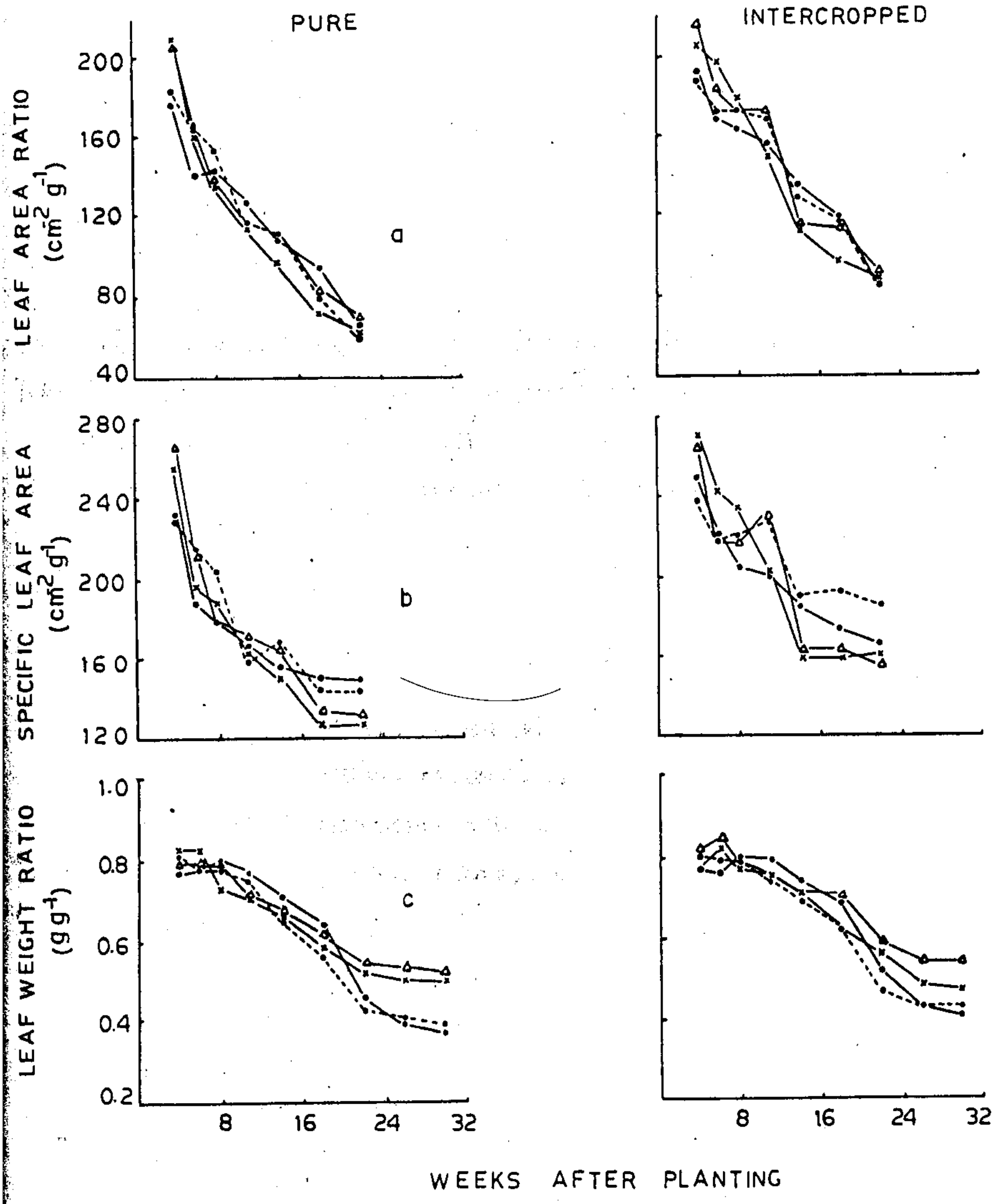

PURE
INTERCROPPED
LEAF AREA RATIO (cm^2 g^{-1})
200
160
120
80
40
a
SPECIFIC LEAF AREA (cm^2 g^{-1})
280
240
200
160
120
b
LEAF WEIGHT RATIO (g g^{-1})
1.0
0.8
0.6
0.4
0.2
c
8
16
24
32
8
16
24
32
WEEKS AFTER PLANTING

FIG. 8

a steady decline was noted for the cultivar C_2 beyond 6th week itself.

The intercropping system registered significantly higher LAR values than the monoculture system throughout the growth period. Cultivars C_2 and C_3 registered significantly higher LAR values than the cultivar C_1 upto 8th week after planting. Between 8th and 11th weeks, no significant difference among the cultivars was noted, whereas during 14th and 18th weeks, the LAR values of the three cultivars were in the orders, $C_1 > C_3 > C_2$, the differences being significant. Beyond 18th week, there was no significant difference among the cultivars.

II Year. The values of leaf area ratio at different periods during the cropping season in the year 1978 are presented in Table 16b. The trend of changes in the LAR of the cultivar C_1 is depicted in Fig.8a. The LAR values of the cultivars C_2 and C_3 were similar during both the years. The LAR values of cultivar C_1 were higher in the second year than in first year during the early period of growth, upto 8th week after planting in monoculture and between 6th to 11th week in case of intercropping. The pattern of LAR in the subsequent periods was similar to that of the first year.

2.2.3.1. Specific leaf area

I Year. The values of specific leaf area at different periods during the cropping season in the year 1977 are presented in Table 17a and its trend changes is shown in Fig.8b. As in the case of LAR, SLA decreased from the very early period of growth onwards under both the cropping systems, the decline being quiet drastic under the monoculture system. Under the monoculture, all the cultivars registered steady decline in SLA upto 14th week, while under the intercropping, cultivar C_3 exhibited such a trend only after 11th week. Under the pure stand, the SLA of cultivar C_1 stabilised by 14th week, while the SLA of the other two cultivars continued to decrease upto 18th week.

The intercropping system registered significantly higher SLA values than the monoculture system throughout the growth period. Upto 8th week after planting, when both the cropping systems had high SLA, the values of cultivars C_2 and C_3 were greater than that of C_1, but after 11th week, C_1 had greater SLA than the other two cultivars.

II Year. The values of SLA during the cropping season in the year 1978 are shown in Table 17b. The trend of changes in the SLA of the cultivar C_1 is depicted in Fig.8b. The SLA values of the cultivars C_2 and C_3 were similar during both the years. Under the pure stand, the SLA values of the cultivar C_1 in the second year were greater than those in the first year only during the early period of growth upto 8th week after planting. Under the intercropped stand, such an increase in the second year was registered by this cultivar during the rest of growth period.

Table 17a. Specific leaf area ($cm^2 g^{-1}$) of three turmeric cultivars at different stages of growth under pure and intercropped stands during the year 1977

Cropping systems	Cultivars	Weeks after planting						
		4	6	8	11	14	18	22
pure	C_1	222	188	179	166	156	150	149
	C_2	257	202	185	167	150	126	126
	C_3	278	215	181	172	168	133	130
Intercropped	C_1	240	221	204	199	184	172	165
	C_2	273	246	238	203	159	155	157
	C_3	260	221	226	230	163	161	154
Mean Cultivars C_1		240	205	192	183	170	161	157
C_2		265	224	211	185	155	140	142
C_3		269	218	203	201	165	147	142
Mean Systems Pure		256	201	182	168	158	136	135
Intercropped		261	230	222	211	168	163	159
CD (P = 0.05) Cultivars (C)		NS	15	13	12	10	5	6
Systems (S)		NS	12	10	10	8	4	5
C x S		NS	21	NS	NS	14	NS	9
CV (%)		11.1	7.3	6.3	6.9	6.5	3.7	4.7

Table 17b. Specific leaf area ($cm^2\ g^{-1}$) of three turmeric cultivars at different stages of growth under pure and intercropped stands during the year 1978

Cropping systems	Cultivars	Weeks after planting						
		4	6	8	11	14	18	22
Pure	C_1	230	216	204	158	168	145	144
	C_2	256	197	188	165	149	127	126
	C_3	252	212	179	171	167	134	131
Intercropped	C_1	236	217	219	226	189	191	185
	C_2	268	241	233	201	158	156	159
	C_3	268	217	218	228	161	162	155
Mean Cultivars								
C_1		233	216	212	192	178	168	165
C_2		262	219	211	183	153	141	143
C_3		260	214	199	199	164	148	143
Mean Systems								
Pure		246	208	190	165	162	135	134
Intercropped		258	225	224	218	169	170	166
CD (P = 0.05) Cultivars (C)		NS	NS	11	12	9	5	8
Systems (S)		NS	12	9	10	8	4	7
C x S		NS	21	16	17	13	6	NS
CV (%)		11.4	7.5	5.9	6.8	6.1	3.2	5.9

2.2.3.2. Leaf weight ratio

I Year. The values of LWR at different periods during the cropping season in the year 1977 are presented in Table 18a and its trend of changes is depicted in Fig.8a. While LAR and SLA followed a similar pattern, the course of LWR deviated from this general trend particularly during the early stages of crop growth. The reduction in LWR as the growth advanced was slow when compared to that of LAR or SLA. Cultivar C_1 registered an increase in the LWR upto 8th week after planting under both the cropping systems. Cultivar C_2 attained the maximum LWR by 6th week under both the cropping systems, while cultivar C_3 attained the maximum by 8th and 6th weeks under the pure and the intercropped stands respectively. Beyond these periods, the LWR values decreased continuously upto 22nd week under the pure stand and upto 26th week under the intercropped stand.

Upto 8th week, there was no significant difference in the LWR between the two cropping systems. Beyond this period and upto 22nd week, the LWR of the crop under the intercropping system were significantly higher than that under the monoculture. Upto 6th week after planting, LWR values of cultivars C_2 and C_3 were considerably higher than those of C_1. But during 8th to 14th week, the values were significantly higher for the cultivar C_1 than those of other two cultivars. Beyond 22nd week, the LWR values of the three cultivars were in the orders, $C_3 > C_2 > C_1$ under

Table [illegible]. Leaf weight ratio (g g^{-1}) of three turmeric cultivars at different stages of growth under pure and intercropped stands during the year 1977

Cropping system	Cultivars	Weeks after planting 4	6	8	11	14	18	22	26	30
Pure	C_1	0.767	0.768	0.790	0.768	0.724	0.630	0.462	0.398	0.360
	C_2	0.809	0.817	0.731	0.706	0.666	0.583	0.518	0.508	0.499
	C_3	0.783	0.785	0.787	0.690	0.680	0.623	0.550	0.529	0.534
Intercropped	C_1	0.770	0.798	0.801	0.787	0.735	0.698	0.518	0.432	0.407
	C_2	0.771	0.814	0.765	0.790	0.716	0.619	0.552	0.479	0.479
	C_3	0.816	0.843	0.780	0.748	0.713	0.705	0.583	0.540	0.540
Mean Cultivars										
C_1		0.769	0.783	0.790	0.777	0.725	0.663	0.490	0.415	0.383
C_2		0.790	0.826	0.748	0.728	0.688	0.601	0.535	0.490	0.489
C_3		0.800	0.814	0.783	0.719	0.687	0.664	0.567	0.536	0.532
Mean Systems										
Pure		0.786	0.790	0.772	0.721	0.690	0.614	0.510	0.476	0.464
Intercropped		0.786	0.805	0.782	0.762	0.719	0.671	0.551	0.484	0.475
CD (P = 0.05) Cultivars (C)		0.028	0.019	0.016	0.030	0.026	0.022	0.036	0.018	0.020
Systems (S)		NS	NS	NS	0.016	0.023	0.018	0.021	NS	NS
C x S		NS	0.027	0.023	NS	NS	NS	NS	0.025	0.030
CV (%)		3.9	2.6	2.2	2.9	4.4	3.8	5.3	3.9	4.5

Table 10b. Leaf weight ratio (g g⁻¹) of three turmeric cultivars at different stages of growth under pure and intercropped stands during the year 1978

Cropping systems	Cultivars	Weeks after planting								
		4	6	8	11	14	18	22	26	30
Pure	C_1	0.806	0.764	0.760	0.745	0.652	0.557	0.437	0.411	0.396
	C2	0.816	0.830	0.732	0.706	0.664	0.581	0.515	0.504	0.497
	C_3	0.795	0.784	0.788	0.690	0.659	0.622	0.552	0.538	0.523
Intercropped	C_1	0.801	0.786	0.786	0.742	0.697	0.619	0.467	0.431	0.428
	C_2	0.766	0.818	0.767	0.752	0.709	0.618	0.555	0.476	0.474
	C_3	0.813	0.846	0.779	0.749	0.712	0.707	0.582	0.530	0.537
Mean Cultivars										
C_1		0.804	0.775	0.773	0.744	0.675	0.588	0.452	0.421	0.412
C_2		0.791	0.824	0.749	0.729	0.687	0.599	0.535	0.490	0.485
C_3		0.804	0.815	0.783	0.720	0.686	0.664	0.567	0.534	0.530
Mean Systems										
Pure		0.806	0.793	0.760	0.714	0.658	0.586	0.501	0.479	0.472
Intercropped		0.793	0.817	0.777	0.748	0.706	0.648	0.535	0.481	0.480
CD (P = 0.05) Cultivars (C)		NS	0.024	0.018	NS	NS	0.027	0.026	0.016	0.020
Systems (S)		NS	0.020	0.015	0.014	0.023	0.022	0.021	NS	NS
C x S		NS	0.034	0.025	NS	NS	NS	NS	0.023	0.028
CV (%)		4.0	3.2	2.5	4.4	4.4	4.7	5.5	3.6	4.4

both the cropping systems. During this period, cultivar C_1 registered significantly higher LWR values under the intercropped stand than under the pure stand, while for the other two cultivars, the values were higher under the pure stand.

II Year. The values of LWR at different periods during the cropping season in the year 1978 are presented in Table 18b. The trend of changes in LWR values of the cultivar C_1 during this year is depicted in Fig.8a. The cultivars C_2 and C_3 did not exhibit any marked difference in the LWR values between the two years of planting. The LWR of the cultivar C_1 was more in the second year than that in first year during 4th and 6th weeks after planting especially under the intercropping system. In the subsequent periods upto 22nd week, the LWR values of this cultivar were low in the second year under both the cropping systems. Beyond 22nd week, LWR values of cultivar C_1 were again higher in second year as compared to first year, which was more pronounced under the pure stand. In spite of the rise in LWR of cultivar C_1 in second year during later stages of crop growth, the LWR of three cultivars was in the order, $C_3 > C_2 > C_1$, under both cropping systems.

3. Efficiency of solar energy conversion and environmental factors

The light climate in the mature coconut plantation was characterised. The interception of photosynthetically active radiation (PAR) and the efficiency of solar energy conversion were studied for the pure and intercropped stands of turmeric. Changes in the other environmental variables such as air temperature, evaporation, humidity, vapour pressure, soil moisture, and soil temperature as influenced by the two cropping systems were also examined.

3.1. Solar energy input and its efficiency of conversion

3.1.1. Characterisation of light climate in the coconut plantation

3.1.1.1. PAR in the open

The average daily incoming PAR for different months of the turmeric growing season in the years 1977 and 1978 is presented in Table 19. The incoming PAR varied widely during these periods. On sunny days the maximum PAR was in the range of 1800 to 1950 $\mu E\ m^{-2}\ s^{-1}$ at mid-day. The maximum PAR noticed was 2,100 $\mu E\ m^{-2}\ s^{-1}$ on 8th September, 1977 which was a clear day with only a few clouds. In cloudy days, according to the intensity

Table 19. Average daily incoming PAR (E m^{-2} d^{-1}) from June to December (turmeric growing season) during the years 1977 and 1978

Month	PAR (E m^{-2} d^{-1}) 1977	1978
June	27.29	18.19
July	22.05	19.80
Aug	32.15	24.66
Sept	38.44	34.94
Oct	37.10	40.55
Nov	34.88	39.56
Dec	48.02	40.93
Average for the season	34.28	31.17

of clouds cover, the PAR in open was in the range of 400 to 1,100 $\mu E\ m^{-2}\ s^{-1}$. The highest average monthly values for the growing season were during September to December of the year, following the predominance of cloudless sky during this period as compared to the early period of crop growth. The average monthly PAR values from June to September were considerably higher in 1977 than in 1978. But in October and November, incoming PAR was greater in 1978 than that in 1977.

3.1.1.2. PAR in the coconut plantation

Seasonal trend in PAR transmission. The average daily PAR in the open and under the coconut canopy during the turmeric growing season are given in Table 20. The per cent PAR transmission by the coconut canopy was higher in the early period of turmeric growth than in the later periods. Eventhough the per cent PAR transmission in the coconut plantation was decreased in the later part of the year, the actual amount of PAR available under the coconut canopy increased. The average PAR transmission in the coconut plantation during the turmeric growing season was about 46 per cent of the open with the highest value recorded in June (54 per cent) and the lowest in December (41 per cent).

Diurnal course of PAR transmission. The PAR transmission in the coconut plantation was studied in four different days

Table 20. Average daily PAR ($\mu E\ m^{-2}\ s^{-1}$) in the open and in the coconut plantation from June to December (turmeric growing season) during the year 1978

Month	PAR ($\mu E\ m^{-2}\ s^{-1}$)		Transmission in the coconut plantation (% of the open)
	In the open	In the coconut plantation	
June	402	216	53.7
July	445	234	52.6
Aug	566	281	49.7
Sept	804	366	45.5
Oct	945	400	42.3
Nov	936	388	41.5
Dec	984	401	40.7

of varying sky conditions during the year 1978. The days selected in March and December were typical clear days, while those in June and July were typical cloudy days with most of the light in the diffused form. The sunshine hours, the average PAR in the open and in the coconut plantation along with the percentage of transmission by coconut canopy for these days are presented in Table 21. Although both the days were clear, the available PAR and the per cent transmission by coconut canopy were higher in March than those in December. The day in June had more incidence and less fluctuation in the PAR than that in July.

The diurnal course of PAR distribution in the open during the above mentioned days is depicted in Fig.9. The diurnal pattern of PAR distribution in the open was similar during both clear days. But the PAR values were fairly higher in March than in December from 11.00 to 16.00 h. During the cloudy day in June, eventhough the extent of PAR in the open was less than that on a clear day, it followed the same diurnal pattern. The pattern of PAR distribution in the open was highly variable in July, with a heavily overcast sky and intermittent rain.

The diurnal pattern of PAR transmission in the coconut plantation during these four days is shown in Fig.10. The transmission was markedly higher early in the morning (6.00 to 7.00 h) on both the clear days. Later, along with

Table 21. Average PAR in the open and in the coconut plantations in four different days of varying sky conditions during the year 1978

Date	Sky condition	Sunshine (h/day)	PAR in the open (μE m^{-2} s^{-1})	PAR in the coconut plantation (μE m^{-2} s^{-1})	Per cent transmission in the coconut plantation
5-3-1978	Clear sky	9.6	1241	601	48
12-6-1978	Uniformly overcast sky with light clouds	0.0	809	436	54
3-7-1978	Heavily overcast sky with rain	0.2	371	189	51
14-12-1978	Clear sky	9.6	1199	503	42

Fig.9. Diurnal course of PAR distribution in the ep
during four different days of varying sky
conditions.

▲	5-3-1978 (clear sky)
×	12-6-1978 (overcast sky)
○	3-7-1978 (Heavily overcast sky)
●	14-12-1978 (clear sky)

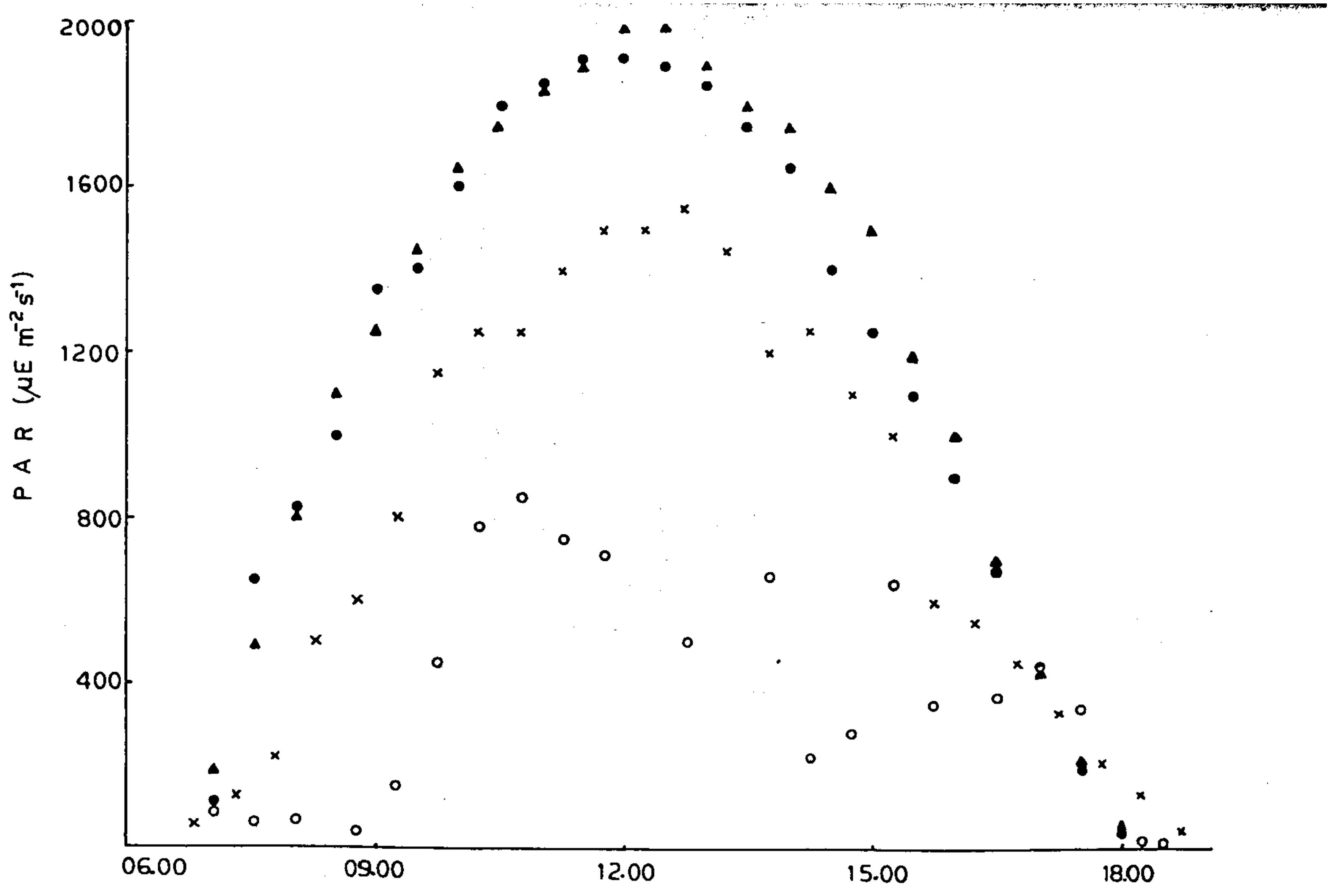

2000
1600
1200
800
400
P A R (μE m^{-2}s^{-1})
06.00
09.00
12.00
15.00
18.00
TIME OF DAY (h)

FIG.9

Fig.10. Diurnal course of PAR transmission by the coconut canopy during four different days of varying sky conditions.

▲ 8-3-1978 (clear sky)
× 12-6-1978 (overcast sky)
○ 3-7-1978 (heavily overcast sky)
● 14-12-1978 (clear sky)

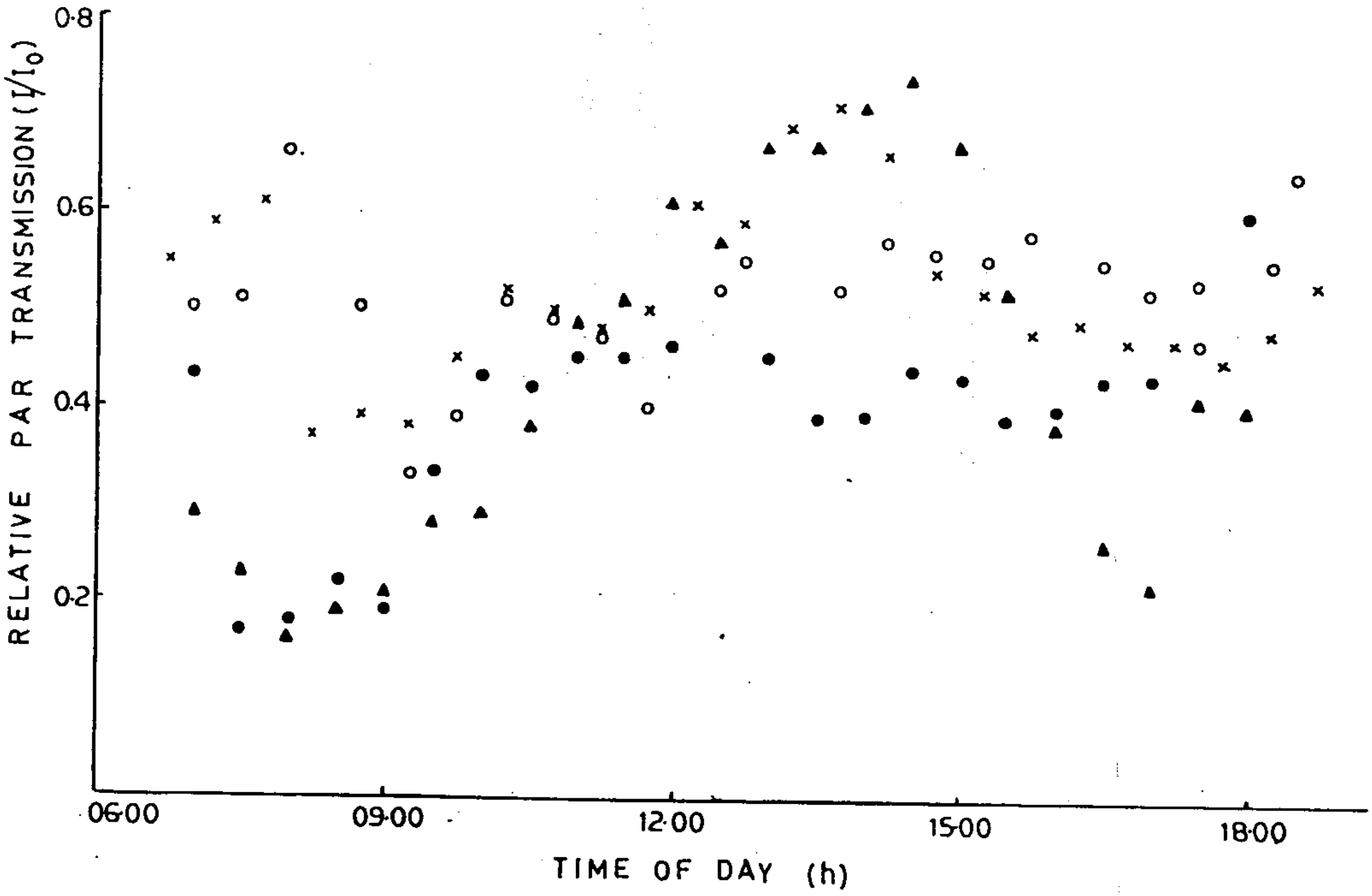

0·8
0·6
0·4
0·2
RELATIVE PAR TRANSMISSION (I/I_0)
06·00
09·00
12·00
15·00
18·00
TIME OF DAY (h)

FIG.10

a marked increase in the total light in the open, there was a gradual reduction in the transmission values and lowest values were recorded between 7.30 to 8.30 h. After 9.00 h. there was a steady increase in the PAR transmission reaching the maximum by noon. For the clear day in December, the maximum PAR transmission was reached by 12.30 h. and decreased in the following hours, while in March, the transmission continued to increase upto 14.30 h. There was a late increase in the transmission in the evening hours (17.00 to 18.00 h.) during both the clear days. During the day (uniformly overcast) in June, the diurnal course of PAR transmission followed the same pattern as that on a clear day. The transmission values upto 11.00 h on cloudy days were considerably higher than those on clear days. During the day (heavily overcast) in July, the transmission pattern did not show much variability after 10.00 h unlike the other days.

Sunflecks. The importance of sunflecks in the distribution of PAR in the coconut plantation was assessed during the time of 12.00 to 14.00 h. on 20th March, 1978. The sky was clear and PAR in the open averaged 1900 $\mu E\ m^{-2}\ s^{-1}$ during the period of study. The data are presented in Table 22. The PAR in the shady area and in the sunfleck area were measured separately. While the PAR in the shady area averaged 144 $\mu E\ m^{-2}\ s^{-1}$, it was 1509 $\mu E\ m^{-2}\ s^{-1}$

Table 22. PAR of sunflecks ($\mu E\ m^{-2}\ s^{-1}$) in the coconut plantation

PAR in the open	Average PAR under the coconut canopy				Ratio (PAR of sunfleck/ PAR in shade)	% area under sunflecks	% of the sunfleck PAR
	In shady area	% of the open	In sunfleck area	% of the open			
1900	144 ± 14	7.6	1500 ± 190	79	10.5	23–35	80

in the sunfleck area with per cent transmissions of 7.6 and 79 respectively of the PAR in the open. The ratio of sunfleck PAR/PAR in shade was about 10.5. The area under the sunflecks reached a maximum of 35 per cent at solar noon. The contribution of the sunfleck PAR was estimated to be about 80 per cent of the total PAR under the coconut canopy.

3.1.1.3. Optical properties of coconut leaf/Spectral distribution of energy in solar radiation

The spectral distribution of energy in the incident solar radiation (300 to 1,100 nm) and an amplification of PAR (400 to 700 nm) recorded at noon on 4th April 1983, a clear day are given in the Figs.11 and 12 respectively. The intensity of reflection, absorption and transmission by an individual leaflet of coconut as a function of the wavelength was also studied.

<u>Reflectance</u>. The reflectance of coconut leaf as a function of the wavelength is given in Fig.13. In the PAR region of the spectrum, the maximum reflectance of 16 per cent was at about 550 nm (green region) and a minimum of 8 per cent was at about 430 (blue) as well as 660 nm (red) regions. The reflectance increased steeply at the near infra red region of the spectrum.

Fig.11. Spectral distribution of energy in the solar radiation (300 to 1,100 nm).

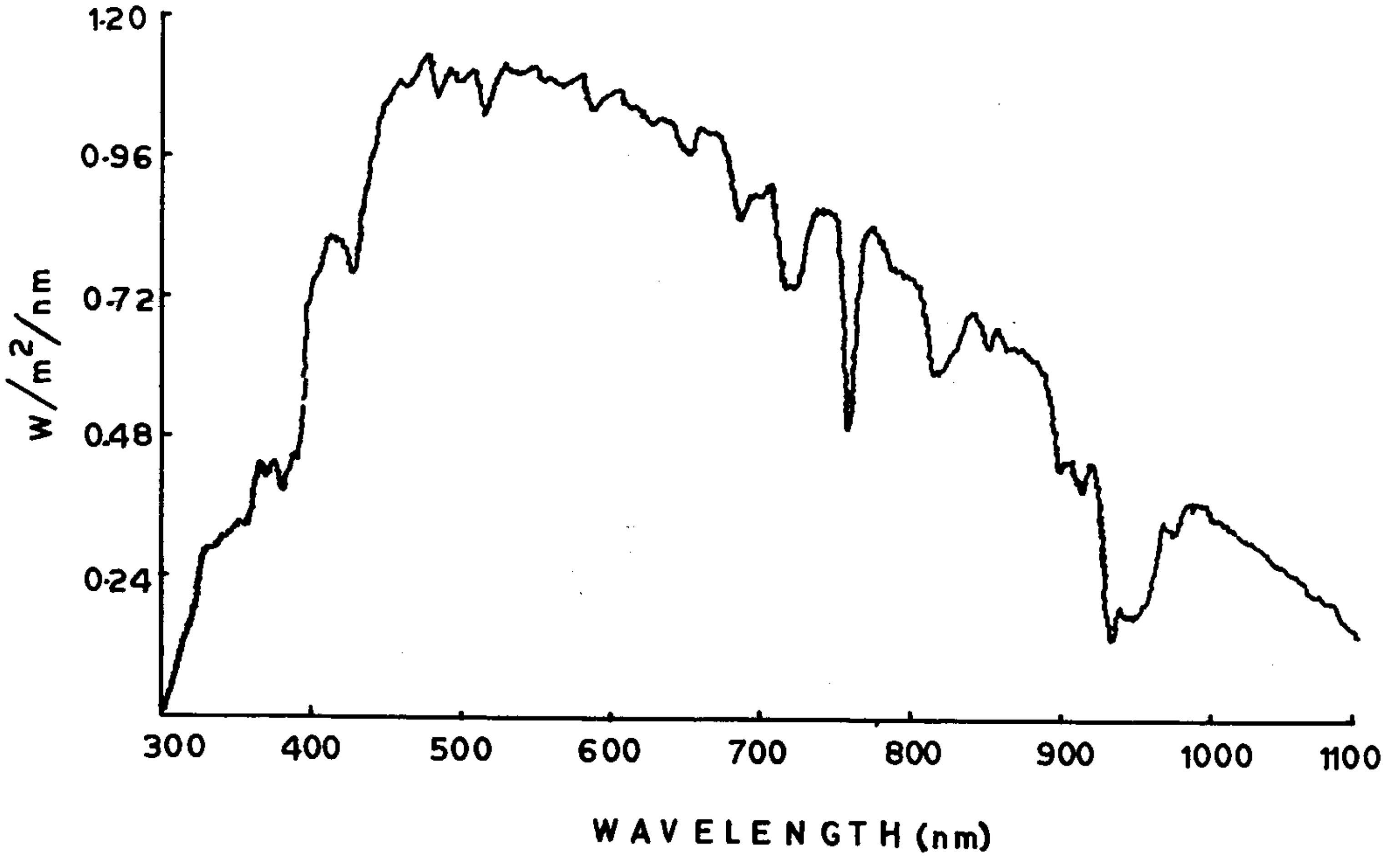

1·20
0·96
0·72
0·48
0·24
W/m2/nm
300
400
500
600
700
800
900
1000
1100
WAVELENGTH (nm)

FIG. 11

Fig.12. Spectral distribution of energy in the PAR region (400 to 700 nm).

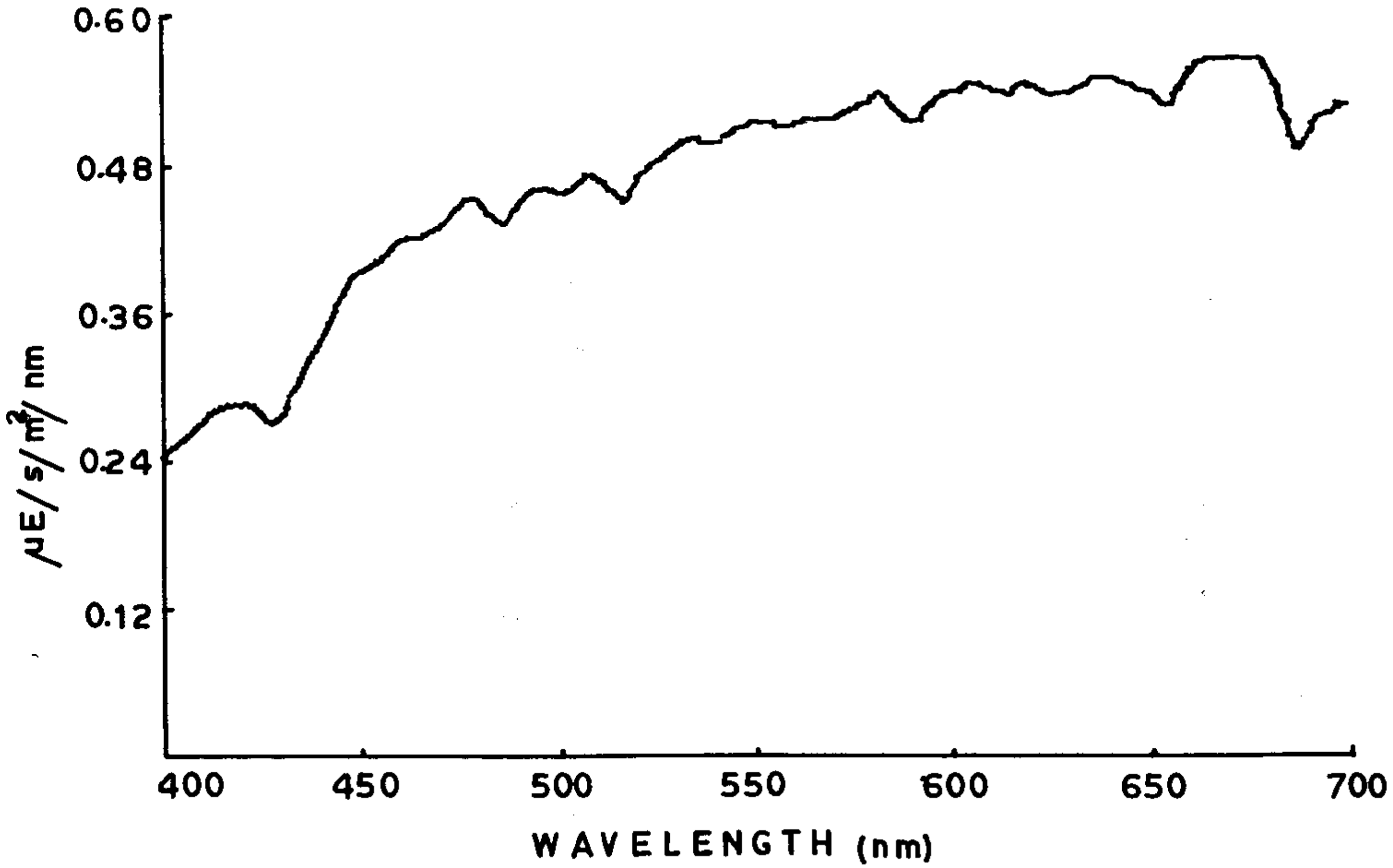

0.60
0.48
0.36
0.24
0.12
μE/s/m²/nm
400
450
500
550
600
650
700
WAVELENGTH (nm)

FIG.12

Fig.13. Reflectance of coconut leaf as a function of wavelength.

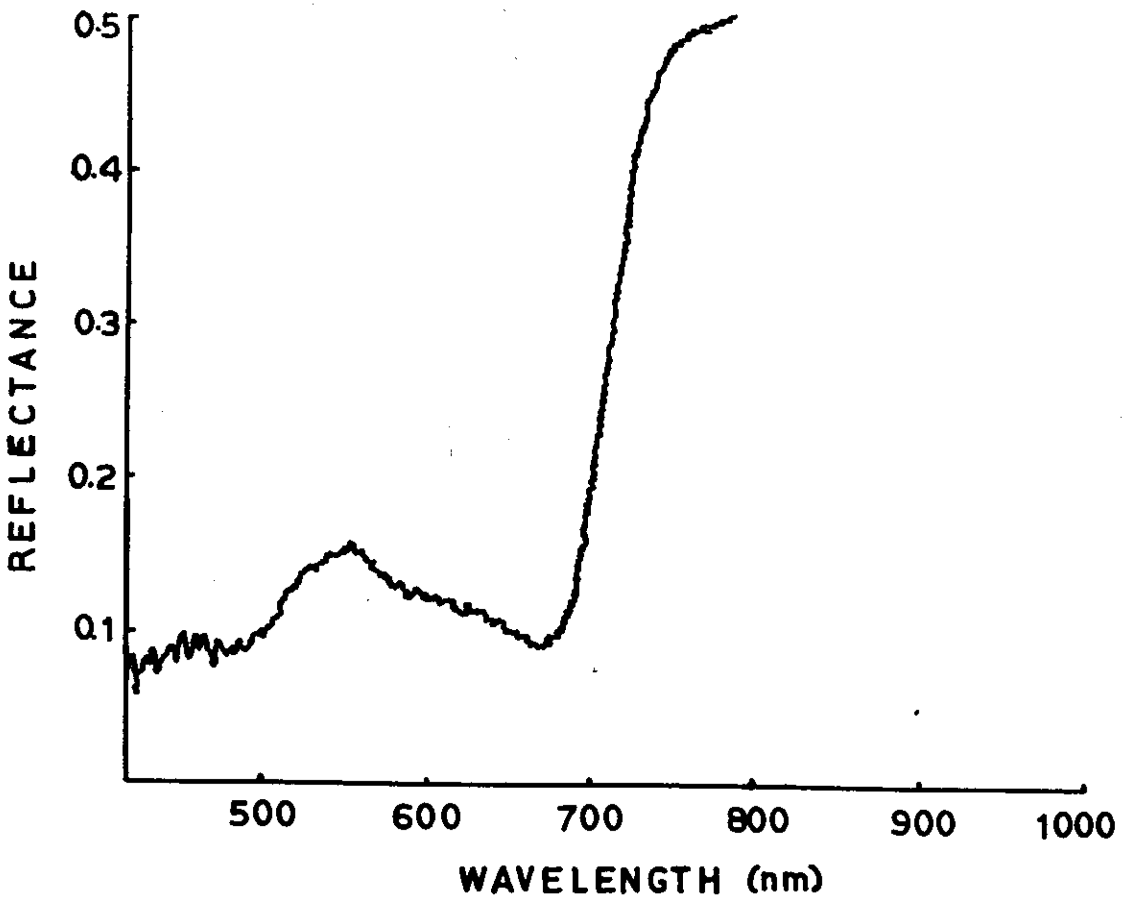

0.5
0.4
0.3
0.2
0.1
REFLECTANCE
500
600
700
800
900
1000
WAVELENGTH (nm)

FIG.13

Fig.14. Absorptance of coconut leaf as a function of wavelength.

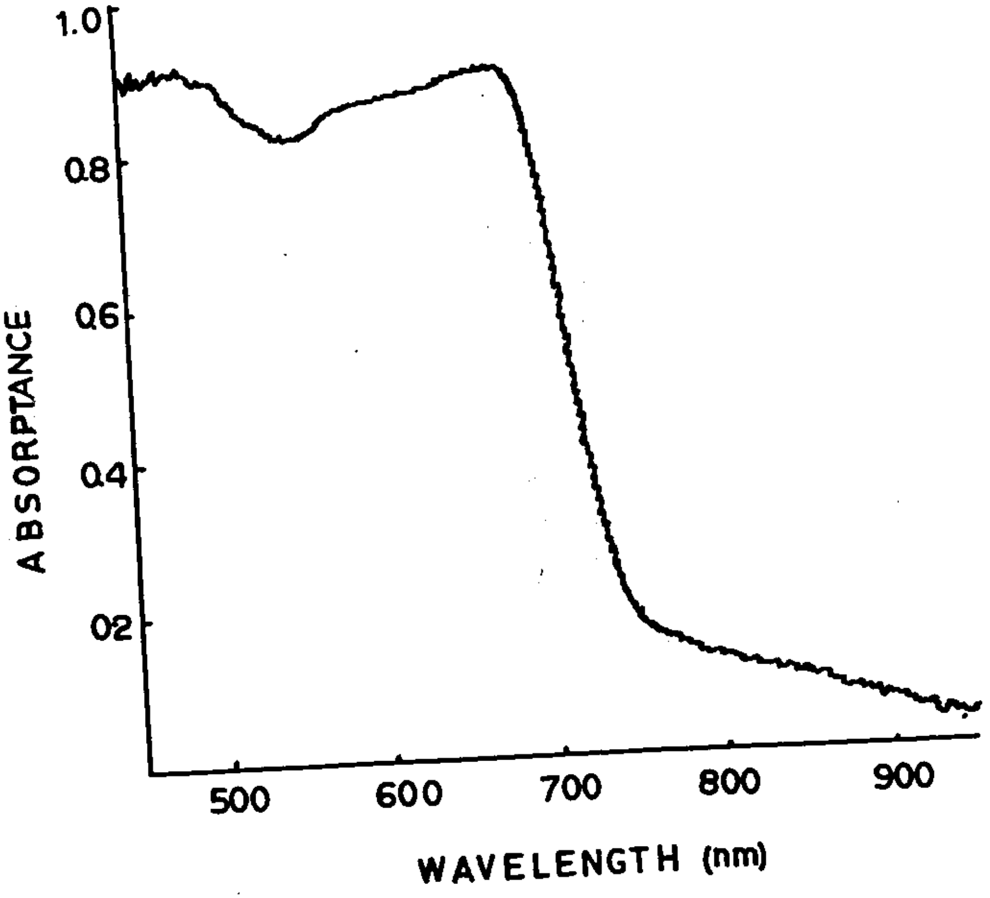


FIG.14

Fig.13. Transmittance of coconut leaf as a function o
wavelength.

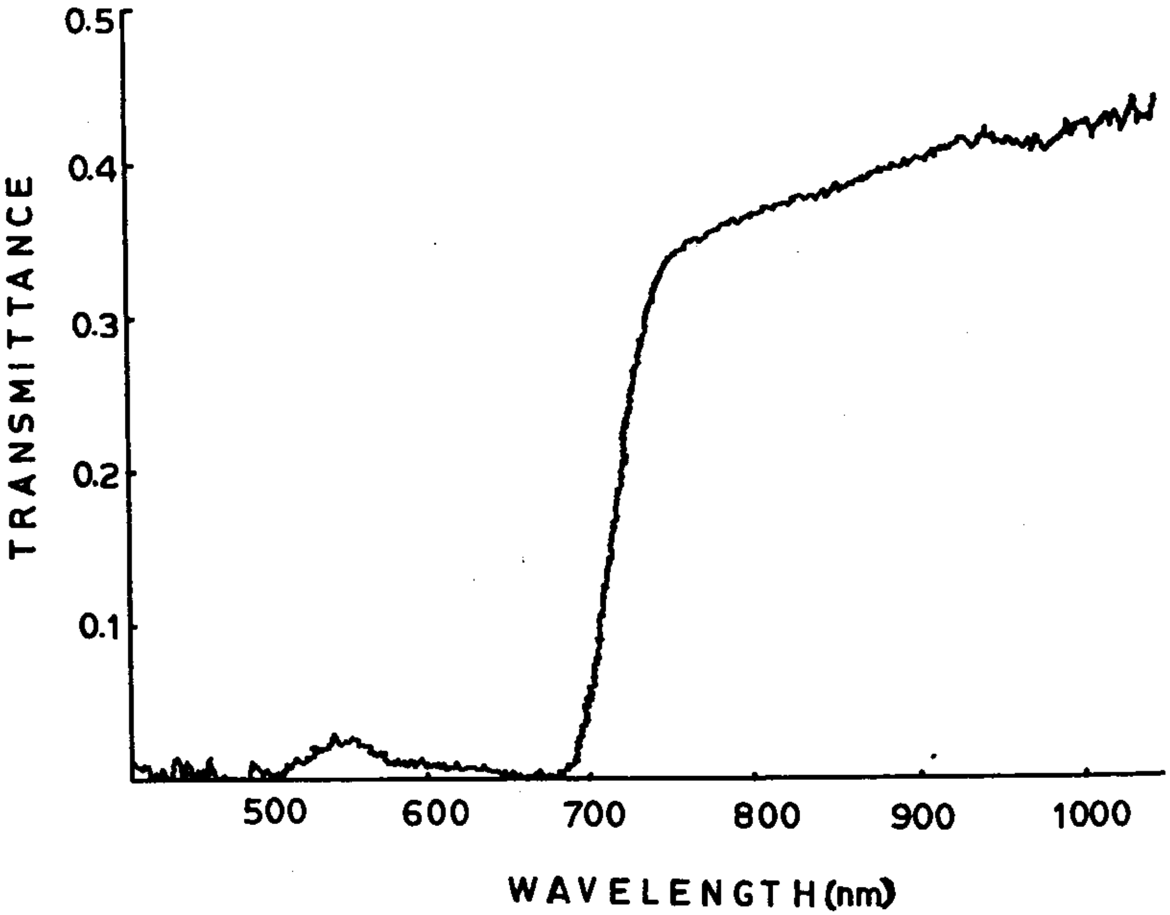

0.5
0.4
0.3
0.2
0.1
TRANSMITTANCE
500
600
700
800
900
1000
WAVELENGTH (nm)

FIG. 15

<u>Absorptance</u>. The spectral absorption of coconut leaf is depicted in Fig.14. The maximum absorptance of 90 per cent was noticed in the blue and red regions of the PAR spectrum corresponding to the zones of minimum reflectance. The lowest absorptance of 80 per cent was at about 550 nm (green). A steep fall in the absorptance occurred at the near infra red region.

<u>Transmittance</u>. The transmittance of coconut leaf as a function of wavelength is illustrated in Fig.15. The maximum transmittance of 3 per cent was in the green region of the PAR spectrum at about 550 nm. The transmittance in the blue and red regions was negligible. As in the case of reflectance a steep rise in transmittance was noticed at the near infra red region of the spectrum.

3.1.2. Interception of PAR and the efficiency of solar energy conversion

3.1.2.1. Interception of PAR

The interception of PAR by the combined canopy of coconut + turmeric as well as by their respective pure stands is given in Table 23a. The superiority of the coconut + turmeric combination in the PAR interception over the pure stand of turmeric was marked during the early period of turmeric growth upto 8th week after planting. Beyond 8th week, when pure stand of turmeric attained nearly maximum PAR interception, the combined interception by the

Table 23a. PAR interception (%) by the crop combination of Coconut + Turmeric and their respective pure stands during the year 1977

Crop	Weeks after planting of turmeric					
	6	8	11	14	18	22
Turmeric alone	21	56	87	95	96	86
Coconut alone	46	47	50	54	57	58
Coconut + Turmeric	56	73	89	97	98	98

Table 23b. PAR interception (%) by three turmeric cultivars at different periods of growth under pure and intercropped stands

Cropping systems	Cultivars	Year	Weeks after planting					
			6	8	11	14	18	22
Pure	C_1	1977	18	65	91	96	96	95
	C_1	1978	20	41	75	96	96	89
	C_2	1977	16	48	78	93	94	74
	C_3	1977	28	55	91	97	97	90
Intercropped	C_1	1977	18	53	82	91	95	95
	C_1	1978	14	37	68	91	96	95
	C_2	1977	7	42	72	93	93	94
	C_3	1977	25	48	79	96	97	97

coconut + turmeric canopy did not markedly differ from that of the pure turmeric stand. The PAR interception of combined canopy of coconut + turmeric was always superior to that of a coconut pure stand.

The PAR interception by the three turmeric cultivars at different periods of growth under pure and intercropped stands is given in Table 22b. Upto 11th week, PAR interception by the pure stand was higher than that of intercropped stand for all the three cultivars. During the year 1977, the PAR interception by the cultivars C_1 and C_3 was greater than those of cultivar C_2, while in 1978, the extent of interception was highest by cultivar C_3 followed by C_2 and C_1, under both cropping systems. The PAR interception by the cultivar C_1 was considerably higher in 1977 than in 1978 upto 11th week after planting under both the cropping systems, while for the other two cultivars there was not much difference in their PAR interception between the two years of study.

The PAR interception by turmeric canopy reached above 90 per cent by the 14th week itself under both the cropping systems. The interception of PAR by the turmeric cultivars as a function of their cumulative LAI under the pure and the intercropped stands is depicted in Fig.16. The extent of PAR interception increased upto an LAI of four. Further increase in LAI, noted for the cultivars C_1 and C_3 under both the cropping systems, did not result in any appreciable increase in the interception of PAR.

Fig.16. PAR interception as a function of cumulativ
LAI for three turmeric cultivars under pure
and intercropped stands.

A. Cls. No.24 (1977)

B. Cls. No.24 (1978)

C. Cll.326 Sugandham (1977)

D. Duggirala (1977)

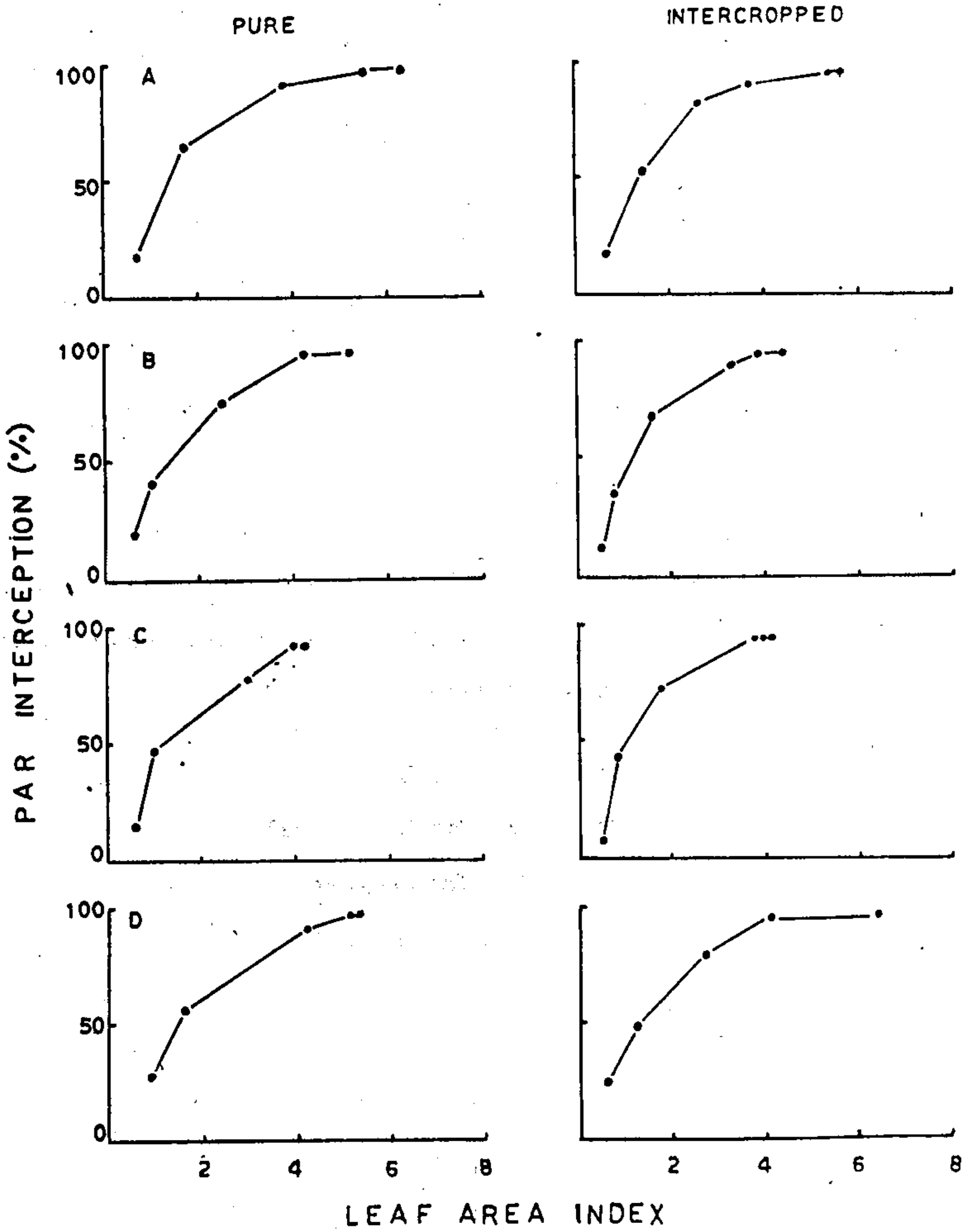

PURE
INTERCROPPED
A
B
C
D
100
50
0
PAR INTERCEPTION (%)
2
4
6
8
LEAF AREA INDEX

FIG.16

3.1.2.2. Efficiency of solar energy conversion

The efficiency of conversion of photosynthetically active energy into dry matter for the three turmeric cultivars under the pure and the intercropped stands during the year 1977 is presented in Table 24. It is assumed that 4.2 kcal are required for the production of 1 g of dry matter. The conversion efficiency was calculated for the period from germination to harvest as well as for the rhizome bulking period (8th to 22nd week). For all the cultivars, the conversion efficiency was higher under the intercropping system than under the monoculture system for the total crop growth period as well as for the rhizome bulking period. In case of cultivars C_2 and C_3, the conversion efficiency almost doubled under the intercropped stand as compared to the pure stand. The conversion efficiency of the three cultivars during the total crop growth period was in the order, $C_1 > C_3 > C_2$ (with significant differences) under both the cropping systems. During the rhizome bulking period the conversion efficiency raised over that of total crop growth period for all the three cultivars under both the cropping systems. Under the monoculture, the conversion efficiency for the three cultivars during the rhizome bulking period was in the order, $C_1 > C_3 > C_2$, while under the intercropping, the order was $C_3 > C_1 > C_2$, differences being significant.

of three turmeric cultivars under pure and intercropped stands during the year 1977

Cropping systems	Cultivars	Conversion efficiency (%)	
		From germination to harvest	During bulking of the rhizome
Pure	C_1	1.41	1.91
	C_2	0.71	1.19
	C_3	0.99	1.55
Intercropped	C_1	2.11	2.85
	C_2	1.48	2.12
	C_3	2.06	3.26
Mean			
Cultivars			
C_1		1.76	2.38
C_2		1.10	1.66
C_3		1.53	2.41
Mean			
Systems			
Pure		1.04	1.55
Intercropped		1.88	2.74
CD (P = 0.05)			
Cultivars (C)		0.17	0.28
Systems (S)		0.14	0.23
C x S		NS	0.39
CV (%)		12.5	13.7

3.2. Other environmental variables

Environmental variables such as air temperature, humidity, vapour pressure, sunshine, rainfall, evaporation, soil moisture and soil temperature recorded in the open condition (observatory) during the turmeric growing season in the years 1977 and 1978 are presented in Tables 25a and 25b. Some environmental parameters like evaporation, air temperature, soil temperature, humidity, vapour pressure and soil moisture were monitored in the pure as well as the intercropped stands of turmeric for five clear days in each month of the crop growth during the year 1977, and the daily mean values for the season are presented in Table 26.

3.2.1. Temperature

Both the maximum and minimum temperatures in the open were higher in the later part of the crop growth than in the earlier part during both the years. The maximum as well as the minimum temperature was generally higher in 1977 than in 1978. The air temperature was lower under the intercropped stand than in the pure stand, the decrease was as much as 1.5° C under some shady spots below the coconut canopy. However, these differences were not consistent and the mean values did not show any marked difference between the two cropping systems. There were no marked differences between pure and intercropped stands in their maximum and minimum temperatures.

Table 25a. Meteorological parameters: monthly mean values of temperature, humidity and vapour pressure from June to December (turmeric growing season) during the years 1977 and 1978

Months	Temperature (°C)				Humidity (%)				Vapour pressure (mm Hg)			
	Maximum		Minimum		Forenoon		Afternoon		Forenoon		Afternoon	
	1977	1978	1977	1978	1977	1978	1977	1978	1977	1978	1977	1978
June	29.8	28.1	23.2	22.5	91	94	83	86	22.7	21.6	23.6	22.4
July	28.5	27.6	22.5	22.5	94	95	86	88	22.0	21.5	22.8	22.7
Aug	29.1	27.9	23.1	23.1	92	95	81	87	22.0	22.0	23.0	23.1
Sept	29.7	28.6	23.2	22.8	91	94	75	76	22.8	21.2	22.5	22.0
Oct	31.5	30.6	22.6	23.0	92	94	71	73	21.6	22.0	22.7	23.1
Nov	30.8	31.5	22.6	22.3	93	90	73	66	21.4	20.0	22.6	21.1
Dec	32.8	32.9	19.6	22.0	84	86	51	55	16.2	17.8	17.7	18.3

Table 25b. Meteorological parameters: monthly mean values of sunshine, rainfall, pan evaporation, soil temperature and soil moisture from June to December (turmeric growing season) during the years 1977 and 1978

Months	Sunshine (h/day)		Rainfall (mm)		USWB pan evaporation (mm/day)		Soil temperature (°C)				Soil moisture (%)	
							Forenoon		Afternoon			
	1977	1978	1977	1978	1977	1978	1977	1978	1977	1978	1977	1978
June	3.5	1.1	915	1337	4.6	3.7	27.7	26.7	29.9	28.9	8.8	9.1
July	2.0	1.7	1577	1178	3.0	2.8	27.1	26.2	28.9	28.5	9.3	9.2
Aug	4.9	3.1	354	914	4.0	3.0	28.1	26.3	29.8	28.0	8.0	9.3
Sept	6.9	6.2	165	285	4.0	3.7	28.5	27.6	30.8	29.9	7.5	8.0
Oct	6.7	7.8	252	119	3.5	3.9	27.9	28.0	30.4	30.5	7.0	7.2
Nov	6.1	7.4	218	148	3.4	3.9	27.2	28.0	30.1	31.0	8.3	5.5
Dec	9.7	7.9	2	7	4.3	3.9	28.1	28.3	31.8	32.1	5.3	1.2

Table 26. Environmental parameters: evaporation, temperature, humidity, vapour pressure, soil temperature and soil moisture under pure and intercropped stands during the year 1977

Environmental parameters	Pure stand (Turmeric alone)	Intercropped stand (Turmeric + Coconut)
Cup evaporation (mm/day)	5.3 ± 0.5	3.7 ± 0.3
Temperature (°C)		
Air temperature		
Forenoon	27.5 ± 0.6	26.6 ± 0.7
Afternoon	32.5 ± 0.6	31.3 ± 0.6
Max. temperature	34.0 ± 0.9	33.1 ± 0.7
Mini. temperature	21.4 ± 0.7	20.5 ± 0.6
Humidity (%)		
Forenoon	70 ± 4	76 ± 3
Afternoon	54 ± 3	60 ± 3
Vapour pressure (mm Hg)		
Forenoon	19.2 ± 0.7	19.2 ± 0.5
Afternoon	20.3 ± 0.7	20.4 ± 0.9
Soil temperature at 15 cm depth (°C)		
Forenoon	28.2 ± 0.7	27.1 ± 0.6
Afternoon	32.0 ± 0.8	31.0 ± 0.5
Soil moisture at 15 cm depth (%)		
Forenoon	7.0 ± 0.3	8.9 ± 0.5
Afternoon	6.3 ± 0.4	6.6 ± 0.4

3.2.2. Humidity

The relative humidity in the open was highest in the earlier part of the crop growth and decreased later. The relative humidity was higher in 1978 than in 1977 during most parts of the crop growth. Eventhough the relative humidity was at times considerably higher in the intercropped stand than that of the pure stand, such difference was not consistent.

3.2.3. Vapour pressure

The vapour pressure in the open condition was greater during the earlier part of the crop growth than in the later stages. During the earlier months of the crop growth, the vapour pressure was higher in 1977 than that in 1978. There was no marked difference between the vapour pressure in the two cropping systems.

3.2.4. Sunshine

The average sunshine hours during the period of June to August was considerably less than those of later months. There was a considerable reduction in the sunshine hours in 1978 from that in 1977 during the early period of crop growth, i.e. June to August. During the months of October and November the sunshine hours were more in 1978 than in 1977.

3.2.5. Rainfall

The rainfall was considerably higher in the early period of crop growth, from June to August than in the later periods during both the years. Nearly 75 per cent of the annual rainfall was available during these three months. Generally, rainfall during the early period of crop growth was higher in 1978 than in 1977. However, during the months of October and November, the rainfall was more in 1977 than in 1978.

3.2.6. Evaporation

During the first four months of crop growth, evaporation in the open condition was higher during 1977 than in 1978. During October and November, evaporation was more in 1978 than in 1977. The extent of evaporation in a pure stand was greater than that of an intercropped stand on all the days studied during the crop growth period.

3.2.7. Soil moisture

The soil moisture level in the open was markedly higher in the earlier part of the crop growth than in the later months during both the years. There was a considerable depletion of soil moisture level during November and December in 1978 which was not much pronounced in 1977. The comparison of soil moisture level between pure and intercropped stands was done during the period of September to November, 1977. During the forenoon hours the soil moisture level under the intercropped stand was considerably higher than that under the pure stand, eventhough this difference was not apparent during the afternoon hours.

3.2.8. Soil temperature

The changes in the soil temperature in the open condition during the crop growing season followed the same pattern as that of the air temperature, the values being higher in the later part of the crop growth than in the earlier parts. The soil temperature was higher in 1977 than in 1978 during the period of June to September. As in the case of air temperature, pure and intercropped stands did not show much differences in the soil temperature.

4. Photosynthetic efficiency

Gas exchange studies were made by the manometric technique. Growth analytical technique was used to estimate NAR, as well as ERR - the latter presents the efficiency in terms of the dry matter partitioned towards the economic end product. Photosynthetic characteristics of turmeric leaf such as concentration of chlorophyll figments, air space volume and SLA were also examined.

4.1. Photosynthetic measurements

4.1.1. Gasometric method

Optimum conditions. The rate of apparent photosynthesis was determined by manometric method with Warburg apparatus. The photosynthetic measurements were made at saturating light intensities in the manometer reaction flasks. Photosynthetic rates of cultivar C_1 were saturated at about 600 and 500 $\mu E\ m^{-2}\ s^{-1}$ grown under pure and intercropped stands respectively, while in the case of cultivars C_2 and C_3, the saturation was at about 400 and 500 $\mu E\ m^{-2}\ s^{-1}$ respectively. The latter two cultivars did not exhibit any marked difference between the plants grown under pure and intercropped stands. Four months old plants which had attained maximum leaf area were selected for the study. Small discs of 7 mm diameter cut from the mid region of the youngest fully opened leaves were used for the

Table 27. Rate of apparent photosynthesis in relation to number of leaf discs

	Number of discs			CD
	5	7	10	(P = 0.05)
Apparent Photosynthesis ($\mu l\ O_2\ cm^{-2}\ h^{-1}$)	30.30	27.05	19.74	4.64

determination of the rate of apparent photosynthesis. Maximal rates of photosynthesis were recorded when 5 discs per reaction flask, were used (Table 27). A temperature of 32° C was optimal during the course of the measurement.

<u>Rate of apparent photosynthesis</u>. The rate of apparent photosynthesis for the three turmeric cultivars grown under pure and intercropped stands is presented in Table 28. While cultivar C_1 recorded significantly higher photosynthetic rate when grown under monoculture than under intercropping, the other two cultivars did not show any significant difference between the two cropping systems. In case of cultivar C_2, the rate of apparent photosynthesis of the intercropped stand was slightly higher than that of the pure stand. The cultivars grown under the intercropped stand did not show any significant difference for the rate of apparent photosynthesis, while under the pure stand, C_2 recorded significantly lower values than C_1 and C_3.

4.1.2. Growth analytical method

4.1.2.1. Net assimilation rate

<u>I Year</u>. The values of net assimilation rate (NAR) at different stages of growth for thee turmeric cultivars under pure and intercropped stands during the year 1977 are presented in Table 29a and its seasonal changes are depicted in Fig. 17. The maximum NAR was in the early period of growth. Under the pure stand, the NAR of the cultivar C_1

leaf area (SLA) of three [illegible] cultivars under pure and intercropped stands

Cropping systems	Cultivars	Apparent photosynthesis (µl O_2 cm^{-2} h^{-1})	Chl.a (mg g^{-1} f.wt)	Chl.b (mg g^{-1} f.wt)	Chl.a+b (mg g^{-1} f.wt)	Chl.a/b	Air space volume (% of total leaf volume)	SLA (cm^2 g^{-1})
Pure	C_1	41.68	0.755	0.304	1.059	2.48	13.86	144
	C_2	30.46	0.585	0.291	0.876	2.01	15.36	126
	C_3	39.79	0.831	0.362	1.192	2.30	14.36	131
Intercropped	C_1	35.11	0.729	0.352	1.082	2.07	17.02	185
	C_2	33.87	0.801	0.455	1.256	1.76	18.26	159
	C_3	37.68	0.765	0.375	1.140	2.04	17.36	155
Mean Cultivars								
C_1		38.39	0.742	0.328	1.070	2.28	15.44	165
C_2		32.16	0.693	0.373	1.066	1.89	16.81	143
C_3		38.72	0.798	0.368	1.166	2.17	15.86	143
Mean Systems								
Pure		37.31	0.724	0.319	1.043	2.27	14.53	134
Intercropped		35.54	0.765	0.394	1.159	1.96	17.55	166
CD (P = 0.05) Cultivars (C)		1.68	0.033	0.032	0.063	0.10	1.01	8.16
Systems (S)		NS	0.027	0.026	0.043	0.08	0.83	6.66
C x S		5.28	0.046	0.046	0.075	NS	NS	NS
CV (%)		10.9	4.8	9.8	8.2	5.3	6.9	5.9

[illegible]

stages of growth under pure and intercropped stands during the year 1977

Cropping systems	Cultivars	Weeks after planting						
		4–6	6–8	8–11	11–14	14–18	18–22	22–25
Pure	C_1	31.94	30.19	23.26	14.37	7.19	11.53	17.26
	C_2	22.07	24.96	24.97	15.96	10.08	0.83	0.00
	C_3	28.50	26.81	26.30	8.02	8.70	5.85	4.43
Intercropped	C_1	23.32	24.97	13.07	11.72	10.08	9.29	7.10
	C_2	18.20	11.95	21.58	23.15	4.79	3.81	8.02
	C_3	10.62	19.66	16.41	17.92	9.77	5.90	3.79
Mean Cultivars								
C_1		27.63	27.58	18.16	13.04	8.64	10.41	12.18
C_2		20.14	18.46	23.27	19.56	7.43	2.32	4.01
C_3		19.56	23.24	21.36	12.97	9.24	5.88	4.11
Mean Systems								
Pure		27.50	27.32	24.84	12.78	8.66	6.07	7.23
Intercropped		17.38	18.86	17.02	17.60	8.21	6.33	6.31
CD (P = 0.05)								
Cultivars (C)		2.60	3.55	2.45	2.32	1.48	1.58	3.04
Systems (S)		2.20	2.90	2.00	1.89	1.21	NS	NS
C x S		3.81	NS	3.46	3.28	2.09	2.23	4.29
CV (%)		13.0	16.6	12.7	16.8	18.8	28.1	46.9

Fig.17. Net assimilation rate (NAR) at different stages of growth in three turmeric cultivar under pure and intercropped stands.

●——●	Cls. No.24 (1977)
○- - -○	Cls. No.24 (1978)
×——×	Cll.328 Sugandham (1977)
△——△	Duggirala (1977)

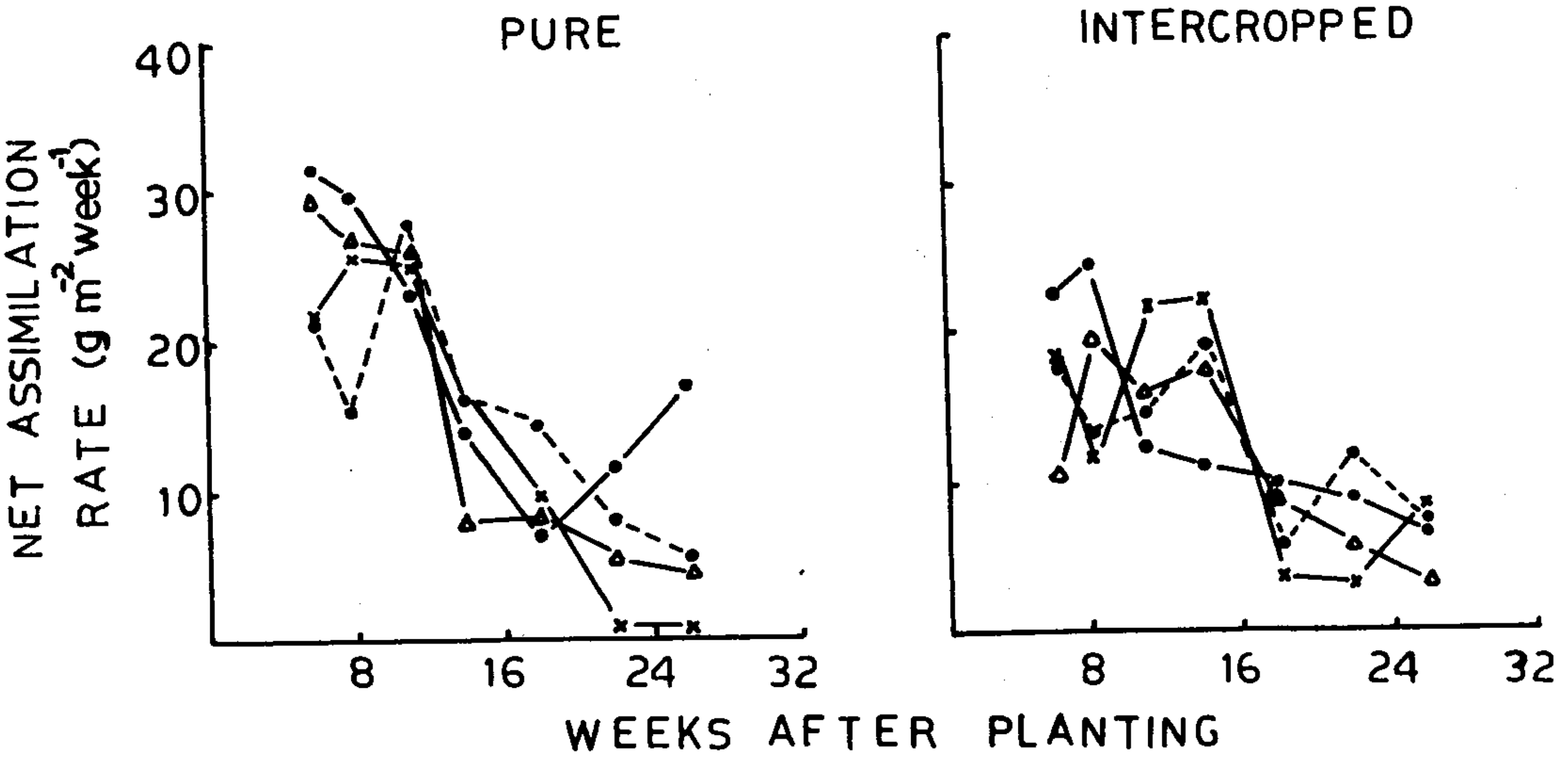

PURE
INTERCROPPED
NET ASSIMILATION RATE (g m^{-2} week^{-1})
40
30
20
10
8
16
24
32
8
16
24
32
WEEKS AFTER PLANTING

FIG.17

which was highest during the period of 4th to 8th week after planting, declined thereafter upto 10th week. Beyond 10th week, a marked rise in NAR was noticed for this cultivar under the pure stand. The intercropped stand of this cultivar showed a steady decline in NAR from 8th week onwards. For the cultivars C_2 and C_3 the maximum NAR values were noticed during the period of 4th to 11th week and decreased thereafter.

Under the monoculture, the maximum NAR attained by cultivar C_1 was considerably higher than those attained by other two cultivars. The maximum NAR attained by cultivars C_1 and C_3 under the pure stand were considerably higher than those attained under the intercropped stand, whereas for the cultivar C_2, this difference was not marked. Beyond 10th week, when the shoot growth was negligible NAR of the cultivar C_1 under the pure stand was significantly higher than that under the intercropped stand, but for the cultivar C_2 the values were significantly higher under the intercropped stand. During this period, no significant difference was noticed for the NAR values of the cultivar C_3 between the two cropping systems. Under the pure stand, the NAR values of three cultivars during this period of leaf senescence were in the order, $C_1 > C_3 > C_2$ with significant differences. Under the intercropped stand also, cultivar C_1 maintained its superiority, while no significant difference was noticed between the other two cultivars.

<u>II Year</u>. The NAR values at different stages of growth for the three cultivars under pure and intercropped stands during the year 1978 are presented in Table 29b. The seasonal changes in the NAR of the cultivar C_1 alone during this year are depicted in Fig.17. The cultivars C_2 and C_3 did not show any marked difference in the NAR values between the two years. The NAR values of the cultivar C_1 were considerably low in the second year as compared to the first year during the early period of growth upto 8th week after planting under both the cropping systems. Unlike in first year, a reduction in NAR was noticed for this cultivar during the period of 6th to 8th week under both the cropping systems. The NAR increased during the period of 8th to 11th week under pure stand and during 8th to 14th week under the intercropped stand. The NAR values of this cultivar were higher in the second year than those in the first year during the periods of 8th to 18th week and 8th to 14th week under pure and intercropped stands respectively. Under the monoculture, in contrast to first year, the NAR showed a decrease during 14th to 22nd week. Beyond 18th week, NAR values of this cultivar under the pure stand were considerably reduced in the second year as compared to the first year, eventhough such a reduction was not noticed under the intercropped stand. In spite of this trend, the photosynthetic rates of cultivar C_1 were higher than those of other two cultivars.

Table 25b. Net assimilation rate (g m^{-2} week^{-1}) of three turmeric cultivars at different stages of growth under pure and intercropped stands during the year 1978

Cropping systems	Cultivars	Weeks after planting						
		4-6	6-8	8-11	11-14	14-18	18-22	22-26
Pure	C_1	21.64	15.92	28.20	16.13	14.77	8.13	5.79
	C_2	22.33	25.75	25.03	16.23	9.75	0.78	0.66
	C_3	29.09	27.32	26.56	7.43	8.43	5.79	5.00
Intercropped	C_1	18.23	13.73	15.40	19.70	6.03	12.21	7.62
	C_2	18.54	12.05	22.11	22.91	4.33	3.54	8.31
	C_3	10.87	20.25	16.56	18.47	9.61	6.02	3.70
Mean								
Cultivars								
C_1		19.93	14.82	21.80	17.92	10.40	10.17	6.70
C_2		20.44	18.90	23.57	19.57	7.04	2.16	4.49
C_3		19.98	23.79	21.56	12.95	9.02	5.91	4.35
Mean								
Systems								
Pure		24.35	23.00	26.60	13.26	10.98	4.90	3.82
Intercropped		15.88	15.34	18.02	20.36	6.66	7.26	6.54
CD (P = 0.05)								
Cultivars (C)		NS	3.90	NS	2.56	1.56	2.06	NS
Systems (S)		2.20	3.18	2.23	2.09	1.27	1.68	2.41
C x S		3.95	5.51	3.87	3.62	2.21	NS	4.18
CV (%)		15.1	22.0	13.3	16.7	19.1	37.1	61.2

4.1.2.2. Economic assimilation rate

I Year. The values of EAR at different periods of growth for three turmeric cultivars under pure and intercropped stands during the year 1977 are given in the Table 30a and its seasonal changes are depicted in Fig.18. The EAR of the cultivar C_1 decreased upto 18th week under the intercropped stand, while a rise in EAR was noticed during the period of 8th to 11th week under the pure stand. The cultivar C_1 recorded the maximum values of EAR after 18th week. For the cultivar C_2, the EAR values increased upto 14th week and thereafter decreased with a further rise during the period of 22nd to 26th week. The EAR values for the cultivar C_3 had attained the maximum during the periods of 8th to 11th week and 11th to 14th week under pure and intercropped stands respectively.

II Year. The values of EAR at different periods of growth for the three cultivars under pure and intercropped stands during the year 1978 are presented in Table 30b. Cultivars C_2 and C_3 did not show any marked difference for EAR values between the two years of study. The values of EAR for cultivar C_1 during the second year are plotted in Fig.18. The differences in EAR of this cultivar between the two years of study were similar to those of NAR.

Table [illegible]. Economic assimilation rate (g m^{-2} $week^{-1}$) of three turmeric cultivars at different stages of growth under pure and intercropped stands during the year 1977

Cropping systems	Cultivars	Weeks after Planting						
		4-6	6-8	8-11	11-14	14-18	18-22	22-26
Pure	C_1	5.05	3.35	4.71	4.66	4.01	11.52	17.70
	C_2	1.25	6.13	6.03	5.95	5.57	2.49	3.26
	C_3	3.11	4.86	7.64	2.64	3.47	5.48	4.26
Intercropped	C_1	4.46	2.58	2.54	3.37	3.71	8.00	7.96
	C_2	1.10	1.98	3.88	6.15	3.85	3.15	7.21
	C_3	1.51	3.07	3.67	4.70	3.46	4.58	3.40
Mean Cultivars								
C_1		4.76	2.96	3.63	4.02	3.86	9.76	12.83
C_2		1.17	4.05	4.96	6.05	4.71	2.81	5.24
C_3		2.31	3.97	5.66	3.67	3.47	5.03	3.83
Mean Systems								
Pure		3.14	4.78	6.13	4.42	4.35	6.50	8.41
Intercropped		2.35	2.54	3.36	4.74	3.67	5.25	6.19
CD (P = 0.05)								
Cultivars (C)		0.62	0.86	1.09	0.91	0.81	1.36	2.12
Systems (S)		0.52	0.70	0.89	NS	0.66	1.11	1.73
C x S		NS	1.21	NS	1.29	NS	1.93	3.00
CV (%)		24.5	24.9	25.0	22.0	21.5	25.2	32.1

Table 30b. Economic assimilation rate (g m^{-2} $week^{-1}$) of three turmeric cultivars at different stages of growth under pure and intercropped stands during the year 1978

Cropping systems	Cultivars	Weeks after planting						
		4-6	6-8	8-11	11-14	14-18	18-22	22-26
Pure	C_1	3.00	3.06	5.83	6.57	8.15	8.95	7.43
	C_2	1.27	6.32	5.83	6.31	5.51	2.39	3.23
	C_3	3.17	5.31	8.02	3.00	3.66	4.93	4.00
Intercropped	C_1	2.59	1.75	3.45	5.94	3.66	9.42	5.75
	C_2	0.89	2.17	4.07	6.03	3.71	2.93	6.85
	C_3	1.54	3.13	4.23	5.15	3.34	4.69	3.28
Mean								
Cultivars								
C_1		2.79	2.41	4.64	6.26	5.91	9.19	6.59
C_2		1.08	4.25	4.95	6.17	4.61	2.66	5.04
C_3		2.35	4.22	6.13	4.08	3.50	4.81	3.64
Mean								
Systems								
Pure		2.48	4.90	6.56	5.29	5.77	5.42	4.89
Intercropped		1.67	2.35	3.92	5.71	3.57	5.75	5.43
CD (P = 0.05)								
Cultivars (C)		0.68	0.96	NS	0.97	1.06	1.48	1.97
Systems (S)		0.56	0.79	1.14	NS	0.87	NS	NS
C x S		NS	1.26	NS	1.37	1.50	NS	2.79
CV (%)		35.5	29.0	29.4	30.0	24.5	28.5	42.2

Fig.18. Economic assimilation rate (EAR) at differe
stages of growth in three turmeric cultiva
under pure and intercropped stands.

●——● Cls. No.24 (1977)

○- - -○ Cls. No.24 (1978)

×——× Cll.326 Sugandham (1977)

△——△ Duggirala (1977)

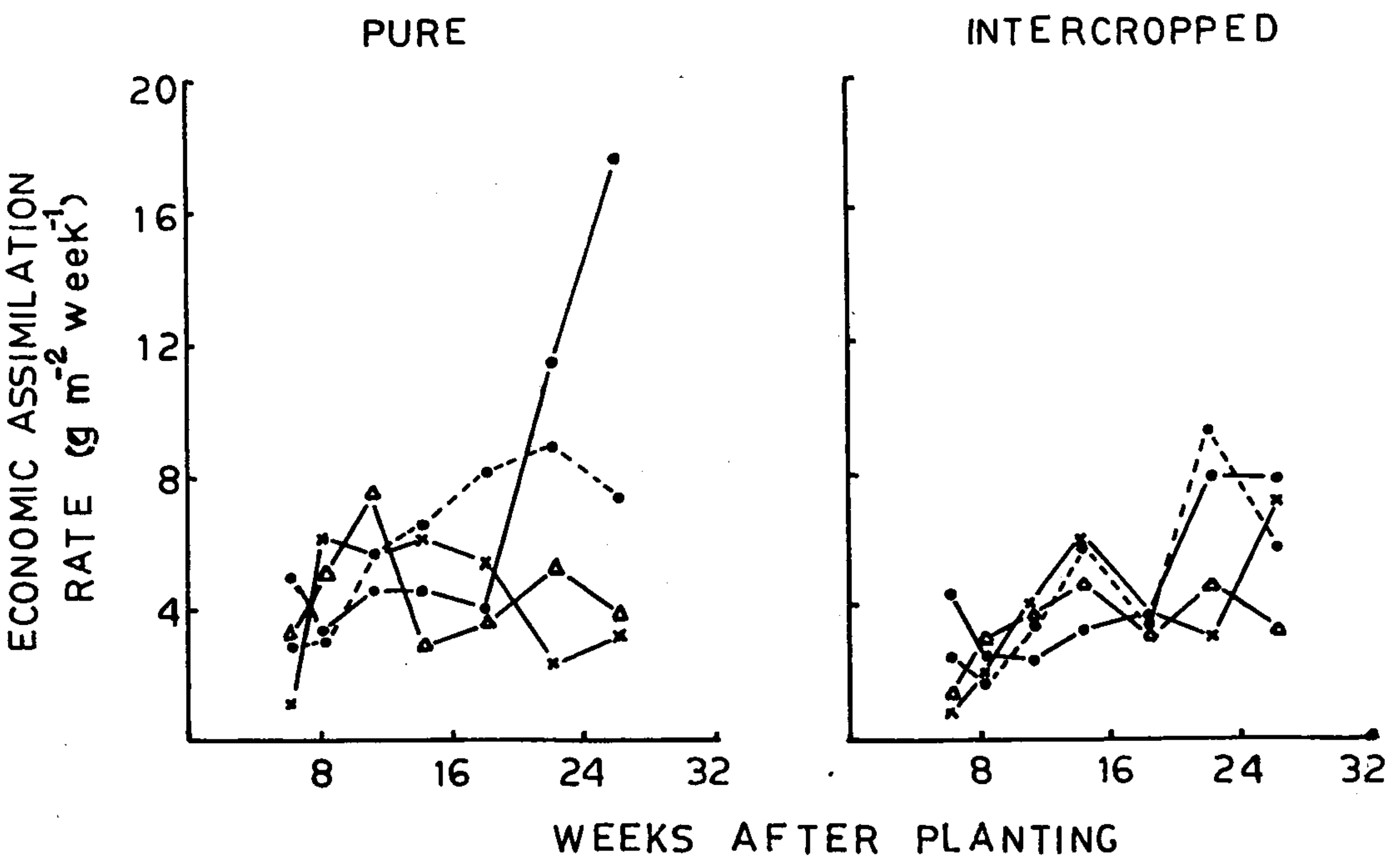

PURE
INTERCROPPED
ECONOMIC ASSIMILATION RATE (g m^{-2} week^{-1})
20
16
12
8
4
8
16
24
32
8
16
24
32
WEEKS AFTER PLANTING

FIG. 18

4.2. Photosynthetic characteristics of turmeric leaf

4.2.1. Chlorophyll pigments

Chlorophyll a. The data on chlorophyll content (per unit fresh weight) are presented in Table 28. There were significant differences in the chlorophyll levels among the cultivars and between the cropping systems. Although the chlorophyll *a* content was higher under the pure stand than under the intercropped stand for the cultivars C_1 and C_3, it was significantly higher under the intercropped stand for cultivar C_2. Under the pure stand, the values of the chlorophyll *a* content for the three cultivars were in the order, $C_3 > C_1 > C_2$ with significant differences, while under the intercropped stand the values were markedly higher for C_2 followed by C_3 and C_1 in that order.

Chlorophyll b. The levels of chlorophyll *b* were higher under the intercropped stand than under the pure stand for all the cultivars, the difference being significant only for C_1 and C_2. Under the pure stand, cultivar C_3 possessed significantly more chlorophyll *b* than C_1 and C_2, while under the intercropped stand C_2 had the maximum chlorophyll *b* content.

Chlorophyll (a + b). The total chlorophyll content was significantly higher under the intercropped stand than under the pure stand for the cultivar C_2, but no significant difference between the two cropping systems was noticed for the other two cultivars. Under the pure stand the total chlorophyll content in cultivars was in the order, $C_3 > C_1 > C_2$. Under the intercropped stand, cultivar C_2 had significantly higher content of total chlorophyll than the cultivars C_1 or C_3.

Chlorophyll a/b ratio. There was no marked difference among cultivars in their response towards the two cropping systems, monoculture system registering significantly higher a/b ratio than the intercropping system. The chlorophyll a/b ratios recorded for the three cultivars were in the order, $C_1 > C_3 > C_2$, with significant differences.

4.2.2. Air space volume

The data on the air space volume in leaves are presented in Table 28. There was no difference among the cultivars in their response towards the cropping systems, leaves from intercropping system having significantly higher air space volume than those from the monoculture system. Among the cultivars, C_2 registered higher leaf air space volume followed by C_3 and C_1 in that order.

4.2.3. Specific leaf area

The values of specific leaf area (SLA) are presented in Table 28. For all the cultivars, SLA was considerably reduced under the pure stand as compared to the intercropped stand. Among the cultivars C_1 had significantly higher SLA than C_2 or C_3.

5. Carbohydrates

The nonstructural carbohydrates, starch and total sugars, in the leaves and rhizomes of three turmeric cultivars were estimated at different stages of growth in monoculture and in association with coconut. The concentration as well as the amount per unit land area of these carbohydrate fractions were calculated. The starch/sugar ratio at different stages of growth was computed.

5.1. Starch

5.1.1. Concentration

The seasonal changes in the starch concentration (percentage of dry weight) of leaf and rhizome at different stages of growth of three turmeric cultivars under pure and intercropped stands during the years 1977 (first year) and 1978 (second year) are presented in Fig.19.

5.1.1.1. Leaf

I Year. The level of starch in leaf of cultivar C_1 increased upto 8th week, under both the cropping systems, followed by a reduction at 11th week. Beyond this period, the starch concentration in the leaves of this cultivar increased reaching the maximum at 18th and 22nd weeks, under the pure and the intercropped stands, respectively.

Fig.19. Seasonal changes in the starch concentrati
in the leaves and rhizomes of three turme
cultivars under pure and intercropped sta

A. Cls. No.24

B. Cll.326 Sugandham

C. Duggirala

○——○ 1977
○- - -○ 1978 Leaf

●——● 1977
●- - -● 1978 Rhizome

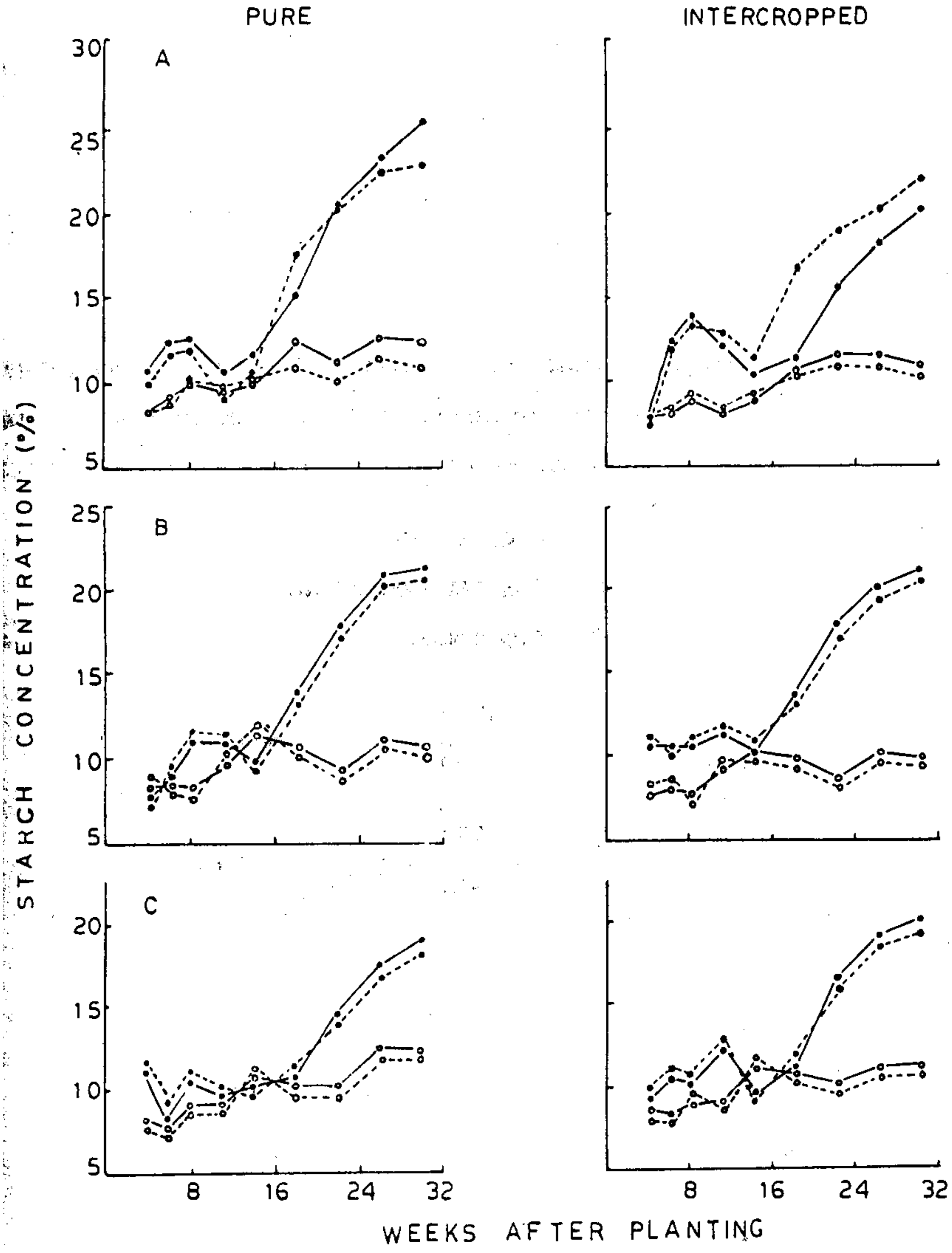

PURE
INTERCROPPED
A
B
C
STARCH CONCENTRATION (%)
30
25
20
15
10
5
25
20
15
10
5
20
15
10
5
8
16
24
32
8
16
24
32
WEEKS AFTER PLANTING

FIG. 19

The pure stand of this cultivar showed a reduction in the starch concentration in the 22nd week, while the intercropped stand did not exhibit such a trend. The leaves did not show any marked build up of starch upto 8th week in the case of cultivar C_2 and upto 6th week for the cultivar C_3. Beyond these periods the starch concentration of these cultivars increased to reach the maximum at 14th week under both the cropping systems. During the period of the 14th to the 22nd week, the starch content of the leaves was considerably reduced in these cultivars, however there was a further rise at 26th week. The leaf starch concentration for the cultivar C_1 was considerably higher than those of the other two cultivars, especially under the pure stand and from 18th week after planting.

II Year. The cultivars C_2 and C_3 did not show much difference for the starch concentration in the leaves, between the two years under both the cropping systems. In the case of cultivar C_1, eventhough the intercropping system did not show up considerable difference between the two years, starch level in leaves under the monoculture system during second year were considerably less than those in the first year, especially after 14th week after planting.

5.1.1.2. Rhizome

I Year. The starch concentration in the rhizome of the cultivar C_1 increased upto 8th week under both the cropping systems followed by a reduction by 11th week. This decrease was more pronounced under the intercropped stand. Beyond 14th week, there was a marked build up of starch in the rhizome which continued upto maturity under both the cropping systems. In the case of cultivars C_2 and C_3, a reduction in the concentration of rhizome starch was noticed by 14th week followed by a marked increase in the subsequent periods. The pure stand of cultivar C_1 registered considerably higher starch concentration than the intercropped stand at maturity, while for the other two cultivars this difference between the two cropping systems was not apparent. Eventhough the cultivar C_1 at maturity registered remarkably higher values of starch concentration in the rhizome than the other two cultivars under the monoculture system, no marked differences could be noticed among the cultivars under the intercropping system.

II Year. The starch concentration in the rhizome of cultivars C_2 and C_3 during the two years of study did not show much difference. In the case of cultivar C_1, the starch concentration in leaves under the intercropping system were comparatively higher in the second year. Under the monoculture system, the leaves had less starch in second year than that in first year, especially in the later part of the season. In contrast to the first year, cultivar C_1 did not show any appreciable difference between the two cropping systems in the starch content of the rhizome at maturity.

5.1.2. Content per unit land area

The amount of starch present in the dry matter produced per unit land area (g m^{-2}), of leaf and rhizome at different stages of growth of three turmeric cultivars under pure and intercropped stands during the years 1977 (first year) and 1978 (second year, C_1 only) are plotted in Fig.20.

5.1.2.1. Leaf

I Year. The leaves of the cultivar C_1 under the pure stand accumulated starch upto 18th week. The starch content fell by 22nd week and increased again in the 26th week. The starch content of this cultivar in an intercropped stand increased markedly upto 22nd week. In case of the cultivar C_2, the accumulation of starch in the leaves continued upto 18th and 22nd weeks, under pure and intercropped stand, respectively. The leaf starch in a pure stand of this cultivar decreased by the 22nd week. For the cultivar C_3, starch accumulated in the leaves upto 26th week under both the cropping systems. During the rhizome bulking period, the amount of starch accumulated in the leaves under the monoculture system was considerably higher than that

Fig.30. Seasonal changes in the amount of starch (expressed as unit ground area basis) in t leaves and rhizomes of three turmeric cultivars under pure and intercropped stan

A. Cls. No.24

B. Cll.326 Sugandham

C. Duggirala

○——○ 1977 | Leaf
○- - -○ 1978 |

●——● 1977 | Rhizome
●- - -● 1978 |

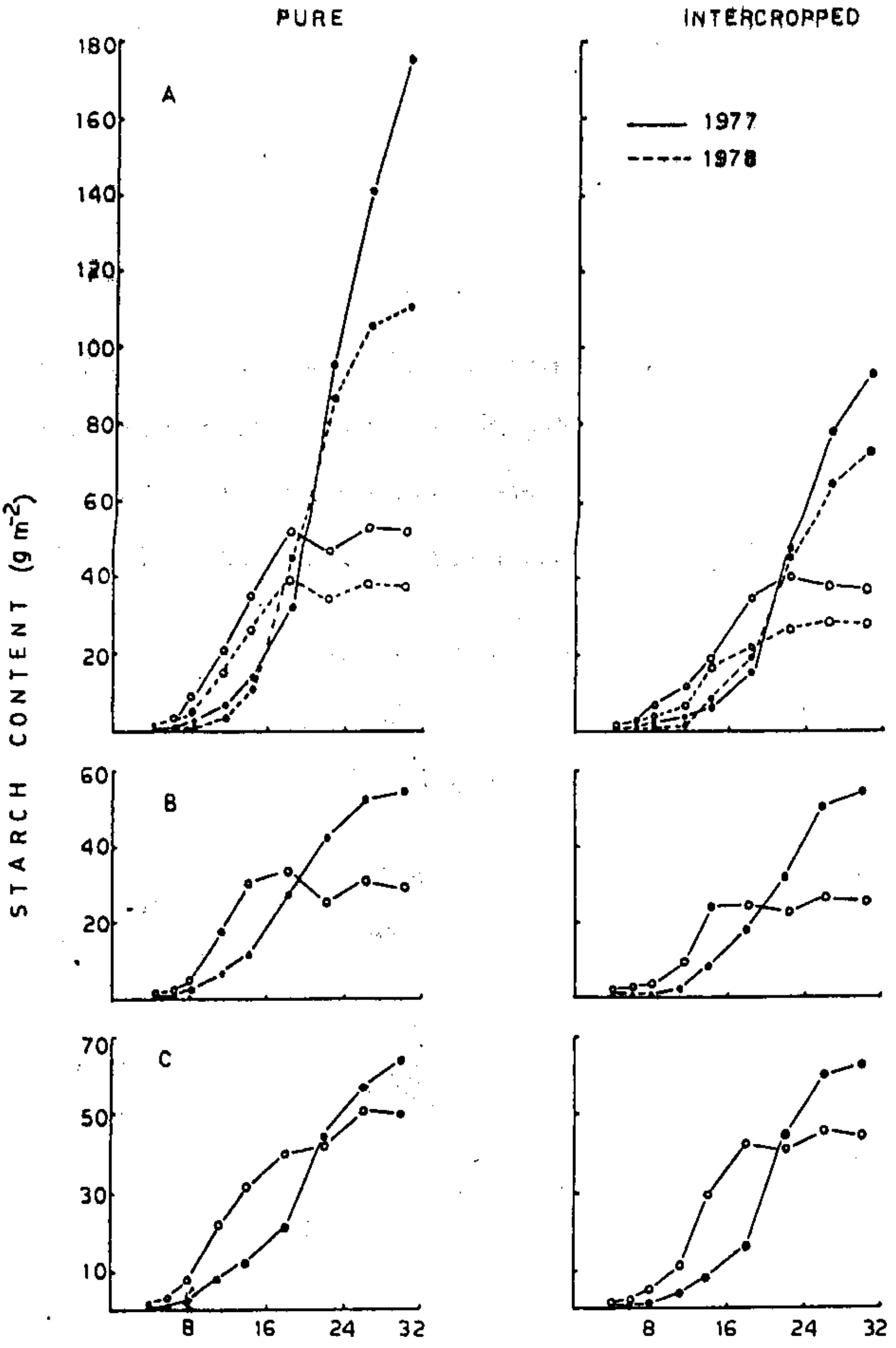

PURE
INTERCROPPED
1977
1978
A
B
C
STARCH CONTENT (g m^{-2})
180
160
140
120
100
80
60
40
20
60
40
20
70
50
30
10
8
16
24
32
8
16
24
32
WEEKS AFTER PLANTING

FIG. 20

accumulated under intercropping system, and this was more pronounced for the cultivar C_1 than for the other two cultivars. Under the monoculture cropping system, the starch content in the leaves during bulking period was in the order, $C_1 > C_3 > C_2$, while under intercropping the order was $C_3 > C_1 > C_2$.

II Year. The starch content of leaves from cultivars C_2 and C_3 during the second year did not show any considerable difference from those of the first year. For the cultivar C_1, it was remarkably reduced in the second year throughout the growth period under both the cropping systems.

5.1.2.2. Rhizome

I Year. The rhizome accumulated starch upto maturity under both the cropping systems; the increase being more pronounced after 14th week under pure stand and after 18th week under the intercropped stand. The starch accumulation in the rhizomes of the pure stand of the cultivar C_1 at maturity was considerably higher than that of the intercropped stand, while there was no marked difference between two cropping systems in case of other two cultivars. Under both the cropping systems, the starch content of rhizomes from cultivar C_1 were the highest, followed by C_3 and C_2 in that order.

II Year. The pattern of starch accumulation in the rhizomes of the cultivar C_2 and C_3 during the second year, was not much different from that of the first year. For the cultivar C_1, although there was no considerable difference between the two years at the initial stages of growth, the starch levels in rhizome were remarkably lower in second year than in the first year during the later parts of the crop growth.

5.2. Sugars

The seasonal changes in the concentration of total sugars (percentage of dry weight) of leaf and rhizome at different stages of growth of three turmeric cultivars under pure and intercropped stands during the years 1977 (first year) and 1978 (second year) are presented in Fig.21.

5.2.1. Concentration

5.2.1.1. Leaf

I Year. The pure stand of the cultivar C_1 registered a reduction in the leaf sugar concentration during the period of 6th to 11th week, while for the intercropped stand the values did not show much changes during the period of 4th to 8th week after planting. The pure stand of this cultivar had the highest sugar concentration (2.3%) at

Fig.21. Seasonal changes in the concentration of total sugars in the leaves and rhizomes of three turmeric cultivars under pure and intercropped stands.

A. Cls. No.24

B. Cll.326 Sugandham

C. Duggirala

○——○ 1977 |
　　　　　　| Leaf
○- - -○ 1978 |

●——● 1977 |
　　　　　　| Rhizome
●- - -● 1978 |

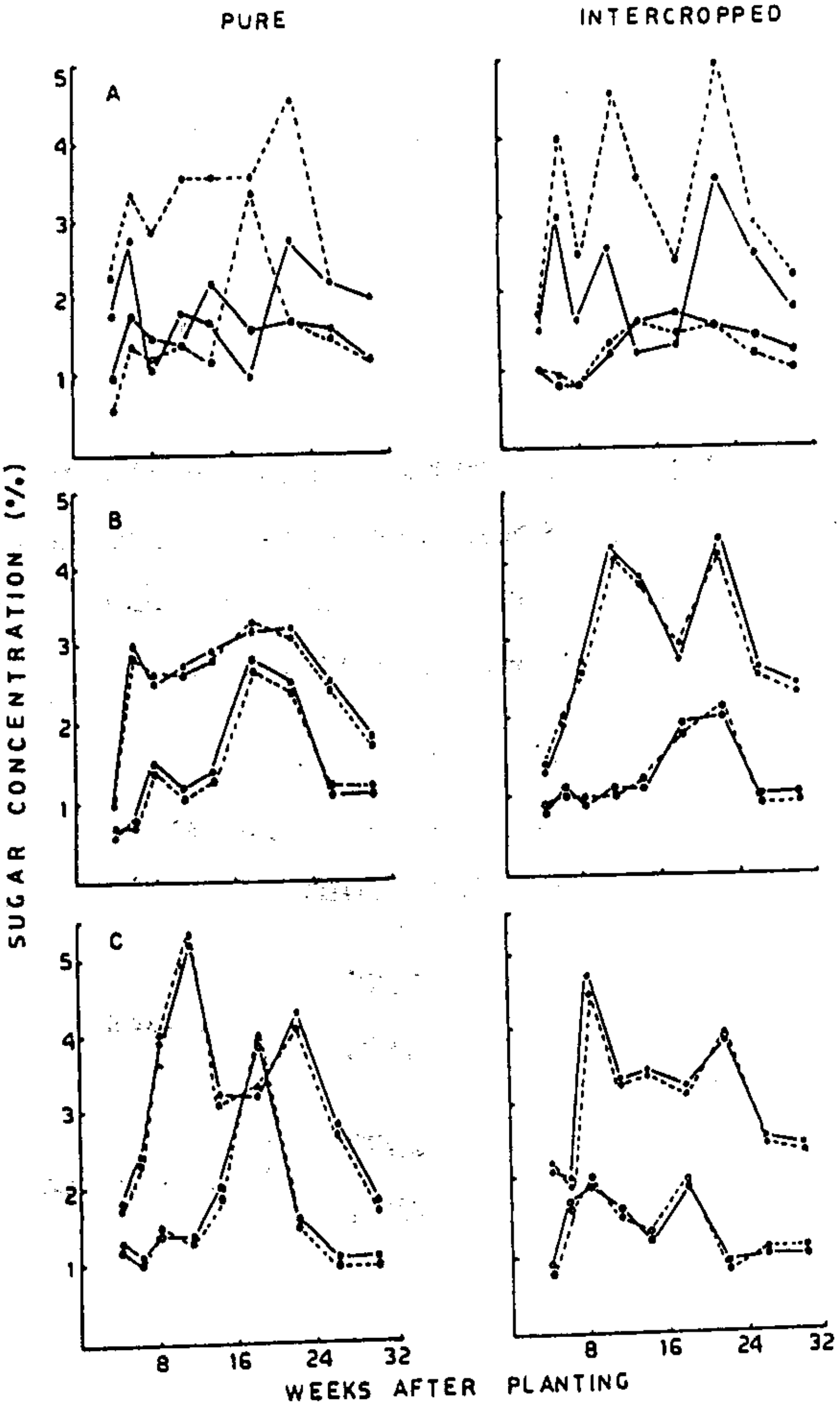

PURE
INTERCROPPED
A
B
C
SUGAR CONCENTRATION (%)
1
2
3
4
5
8
16
24
32
WEEKS AFTER PLANTING

FIG. 21

14th week and decreased markedly thereafter, whereas the leaf sugar in intercropped stand reached the maximum (1.7%) by 18th week and decreased thereafter. In case of the cultivar C_2, the sugar levels in leaves of pure stand showed a reduction by 11th week, increased thereafter to reach the maximum (2.8%) by 18th week and decreased considerably in subsequent periods. The sugar content in leaves of intercropped stand of this cultivar did not change considerably upto 14th week beyond which it increased to attain the maximum (2.0%) by 22nd week. The sugar levels however decreased markedly in the following periods. The pure stand of the cultivar C_3 showed a remarkable build up of sugars in the leaves beyond 11th week attaining the maximum (3.9%) by 18th week after planting and declined sharply in the ensuing periods. The intercropped stand of this cultivar showed a build up of sugars in the early period of growth with attaining a maximum value of 19 per cent in 8th week after planting, followed by a reduction during the periods of 11th week onwards with a small spike during the 18th week.

II Year. The concentration of sugars in the leaves of the cultivars C_2 and C_3 did not show any marked difference between the two years of the study. The pure stand of the cultivar C_1 registered maximum leaf sugar concentration during 18th week after planting, as against 14th week in the first year. The pure stand of this cultivar recorded a maximum value of 3.4 per cent as against 2.2 per cent during the first year. The intercropped stand of this cultivar did not reveal much difference in the leaf sugar concentration between the two years of study.

5.2.1.2. Rhizome

I Year. The level of sugar in rhizomes of cultivar C_1 increased remarkably upto 6th week under both the cropping systems. At the 8th week, the sugar concentration in the rhizomes of this cultivar decreased. The concentration increased again in the 11th week, the rise being more pronounced under the intercropped stand than in the pure stand. After a reduction during 14th and 18th weeks, the sugar levels in rhizomes of cultivar C_1 markedly increased during the 22nd week to reach peak values of 2.8 and 3.5 per cent, under the pure and the intercropped stands respectively. Beyond 22nd week, there was a drastic reduction in the concentration of sugars in the rhizome of this cultivar under both the cropping systems. The other two cultivars also showed an initial build up of sugars in the rhizome which was followed by a reduction. The values again rose by 22nd week attaining the maximum before falling again in the subsequent periods. For cultivar C_2, the maximum sugar concentration in the rhizome was 3.2 and 4.3 per cents for pure and intercropped stands respectively, while for cultivar C_3 the corresponding figures were 4.3 and 4.7 per cent respectively.

II Year. Cultivars C_2 and C_3 did not register any appreciable difference in the concentration of sugars in the rhizomes between the two years of the study. In case of cultivar C_1, the values were considerably higher in the second year than in the first year, under both the cropping systems.

5.2.2. Content per unit land area

The amount of total sugars present in the dry matter produced per unit land area (g m^{-2}) of leaf and rhizome at different stages of growth of three turmeric cultivars under pure and intercropped stands during the years 1977 (first year) and 1978 (second year, C_1 only) are plotted in Fig.22.

5.2.2.1. Leaf

I Year. The amount of total sugars in leaves of the cultivar C_1 increased upto 14th week under the pure stand and upto 22nd week under the intercropped stand. Beyond these periods, there was a reduction in the amount of leaf sugar under both the cropping systems eventhough it was not

Fig.22. Seasonal changes in the amount of total su
(expressed as unit ground area basis) in th
leaves and rhizomes of three turmeric cult
under pure and intercropped stands.

A. Cls. No.24
B. Cll.326 Sugandham
C. Duggirala

○——○ 1977
○- - -○ 1978
Leaf

●——● 1977
●- - -● 1978
Rhizome

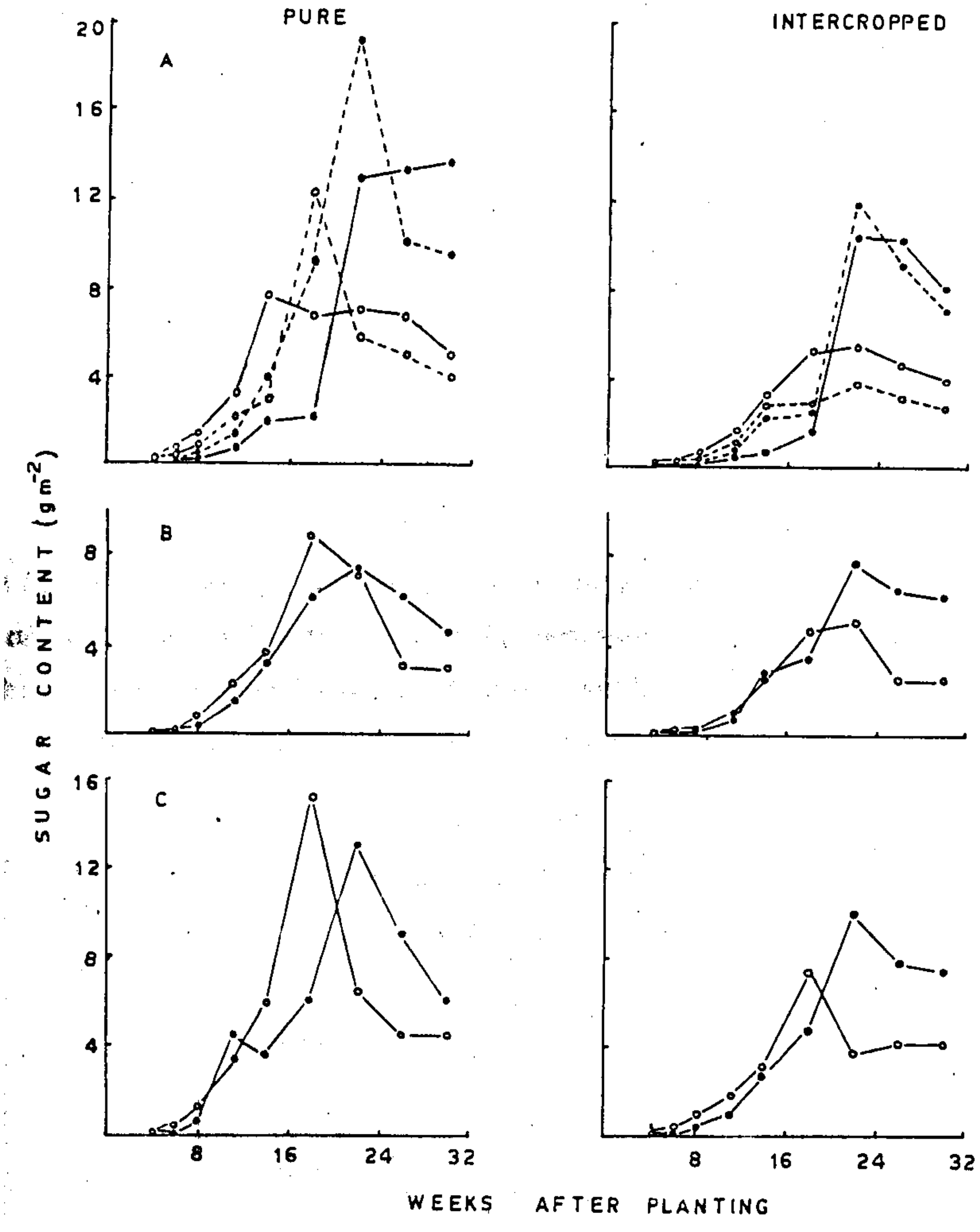

PURE
INTERCROPPED
A
B
C
20
16
12
8
4
SUGAR CONTENT (g m-2)
8
4
16
12
8
4
8
16
24
32
8
16
24
32
WEEKS AFTER PLANTING

FIG. 22

so marked as seen in the other two cultivars. In the case of cultivar C_2, the maximum amount of sugars in the leaves was recorded during 18th and 22nd weeks under the pure and intercropped stands respectively. Cultivar C_3 showed maximum amount of sugars in the leaves during 18th week under both the cropping systems, followed by a marked reduction in the subsequent periods of growth. Generally, all the cultivars produced higher amount of sugars in the leaves when grown under monoculture system than under the intercropping system.

<u>II Year</u>. The amount of total sugars in leaves of cultivars C_2 and C_3 during the second year were not much different from those of the first year. The leaves of the cultivar C_1 had less sugar in the second year than in first year.

5.2.2.2. Rhizome

<u>I Year</u>. The amount of total sugars in the rhizomes increased upto 22nd week for the cultivar C_1, under both the cropping systems. The intercropped stand of this cultivar showed a reduction in the amount of sugars in the rhizome at maturity, while the pure stand did not exhibit such a trend. The increase in the amount of sugars in the rhizomes of this cultivar was quite pronounced beyond 18th week under both the cropping systems. In case of cultivars C_2 and C_3, the maximum amount of sugars in the rhizomes

was noticed during the 22nd week, followed by a reduction in the subsequent periods when the rhizomes were getting matured. The maximum amount of sugars recorded during the 22nd week was considerably higher for the cultivars C_1 and C_3 than for the C_2 under both the cropping systems.

II Year. The level of total sugars in the rhizomes of the cultivars C_2 and C_3 during the second year was not appreciably different from that of the first year. In the case of the cultivar C_1, there was not much difference in the amount of rhizome sugar between the two years under the intercropped stand. The sugar content in rhizomes was higher in the second year than in the first year under the pure stand.

5.3. Starch/sugar ratio

I Year. The starch/sugar ratios of leaf and rhizome in relation to the rhizome growth rate of three turmeric cultivars under pure and intercropped stands are depicted in Fig.23. The pure stand of the cultivar C_1 had the highest starch/sugar ratio in the rhizome in the 18th week after planting followed by a sharp reduction during the 22nd week. The starch/sugar ratio of the leaves of this cultivar under the pure stand was markedly reduced during 14th and 22nd weeks, coinciding with higher rhizome growth rates. The maximum rhizome growth rate noted for this cultivar under the pure stand by 22nd week was associated

Fig.23. Seasonal changes in starch/sugar ratios in leaves and rhizomes as influenced by rhizo growth rate in three turmeric cultivars un pure and intercropped stands.

A. Cls. No.24 (1977)

B. Cls. No.24 (1978)

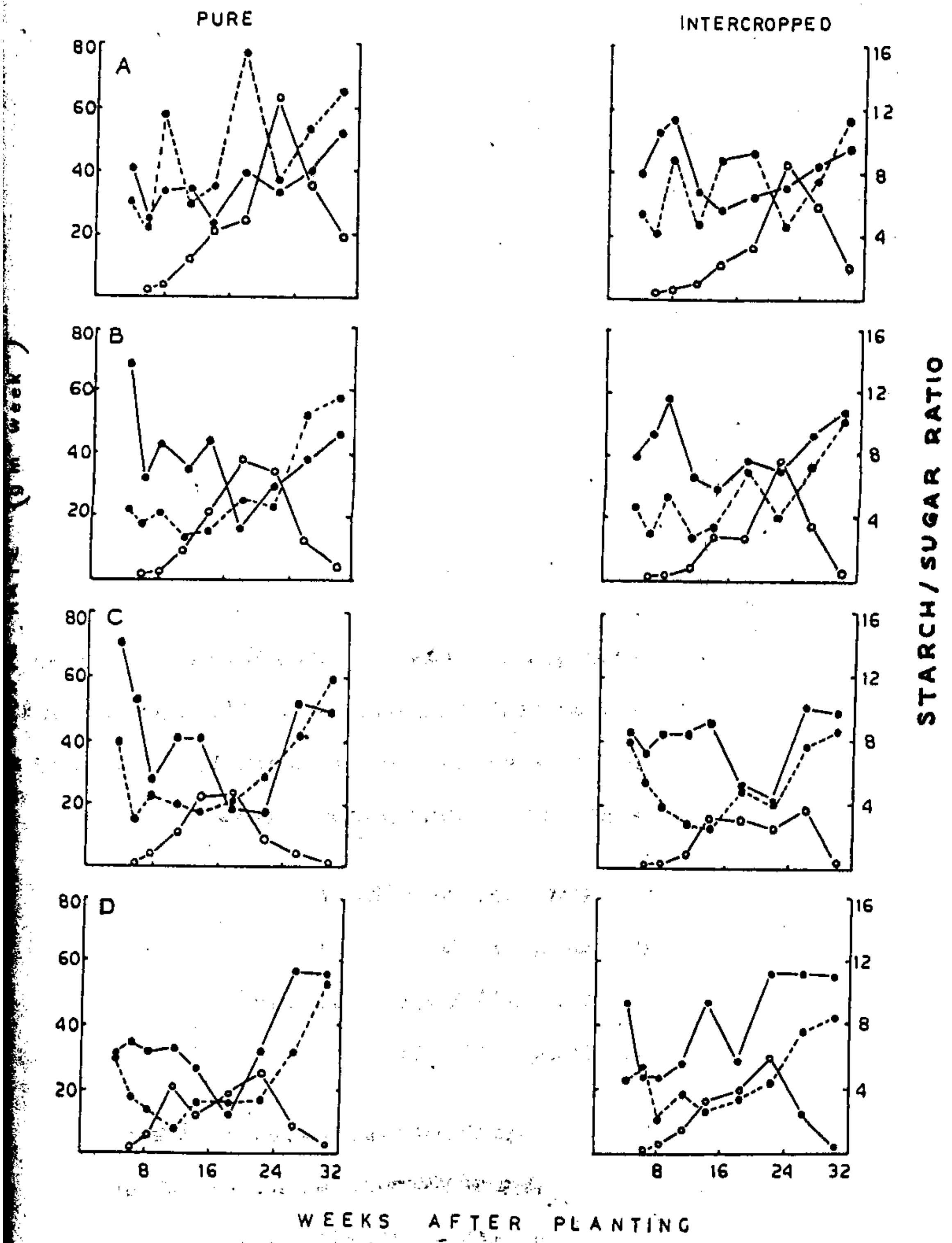
C. Cll.328 Sugandham (1977)

D. Duggirala (1977)

•——• Starch/sugar ratio in leaf

•----• Starch/sugar ratio in rhizome

○——○ Rhizome growth rate



PURE
INTERCROPPED
A
B
C
D
80
60
40
20
16
12
8
4
(g m week)
STARCH/SUGAR RATIO
8
16
24
32
WEEKS AFTER PLANTING

FIG. 23

with a reduction in the starch/sugar ratio of rhizomes also. The intercropped stand of this cultivar also showed a close association of its maximum rhizome growth rate by 22nd week with a marked reduction in the starch/sugar ratio in the rhizome, eventhough this reduction in the starch/sugar ratio in the leaves had noticed much earlier. Similarly, the starch/sugar ratio in the leaves of cultivar C_2 was considerably reduced during the periods when the rhizome growth rate was higher. In the case of cultivar C_3, the maximum rhizome growth noticed by 22nd week was preceded by a remarkable reduction in the starch/sugar ratio in the leaves i.e. during the 18th week under both the cropping systems. Beyond 22nd week when the rhizome growth was considerably reduced, the starch/sugar ratio of both the leaves and rhizomes of all the cultivars increased.

<u>II Year</u>. The values of starch/sugar ratio in the rhizomes and leaves and its relationship with the rhizome growth rate during the second year of study did not show any appreciable difference from those of the first year for the cultivars C_2 and C_3. The pure stand of the cultivar C_1 attained maximum rhizome growth rate earlier in the second year, by 18th week itself which coincided with a sharp reduction in the starch/sugar ratio in the leaves.

The intercropped stand of this cultivar had also shown the coincidence of the maximum rhizome growth rate attained by 22nd week with lower values of starch/sugar ratio in both the rhizomes and leaves.

6. Partitioning of assimilates and yield

The pattern of assimilate partitioning between root, shoot and rhizome at various stages of growth was studied. The data were used to calculate partition coefficient, rhizome/shoot ratio, and harvest index. Biological as well as rhizome yield of three turmeric cultivars as influenced by the cropping systems was examined.

6.1. Partitioning of assimilates

6.1.1. Partitioning of assimilates among plant parts

<u>I Year</u>. The pattern of assimilate partitioning among root, shoot and rhizome at successive stages of growth (expressed as the percentage of the total dry matter accumulated at maturity) of three turmeric cultivars under pure and intercropped stand during the year 1977 is depicted in Fig.24. The shoot accumulated the most of dry matter upto 18th week under both the cropping systems. During this period, the dry matter partitioned into rhizome was negligible. Beyond 18th week after planting, there was a steady increase in the extent of dry matter in the rhizome under both the cropping system. The amount of dry matter in root was generally meagre in all the cultivars.

Fig.24. Partitioning of dry matter among various plant parts (expressed as per centage of to of three turmeric cultivars under pure and intercropped stands.

A. Cls. No.24 (1977)
B. Cls. No.24 (1978)
C. Cll.328 Sugandham (1977)
D. Duggirala (1977)

Rh - Rhizome
St - Shoot
Rt - Root

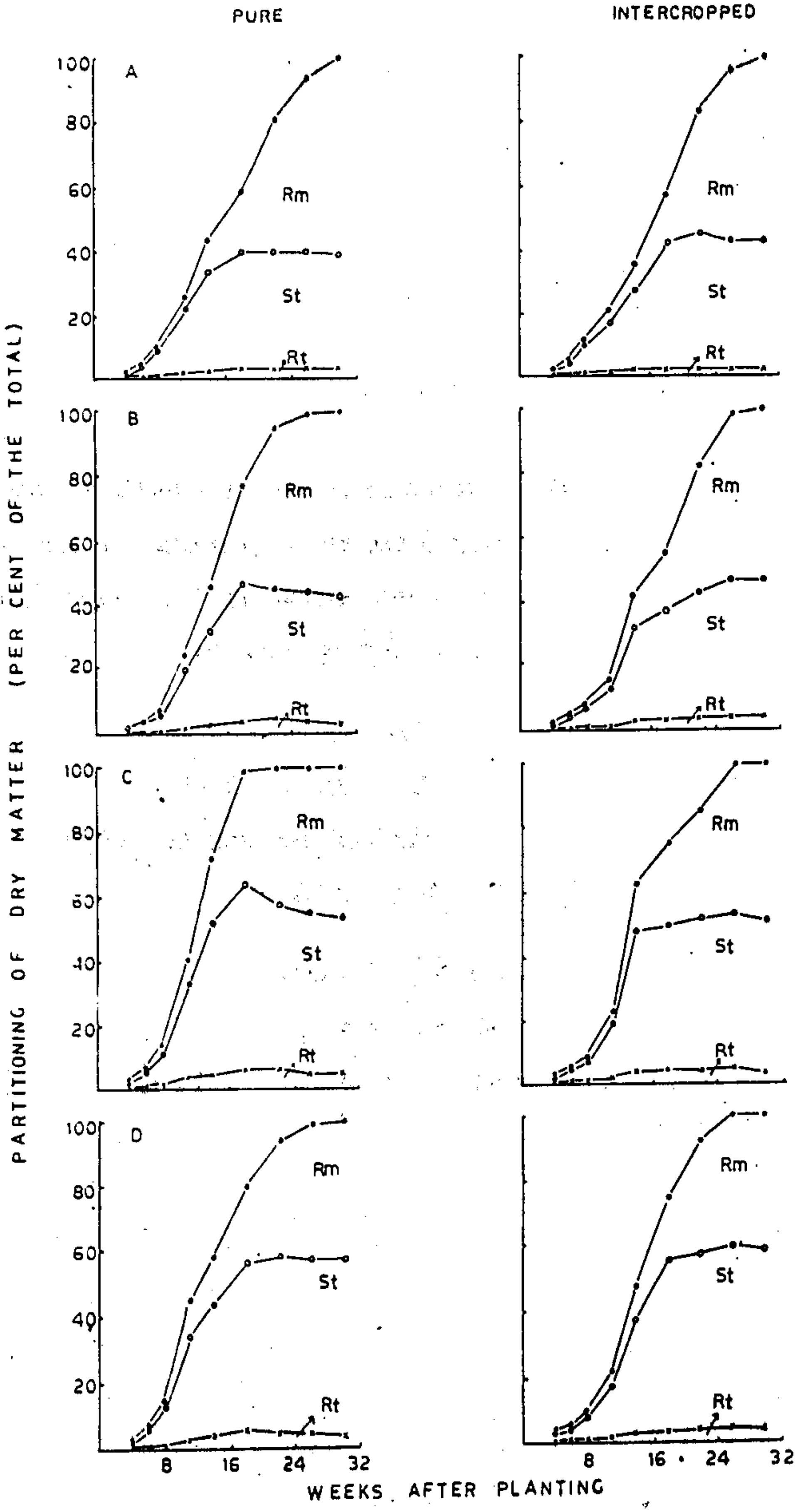

PURE
INTERCROPPED
PARTITIONING OF DRY MATTER (PER CENT OF THE TOTAL)
A
B
C
D
Rm
St
Rt
100
80
60
40
20
8
16
24
32
WEEKS AFTER PLANTING

FIG. 24

At maturity the root, shoot and rhizome of the pure stand of the cultivar C_1 contributed 2.5, 36.9 and 60.6 per cent, respectively, of the total dry matter produced. The corresponding figures for the intercropped stand of this cultivar were 2.1, 40.8 and 57.1 per cent, respectively. The pure stand of the cultivar C_2 did not show much increase in the total dry matter accumulation beyond 18th week but the dry matter partitioned in rhizome increased. At maturity the root, shoot and rhizome of the pure stand of this cultivar contributed 4.7, 49.7 and 45.6 per cent, respectively, of the total dry matter produced. The corresponding figures for the intercropped stand were 3.3, 48.0 and 48.7 per cents respectively. At maturity, the root, shoot and rhizome of the pure stand of the cultivar C_3 contributed 4.2, 52.4 and 43.4 per cents respectively, of the total dry matter produced. The corresponding figures for the intercropped stand were 3.8, 53.7 and 42.5 per cents respectively. By 18th week itself, the pure stand of the cultivars C_2 and C_3 had reached 99 and 80 per cents respectively, of the total dry matter accumulated at maturity as against 59 per cent for the cultivar C_1. The corresponding figures for the intercropped stand of the cultivars C_2 and C_3 were 75 and 74 per cents respectively, as against 58 per cent for the cultivar C_1. During the 14th and 18th weeks, the extent of dry matter contribution from rhizomes of cultivars C_2 and C_3 was considerably higher than that of C_1, but beyond 18th week, the dry matter contribution by rhizome was remarkably higher in cultivar C_1 than that of other two cultivars.

<u>II Year</u>. The assimilate partitioning pattern of the cultivars C_2 and C_3 during the second year was similar to that of the first year. The pure stand of the cultivar C_1 did not show much increase in the amount of dry matter partitioned towards the rhizome beyond 22nd week. About 77 per cent of the total dry matter accumulated at maturity was attained by 18th week for the pure stand of this cultivar as against 59 per cent in the first year during the same period. The dry matter partitioned in the rhizome in a pure stand of this cultivar, during the period of 14th to 22nd week was higher in the second year than that in the first year. Intercropped stand of this cultivar showed increasing contribution of shoot towards total dry matter upto 26th week after planting (Fig.24b).

6.1.2. Partition coefficient

<u>I Year</u>. The values of partition coefficient (PC) at different stages of growth of the three turmeric cultivars under pure and intercropped stands during 1977 are given in Table 31a. During the early period of crop growth, starting from 6th to 11th week, the partition coefficients were higher for the cultivars C_2 and C_3 than for C_1. At this time, pure stands of cultivars C_2 and C_3 registered markedly higher partition coefficients than their intercropped stands, eventhough the difference was not pronounced

under pure and intercropped stands during the year 1977

Cropping systems	Cultivars	Weeks after planting					
		4-6	6-8	8-11	11-14	14-18	18-22
Pure	C_1	15.8	11.0	20.2	32.3	59.4	100.0
	C_2	5.4	24.6	23.1	38.7	56.0	140.0
	C_3	10.9	19.3	29.0	35.1	39.7	89.4
Intercropped	C_1	19.0	10.3	19.6	28.9	37.0	86.5
	C_2	5.9	16.8	18.4	26.2	82.0	89.5
	C_3	14.5	15.4	21.7	27.4	35.5	79.5
Mean Cultivars							
C_1		17.4	10.7	19.9	30.6	48.2	93.3
C_2		5.7	20.7	20.7	32.5	69.0	114.8
C_3		12.7	17.3	25.3	31.3	37.6	84.5
Mean Systems							
Pure		10.7	18.3	24.1	35.4	51.7	109.8
Intercropped		13.2	14.2	19.9	27.5	51.5	85.2
CD (P = 0.05)							
Cultivars (C)		2.8	2.8	3.4	NS	10.0	8.6
Systems (S)		2.3	2.3	2.8	5.6	NS	7.0
C x S		NS	4.0	NS	NS	14.1	16.4
CV (%)		25.3	18.7	16.6	24.0	20.8	18.2

Table 33b. Partition coefficient (%) of three turmeric cultivars at different stages of growth under pure and intercropped stands during the year 1978

Cropping systems	Cultivars	Weeks after planting					
		4-6	6-8	8-11	11-14	14-18	18-22
Pure	C_1	13.7	19.7	20.5	40.8	55.3	102.3
	C_2	5.5	24.7	23.1	39.3	56.8	145.1
	C_3	10.9	19.3	29.0	35.6	39.7	89.5
Intercropped	C_1	14.2	11.5	22.1	29.4	60.2	77.1
	C_2	4.8	16.6	18.3	26.4	87.6	92.7
	C_3	14.5	15.2	21.7	27.7	35.0	80.4
Mean							
Cultivars							
C_1		13.9	15.6	21.3	35.1	57.8	89.7
C_2		5.2	20.6	20.7	32.8	72.2	118.9
C_3		12.7	17.2	25.3	31.7	37.4	85.0
Mean							
Systems							
Pure		10.0	21.2	24.2	38.6	50.6	112.3
Intercropped		11.2	14.4	20.7	27.8	60.9	83.4
CD (P = 0.05)							
Cultivars (C)		3.0	3.5	NS	NS	10.6	8.5
Systems (S)		NS	2.8	3.4	5.7	8.7	7.0
C x S		NS	NS	NS	NS	15.0	17.1
CV (%)		30.7	21.0	20.3	23.3	19.9	18.2

for the cultivar C_1. Between 14th to 18th week, the partition coefficients of cultivars C_1 and C_2 were markedly higher than that of C_3. During this period, the PC of the pure stand of the cultivar C_1 was significantly higher than that of the intercropped stand, while a reverse trend was true in case of cultivar C_2. There was no significance difference between the two cropping systems for the PC values of cultivar C_3 during this period. Beyond 18th week also, the partition coefficient noted for the cultivars C_1 or C_2 were higher than that for C_3. The intercropped stand of cultivar C_2 attained the highest PC during the period of 14th to 18th week itself.

II Year. The values of PC at different stages of growth of three turmeric cultivars under pure and intercropped stands during the year 1978 are given in Table 31b. There was not much difference in the values of two years of study for cultivars C_2 and C_3. In the case of cultivar C_1, the values of PC were higher in the second year than in the first year during the early period of growth i.e. 6th to 14th and 6th to 18th weeks, under pure and intercropped stands, respectively.

6.1.3. Rhizome/shoot ratio

I Year. The values of rhizome/shoot ratio at different stages of growth of three turmeric cultivars under pure and

Table 32a. Rhizome/shoot ratio (g g^{-1}) of three turmeric cultivars at different stages of growth under pure and intercropped stands during the year 1977

Cropping systems	Cultivars	Weeks after planting								
		4	6	8	11	14	18	22	26	30
Pure	C_1	0.216	0.220	0.164	0.228	0.330	0.400	1.104	1.452	1.650
	C_2	0.142	0.102	0.226	0.280	0.414	0.608	0.818	0.896	0.922
	C_3	0.162	0.144	0.202	0.358	0.411	0.494	0.718	0.808	0.840
Intercropped	C_1	0.198	0.222	0.168	0.208	0.290	0.480	0.882	1.270	1.410
	C_2	0.162	0.110	0.152	0.214	0.322	0.530	0.707	0.976	1.018
	C_3	0.121	0.128	0.170	0.244	0.330	0.388	0.654	0.778	0.794
Mean										
Cultivars										
C_1		0.207	0.221	0.166	0.218	0.310	0.440	0.993	1.361	1.530
C_2		0.152	0.106	0.189	0.247	0.368	0.569	0.763	0.936	0.970
C_3		0.142	0.136	0.186	0.301	0.371	0.441	0.686	0.793	0.817
Mean										
Systems										
Pure		0.173	0.152	0.197	0.289	0.385	0.533	0.880	1.052	1.137
Intercropped		0.160	0.157	0.163	0.222	0.314	0.439	0.748	1.008	1.070
CD (P = 0.05)										
Cultivars (C)		0.029	0.025	0.019	0.040	NS	0.052	0.086	0.074	0.082
Systems (S)		NS	NS	0.016	0.033	0.043	0.042	0.070	NS	0.067
C x S		NS	NS	0.027	NS	NS	NS	NS	0.104	0.115
CV (%)		19.0	17.5	11.5	16.9	16.7	11.6	11.3	7.8	8.0

Table 32b. Rhizome/shoot ratio (g g^{-1}) of three turmeric cultivars at different stages of growth under pure and intercropped stands during the year 1978

Cropping systems	Cultivars	Weeks after planting								
		4	6	8	11	14	18	22	26	30
Pure	C_1	0.118	0.136	0.190	0.250	0.444	0.712	1.175	1.347	1.432
	C_2	0.132	0.096	0.224	0.275	0.436	0.612	0.832	0.904	0.926
	C_3	0.150	0.142	0.202	0.358	0.413	0.496	0.715	0.830	0.840
Intercropped	C_1	0.126	0.154	0.150	0.238	0.344	0.536	1.062	1.216	1.244
	C_2	0.170	0.106	0.148	0.212	0.322	0.530	0.709	0.986	1.017
	C_3	0.124	0.122	0.168	0.244	0.332	0.384	0.654	0.772	0.798
Mean Cultivars										
C_1		0.122	0.155	0.170	0.248	0.394	0.624	1.119	1.282	1.338
C_2		0.151	0.101	0.186	0.244	0.389	0.571	0.766	0.940	0.972
C_3		0.137	0.132	0.186	0.301	0.373	0.440	0.686	0.791	0.819
Mean Systems										
Pure		0.140	0.131	0.205	0.297	0.424	0.607	0.904	1.017	1.066
Intercropped		0.123	0.127	0.155	0.231	0.333	0.483	0.808	0.991	1.020
CD (P = 0.05) Cultivars (C)		NS	0.024	NS	NS	NS	0.068	0.087	0.062	0.073
Systems (S)		NS	NS	0.017	0.041	0.044	0.055	0.071	NS	NS
C x S		0.036	NS	NS	NS	NS	NS	NS	0.087	0.103
CV (%)		30.0	20.1	12.5	20.2	15.3	13.3	10.9	6.6	7.6

intercropped stands during the year 1977 are given in Table 32a. Monoculture system favoured higher ratios than the intercropping systems throughout the growth cycle. A reduction in the rhizome/shoot ratio of cultivar C_1 occurred during 8th week under both the cropping systems, while for C_2 and C_3, such a trend was visible during 6th week itself. Beyond these periods the rhizome/shoot ratio increased upto maturity. Cultivar C_1 recorded higher rhizome/shoot ratio than the other two cultivars upto 6th week while after this period upto 18th week, the rhizome/shoot ratios of cultivars C_2 and C_3 were greater than that of C_1. Beyond 18th week, the rhizome/shoot ratios of the three cultivars was in the order, $C_1 > C_2 > C_3$, with significant differences. During this period, cultivar C_1 under the pure stand recorded significantly higher values than under the intercropped stand, while for the other two cultivars, there was no significant difference between the two cropping systems.

<u>II Year</u>. The values of rhizome/shoot ratio at different stages of growth of three turmeric cultivars under pure and intercropped stands during the year 1978 are given in Table 32b. The rhizome/shoot ratio of the cultivars C_2 and C_3 did not show up any marked difference between the two years of study. The rhizome/shoot ratio of the cultivar C_1 in the second year was less than that in the first year upto 6th and 8th weeks, under pure and

intercropped stands respectively. Beyond these periods and upto 22nd week, the values recorded for this cultivar in the second year were higher than those in the first year. Beyond 22nd week, the rhizome/shoot ratio of this cultivar in the second year was considerably less than that in the first year, under both the cropping systems.

6.1.4. Harvest Index (HI)

The harvest indices of the three cultivars under both the cropping systems during the years 1977 (first year) and 1978 (second year) are presented in Table 33. Under the monoculture system, the HI of the cultivar C_1 was significantly higher than those of cultivars C_2 and C_3, without any significant difference between the latter two. Under intercropping system, the harvest indices of the three cultivars were in the order, $C_1 > C_2 > C_3$ with significant differences. Harvest index of the cultivar C_1 under monoculture was significantly higher than that under the intercropping, while for the other two cultivars this difference between the two cropping systems was not significant during both the years. Harvest indices of the cultivars C_2 and C_3 did not register any marked difference between the two years of study, whereas that of the cultivar C_1 was considerably reduced in the second year than that in first year under both the cropping systems. In spite of this reduction, the HI of cultivar C_1 was greater than that

Table 33. Yield and harvest index of three turmeric cultivars grown under pure and inter-cropped stands during the years 1977 and 1978

Cropping systems	Cultivars	Biological yield (t/ha) 1977	Biological yield (t/ha) 1978	Rhizome yield (t/ha) 1977	Rhizome yield (t/ha) 1978	Harvest index 1977	Harvest index 1978
Pure	C_1	11.18	8.37	6.78	4.75	0.61	0.57
	C_2	5.68	5.55	2.59	2.53	0.46	0.46
	C_3	7.90	7.77	3.44	3.38	0.44	0.44
Intercropped	C_1	7.88	6.05	4.50	3.21	0.57	0.53
	C_2	5.51	5.38	2.65	2.59	0.48	0.48
	C_3	7.71	7.57	3.27	3.22	0.43	0.43
Mean							
Cultivars							
C_1		9.53	7.21	5.64	3.98	0.59	0.55
C_2		5.59	5.46	2.62	2.56	0.47	0.47
C_3		7.81	7.67	3.36	3.30	0.44	0.44
Mean							
Systems							
Pure		8.25	7.23	4.27	3.56	0.50	0.49
Intercropped		7.03	6.33	3.47	3.01	0.49	0.48
CD (P = 0.05)							
Cultivars (C)		0.80	0.72	0.35	0.34	0.02	0.02
Systems (S)		0.65	0.59	0.29	0.27	NS	NS
C x S		1.12	1.02	0.50	0.47	0.03	0.03
CV (%)		11.3	11.5	9.9	11.2	3.9	4.0

of other two cultivars under both the cropping systems in the second year also.

6.2. Yield

6.2.1. Biological yield

The extent of biological yield of three turmeric cultivars under pure and intercropped stands during the years 1977 (first year) and 1978 (second year) are given in Table 33. The biological yield of the three cultivars under the monoculture during first year was in the order, $C_1 > C_3 > C_2$ with significant differences. Under the intercropping system, the biological yield during the first year of cultivars C_1 or C_3 was significantly higher than that of C_2; the former two did not differ much. The biological yield of the cultivar C_1 under the pure stand was significantly higher than that under the intercropped stand, but for the other two cultivars, the difference between the two cropping systems was not significant. The biological yield of the cultivar C_1 was considerably reduced in the second year as compared to the first year under both the cropping systems, while for the other two cultivars this difference between the two years was negligible. During second year, in contrast to first year, there was no significant difference between the cultivars C_1 and C_3 for the biological yield under the monoculture system, eventhough both of these cultivars maintained significantly higher biological yield than that of the cultivar C_2. Under the intercropping system, cultivar C_3 recorded significantly higher biological yield than the other two cultivars.

6.2.2. Rhizome yield

The rhizome yield of three turmeric cultivars under pure and intercropped stands during the year 1977 (first year) and 1978 (second year) is presented in the Table 33. The rhizome yield of the three cultivars under both the cropping systems during the first year of study were in the order, $C_1 > C_3 > C_2$, the differences being significant. The rhizome yield of the cultivar C_1 under the pure stand was significantly higher than that under the intercropped stand, while for the other two cultivars this difference between the two cropping systems was not significant during both the years of study. The rhizome yield of cultivar C_1 was considerably reduced in the second year compared to the first year under both the cropping systems while for the other two cultivars, no remarkable difference was noticed between the two years of study. During second year, in spite of a reduction, cultivar C_1 still maintained significantly higher rhizome yield than the other two cultivars under the monoculture system. Under the intercropping system, the rhizome yield of the cultivar C_1 was in par with that of the cultivar C_2 during the second year of study, and the rhizome yield of these two cultivars was significantly higher than that of cultivar C_3.

7. Uptake of nutrients

The seasonal changes in concentration, accumulation and partitioning of major nutrients, nitrogen, phosphorus and potassium were investigated for three turmeric cultivars under the two cropping systems. An attempt was made to establish the extent of redistribution of nutrients to the rhizome. The relation between nutrient accumulation and growth was examined.

7.1. Nutrient concentration

7.1.1. Nitrogen

The N concentration in the leaves, roots and rhizomes at different stages of growth of three turmeric cultivars under pure and intercropped stands during the year 1977 are presented in Fig.25. The N concentration in the leaves and roots declined from the earlier periods of growth upto maturity. The cultivars did not show any marked difference between the cropping systems for the N concentration in the leaves and roots. The maximum N concentration in leaves and roots was 2.5 and 1.6 per cents respectively. In case of rhizome, cultivar C_1 showed a continued decrease in the N concentration upto 22nd week beyond which the concentration increased upto maturity. In the case of cultivar C_2, the N concentration in the rhizome declined upto 18th week under

Fig.25. Nitrogen concentration at different stag
growth in three turmeric cultivars under
and intercropped stands.

A. Cls. No.24 (1977)
B. Cls. No.24 (1978)
C. Cll.328 Sugandham (1977)
D. Duggirala (1977)

○——○ Leaf
●——● Rhizome
×——× Root

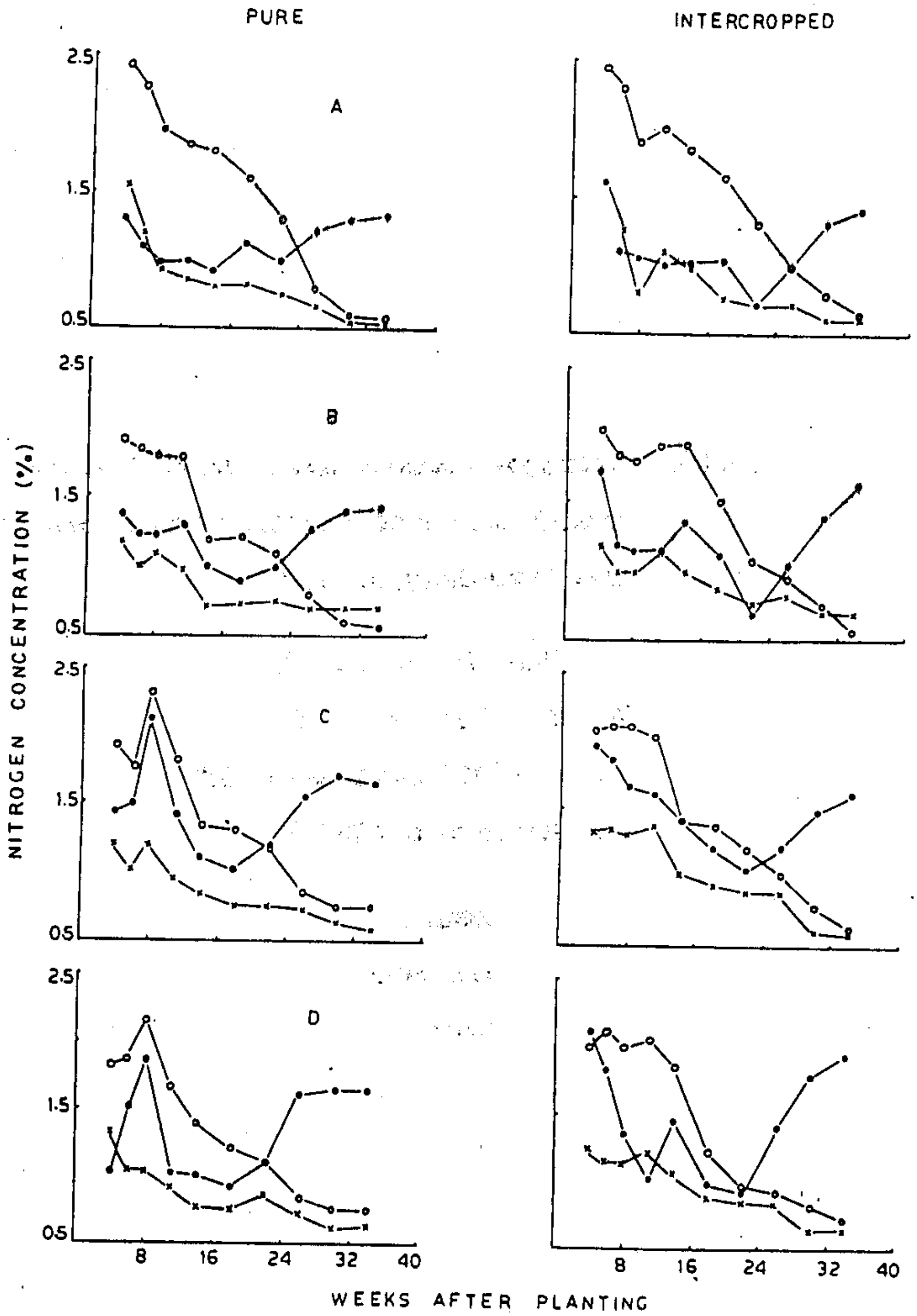

PURE
INTERCROPPED
A
B
C
D
NITROGEN CONCENTRATION (%)
2.5
1.5
0.5
8
16
24
32
40
WEEKS AFTER PLANTING

FIG. 25

pure stand and upto 22nd week under intercropped stand beyond which it continued to increase upto maturity. The cultivar C_3 showed a rise in the rhizome N concentration by 8th and 14th weeks under pure and intercropped stands respectively. It further increased beyond 18th week under both the cropping systems.

The maximum N concentration in the rhizome during early period of growth was 1.3, 2.1 and 1.9 per cents for the cultivars C_1, C_2 and C_3 respectively under the pure stand as against 1.6, 2.0 and 2.1 per cents respectively under the intercropped stand. The corresponding figures at the time of maturity were 1.3, 1.6 and 1.6 per cents respectively under the pure stand and 1.4, 1.6 and 1.9 per cents respectively under the intercropped stand. It was found that the leaf N concentration was higher than that of root and rhizome upto 22nd week beyond which N was higher in the rhizome than in the other plant parts.

The seasonal changes in the N concentration in different plant parts of the cultivar C_1 during the year 1978 are presented in Fig.23b. The N concentration in the different plant parts of the cultivar C_2 and C_3 did not show any considerable difference between the two years of planting. In case of cultivar C_1 the leaf N concentration was reduced in the second year as compared to the first year.

The root N concentration of this cultivar was comparatively less in second year in the early period of growth; while in the case of rhizome, it was higher in the second year throughout the growth period.

7.1.2. Phosphorus

The seasonal changes in the phosphorus concentration in the leaves, roots and rhizomes of three turmeric cultivars under pure and intercropped stands during the year 1977 are presented in Fig.26. The leaf P concentration for the cultivar C_1 attained the maximum by 11th week beyond which it declined considerably under both the cropping systems, the maximum being 0.43 and 0.50 per cents under pure and intercropped stands respectively. For cultivar C_2, the leaf P concentration decreased from the earlier periods upto maturity, the maximum concentration registered being 0.44 and 0.46 per cents under pure and intercropped stands respectively. In the case of cultivar C_3 also, the decline in leaf P concentration was noticed from earlier periods onwards, the maximum recorded being 0.42 and 0.47 per cents under pure and intercropped stands respectively. There was a steady decrease in the root P concentration from the earlier periods upto maturity. The maximum root P concentration recorded for different cultivars was in the range of about 0.25 to 0.30 per cent.

Fig.24. Phosphorus concentration at different stag
of growth in three turmeric cultivars und
pure and intercropped stands.

A. Cls. No.24 (1977)

B. Cls. No.24 (1978)

C. Cll.328 Sugandham (1977)

D. Duggirala (1977)

○——○ Leaf

●——● Rhizome

×——× Root

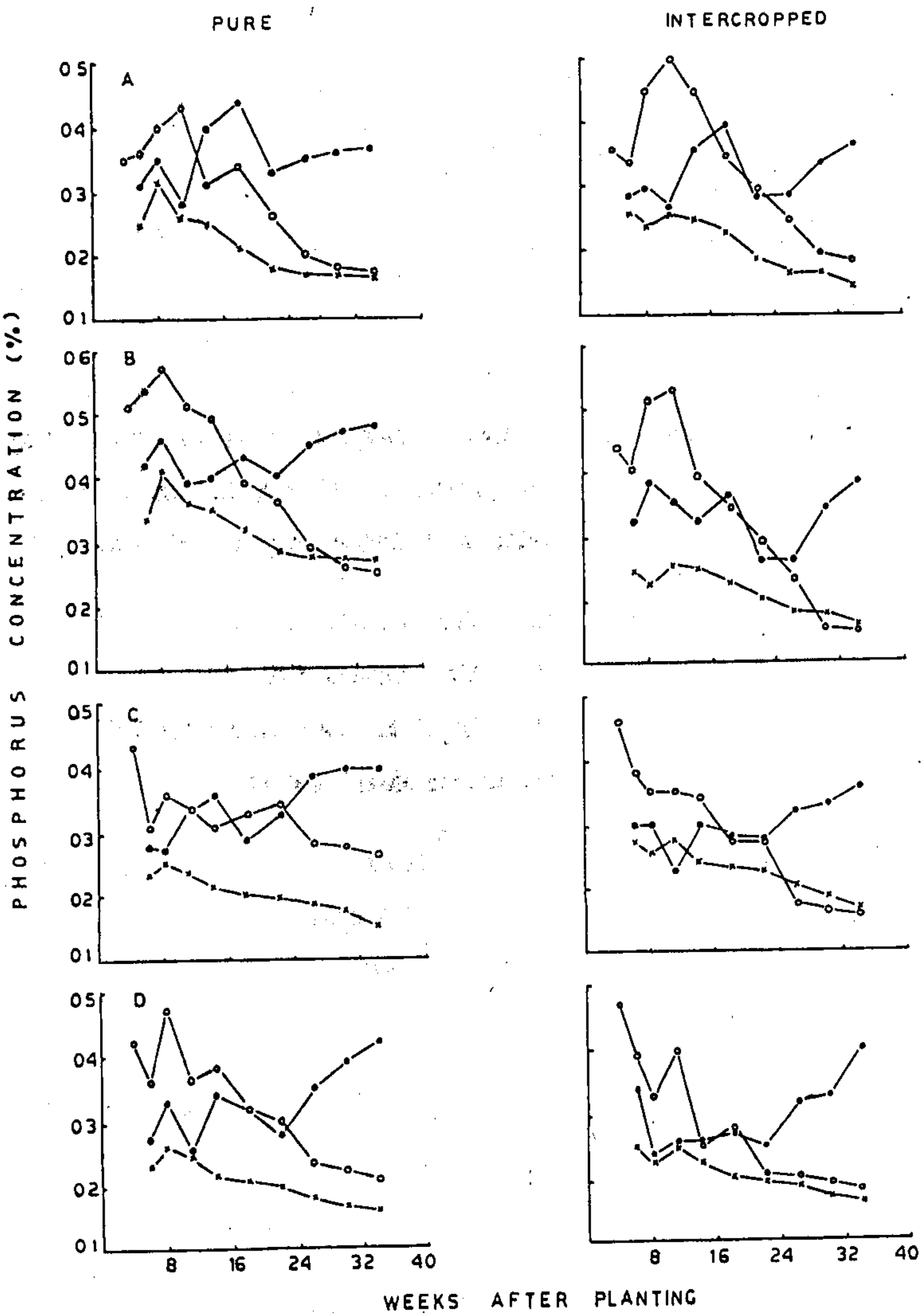

PURE
INTERCROPPED
A
B
C
D
0 5
0 4
0 3
0 2
0 1
0 6
PHOSPHORUS CONCENTRATION (%)
8
16
24
32
40
WEEKS AFTER PLANTING

FIG. 26

Cultivar C_1 registered considerable increase in the rhizome P concentration beyond 11th week which continued upto 18th week. This was followed by a marked reduction during 22nd week beyond which it further increased upto maturity. In case of cultivar C_2 also, a rise in the rhizome P concentration was noticed during the 14th week, but a remarkable increase was shown only after the 18th week. In the case of cultivar C_3, a marked increase in the rhizome P concentration was seen only after 22nd week.

The maximum P concentration in the rhizome was 0.44, 0.36 and 0.34 per cents for the cultivars C_1, C_2 and C_3 respectively under the pure stand as against 0.40, 0.30 and 0.34 per cents respectively under the intercropped stand. The corresponding figures at the time of maturity were 0.37, 0.40 and 0.42 per cents respectively under the pure stand and 0.37, 0.36 and 0.40 per cents respectively under the intercropped stand. The P concentration in the leaf was higher than that in rhizome during the early period of growth upto 14th week. In case of pure stand of cultivar C_1, the rhizome P concentration was higher than that in the other plant parts from 14th week onwards, while for other cultivars this trend was seen beyond 22nd week only.

The seasonal changes in the P concentration in different plant parts of the cultivar C_1 during the year 1978 are presented in the Fig.26b. The P concentration in different plant parts of the cultivars C_2 and C_3 did not register any considerable difference between the two years of study. The intercropped stand of the cultivar C_1 registered comparatively higher P concentration in the leaves and rhizomes during the second year upto the 11th week after planting. Pure stand of this cultivar showed considerably higher leaf P concentration in the second year as compared to first year throughout the growth period.

7.1.3. Potassium

The seasonal changes in potassium concentration in different plant parts of three turmeric cultivars under pure and intercropped stands during the year 1977 are presented in Fig.27. The K concentration in leaves and roots steadly declined from earlier periods upto maturity. The maximum K concentration in the leaves recorded by the cultivar C_1 was 6.8 and 7.3 per cents under pure and intercropped stands respectively. The maximum leaf K concentration registered by cultivars C_2 and C_3 was 7.4 and 6.7 per cents respectively without any marked difference betweek the cropping systems. In case of root, cultivar C_1 registered maximum K concentration of 5.3 and 4.9 per cents under

Fig.27. Potassium concentration at different stages of growth in three turmeric cultivars under pure and intercropped stands.

A. Cls. No.24 (1977)

B. Cls. No.24 (1978)

C. Cll.328 Sugandham (1977)

D. Duggirala (1977)

o——o Leaf

●——● Rhizome

×——× Root

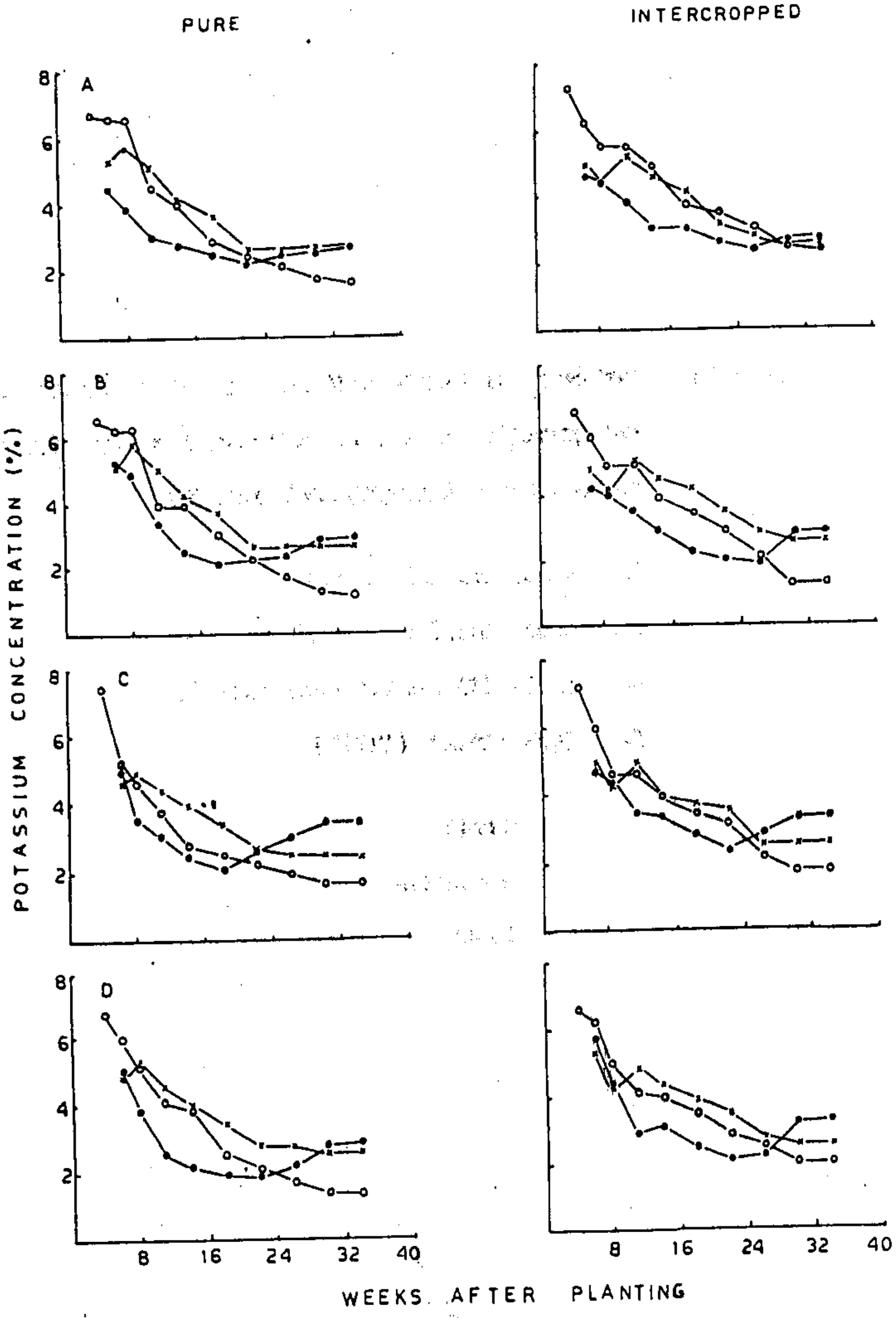

PURE
INTERCROPPED
A
B
C
D
8
6
4
2
POTASSIUM CONCENTRATION (%)
8
16
24
32
40
WEEKS AFTER PLANTING

FIG.27

pure and intercropped stands respectively. The corresponding figures were 4.8 and 5.0 per cents respectively for the cultivar C_2 and 5.0 and 5.4 per cents respectively for the cultivar C_3. The K concentration in the rhizome continued to decrease upto the 22nd week under the pure stand and upto the 36th week under the intercropped stand. Eventhough the rhizome K concentration rose beyond these periods it was not so pronounced as in the case of N and P, and the maximum K concentration was recorded early in the growth cycle.

The maximum K concentration in the rhizome was 4.5, 5.0 and 5.1 per cents for the cultivars C_1, C_2 and C_3 respectively under the pure stand as against 4.6, 4.8 and 5.8 per cents respectively under the intercropped stand. The corresponding figures at the time of maturity were 2.6, 3.4 and 2.9 per cents respectively under the pure stand, and 2.7, 3.3 and 3.3 per cents respectively under the intercropped stand. The K concentration in the leaves and roots were considerably higher than that in rhizome upto 18th week under the pure stand and upto 22nd week under the intercropped stand beyond which the concentration was higher in the rhizome than in the other plant parts.

The seasonal changes in the K concentration in different plant parts of the cultivar C_1 during the year 1978 are presented in Fig.27b. The K concentration in different plant parts of the cultivar C_2 and C_3 did not show any considerable difference between the two years. The Leaf K concentration of the cultivar C_1 was reduced in the second year as compared to first year under both the cropping systems.

7.2. Nutrient accumulation

7.2.1. Nitrogen

The seasonal pattern of N accumulation in the whole plant and its components of the three turmeric cultivars under pure and intercropped stands during the year 1977 is shown in Fig.28. As in the case of dry matter accumulation, the accumulation of N was slow during the early period of growth upto the 8th week after planting. During this period, the accumulation of N in the rhizome was negligible, beyond which it continued to increase upto maturity. The N accumulation in the root was negligible as compared to the other plant parts. Shoot continued to accumulate N upto 18th week. A rapid loss of nitrogen from the shoot was seen after 18th week.

It was found that about 65, 50 and 37 per cents of the maximum N accumulated in the shoot were redistributed

Fig.28. Nitrogen accumulation at different stages
growth in three turmeric cultivars under
pure and intercropped stands.

A. Cls. No.24 (1977)

B. Cls. No.24 (1978)

C. Cll.326 Sugandham (1977)

D. Duggirala (1977)

○—○ Leaf

●—● Rhizome

×—× Root

△—△ Whole plant

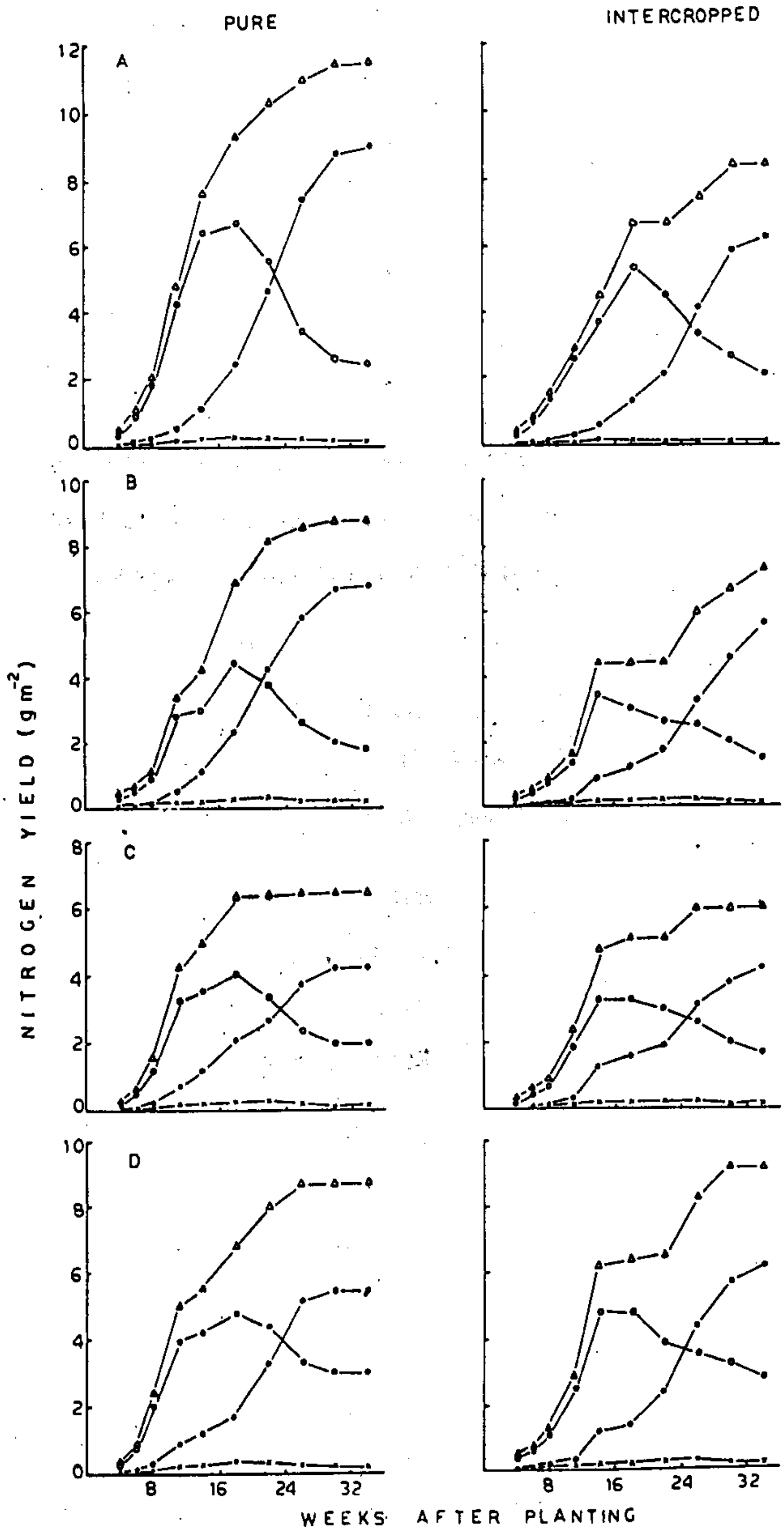

PURE
INTERCROPPED
A
B
C
D
0
2
4
6
8
10
12
NITROGEN YIELD (g m^{-2})
8
16
24
32
WEEKS AFTER PLANTING

FIG. 28

for the accumulation in the rhizome in the case of the pure stands of the cultivars C_1, C_2 and C_3 respectively, which constituted about 49, 49 and 32 per cents respectively of the total N accumulated in the rhizome. In the case of the intercropped stands of the cultivars C_1, C_2 and C_3, the redistribution from the shoot was about 61, 50 and 41 per cents respectively of the maximum N accumulated in it, which had provided about 51, 40 and 32 per cents respectively of the total N accumulated in the rhizome. The amount of N withdrawn from the root was negligible. The total N yield at harvest were 11.5, 6.5 and 8.8 g m^{-2} for the pure stands of the cultivars C_1, C_2 and C_3 respectively, and the corresponding figures for the intercropped stands were 8.5, 6.0 and 9.2 g m^{-2} respectively. The nitrogen yield by rhizomes were 9.0, 4.3 and 5.5 g m^{-2} for the pure stands of the cultivars C_1, C_2 and C_3 respectively, and the corresponding figures for the intercropped stands were 6.3, 4.2 and 6.2 g m^{-2} respectively.

The pattern of N accumulation at different stages of growth by the whole plant and its components of the cultivar C_1 during the year 1978 is presented in Fig.28b. The pattern of N accumulation in the case of cultivars C_2 and C_3 did not show any marked difference between the two years of study. The amount of N accumulated in the shoot and rhizome of cultivar C_1 was considerably reduced in the second year as compared to the first year. In case of cultivar C_1, the redistribution of N from the shoot as well as its contribution towards the rhizome was comparatively reduced in the second year. About 59 and 55 per cents of the maximum N accumulated in the shoot of this cultivar was withdrawn in case of pure and intercropped stands respectively, which constituted about 38 and 33 per cents respectively of the total N accumulated in the rhizome. The total N yield of this cultivar at harvest were 8.8 and 7.3 g m^{-2} under the monoculture and intercropping systems respectively, while the N yield by rhizomes were 6.8 and 5.6 g m^{-2} under the same respective cropping systems.

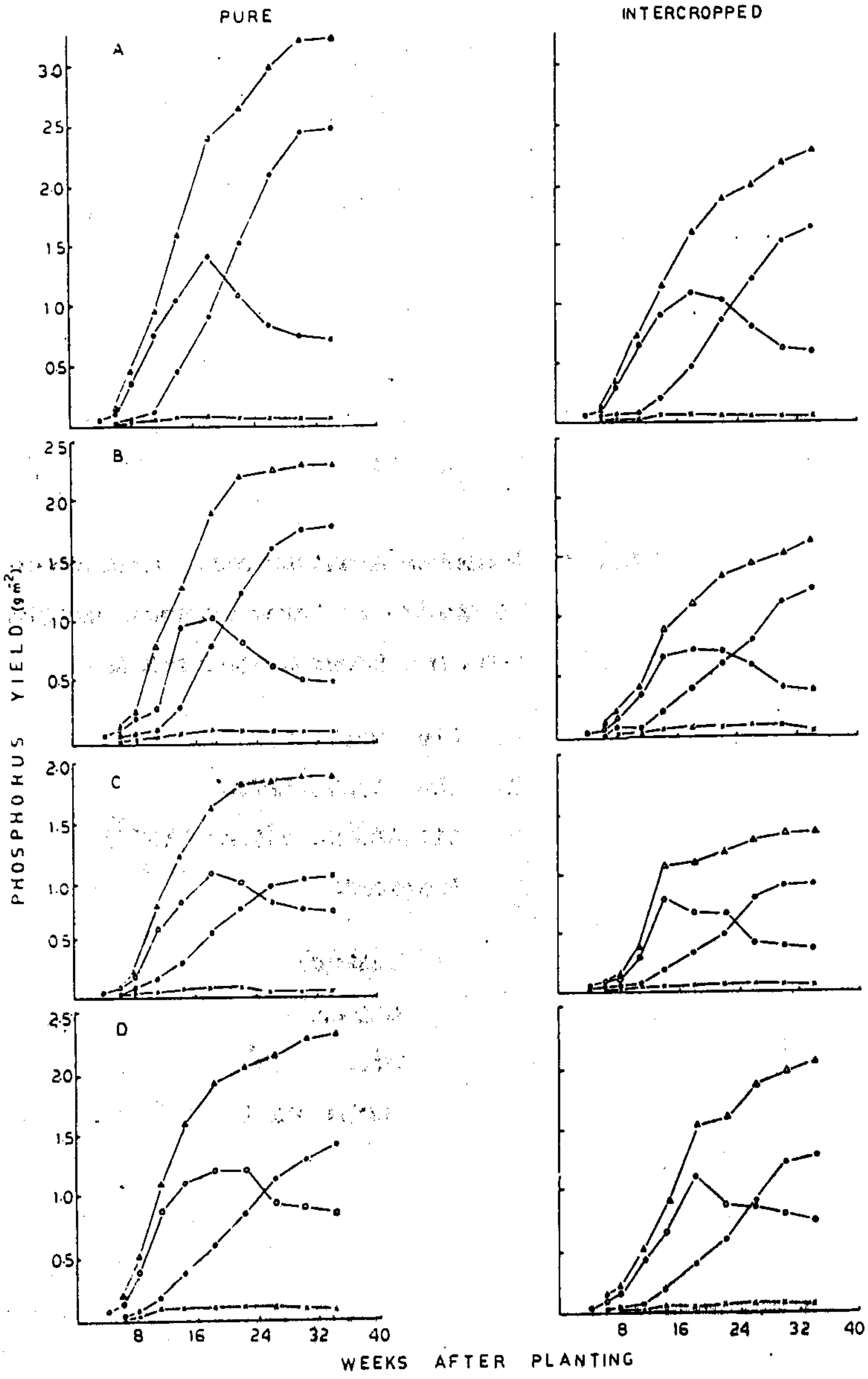
7.2.2. Phosphorus

The seasonal pattern of P accumulation in the whole plant and its components of three turmeric cultivars under pure and intercropped stands during the year 1977 is shown in Fig.29. The accumulation of P in the rhizome and whole plant was slow during the early period upto 8th week after planting. Beyond this period it continued to increase upto maturity. The P accumulation in the root was negligible as compared to other plant parts. Shoot continued to accumulate P upto the 18th week beyond which a rapid loss

Fig.29. Phosphorus accumulation at different stag
of growth in three turmeric cultivars und
pure and intercropped stands.

A. Cls. No.24 (1977)
B. Cls. No.24 (1978)
C. Cll.326 Sugandham (1977)
D. Duggirala (1977)

○——○ Leaf
●——● Rhizome
×——× Root
△——△ Whole plant



PURE
INTERCROPPED
A
B
C
D
3.0
2.5
2.0
1.5
1.0
0.5
PHOSPHORUS YIELD (g m^{-2})
8
16
24
32
40
WEEKS AFTER PLANTING

FIG. 29

in shoot P was noticed except for the intercropped stand of the cultivar C_2 where shoot started to lose P from the 14th week itself and for the pure stand of cultivar C_3 where this trend was noticed only after 22nd week.

It was observed that about 58, 30 and 32 per cents of the maximum P accumulated in the shoot were redistributed for the accumulation in the rhizome in the case of the pure stands of the cultivars C_1, C_2 and C_3 respectively, which contributed about 29, 30, 28 per cents respectively of the total P accumulated in the rhizome. In case of the intercropped stands of the cultivars C_1, C_2 and C_3, the redistribution from the shoot was about 44, 51 and 32 per cents respectively of the maximum P accumulated in it, which had provided about 29, 44 and 28 per cents respectively of the total P accumulated in the rhizome. The amount of P withdrawn from the root was negligible. The total P yield at harvest were 3.2, 1.8 and 2.3 g m^{-2} for the pure stands of the cultivars C_1, C_2 and C_3 respectively and the corresponding figures for the intercropped stands were 2.3, 1.4 and 2.1 g m^{-2} respectively. The phosphorus yield by rhizomes were 2.5, 1.0 and 1.4 g m^{-2} for the pure stands of the cultivars C_1, C_2 and C_3 respectively and the corresponding figures for the intercropped stands were 1.7, 0.9 and 1.3 g m^{-2} respectively.

The pattern of P accumulation at different stages of growth by the whole plant and its components of the cultivar C_1 during the year 1978 is presented in Fig.29b. The pattern of P accumulation in the case of cultivars C_2 and C_3 did not show considerable difference between the two years. The amount of P accumulated in the shoot and rhizome of cultivar C_1 were considerably reduced in the second year as compared to the first year. In case of cultivar C_1, the redistribution of P from the shoot as well as its contribution towards the accumulation in the rhizome was more or less the same during both the years of study. The total P yield of this cultivar at harvest were 2.3 and 1.6 g m^{-2} under the monoculture and intercropping systems respectively, while the P yield by rhizomes were 1.8 and 1.2 g m^{-2} under the same respective cropping systems.

7.2.3. Potassium

The seasonal pattern of K accumulation in the whole plant and its components of three turmeric cultivars under pure and intercropped stands during the year 1977 is presented in Fig.30. The accumulation of K in the rhizome was slow during the early period as in the case of other nutrients, but steadily increased beyond the 8th week upto maturity. The K accumulation in the root was negligible eventhough its contribution was comparatively higher than

Fig.20. Potassium accumulation at different stages of growth in three turmeric cultivars under pure and intercropped stands.

A. Cls. No.24 (1977)

B. Cls. No.24 (1978)

C. Cll.326 Sugandham (1977)

D. Duggirala (1977)

○—○ Leaf

●—● Rhizome

×—× Root

△—△ Whole plant

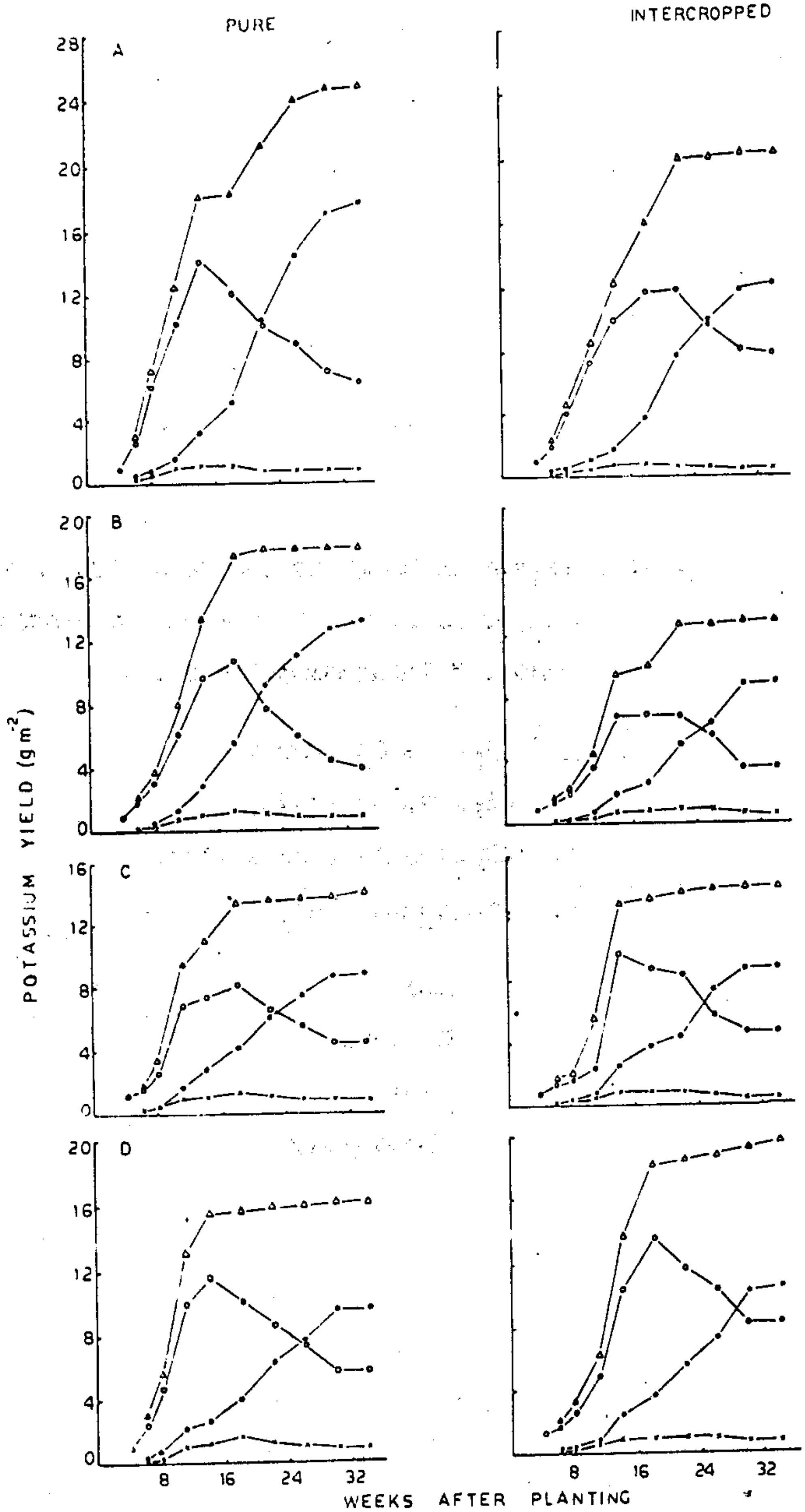

PURE
INTERCROPPED
A
B
C
D
28
24
20
16
12
8
4
0
POTASSIUM YIELD (g m^{-2})
8
16
24
32
WEEKS AFTER PLANTING

FIG.30

those of N and P. The pure stands of cultivars C_1 and C_3 started to lose K from the shoot from the 14th week onwards, whereas in the case of pure stand of the cultivar C_2, this trend was noticed only after 18th week. Under the intercropping system cultivars C_1, C_2 and C_3 started to lose K from the shoot from 22nd, 14th and 18th week onwards respectively.

It was observed that about 55, 45 and 51 per cents of maximum K accumulated in the shoot were redistributed in the case of the pure stands of the cultivars C_1, C_2 and C_3 respectively, which contributed about 44, 41 and 62 per cents respectively of the total K accumulated in the rhizome. In the case of the intercropped stands of the cultivars C_1, C_2 and C_3 the redistribution from the shoot was about 34, 51 and 40 per cents respectively of the maximum K accumulated in it, which had provided about 33, 57 and 51 per cents respectively of the total K accumulated in the rhizome. The amount of K withdrawn from the root was negligible. The total K yield at harvest were 24.7, 13.9 and 16.2 g m^{-2} for the pure stand of the cultivars C_1, C_2 and C_3 respectively and the corresponding figures for the intercropped stands were 20.4, 13.7 and 19.6 g m^{-2} respectively. The potassium yield by rhizome were 17.6, 8.8 and 9.6 g m^{-2} for the pure stands of the cultivars C_1, C_2 and C_3 respectively and the corresponding figures for the intercropped stands were 12.2, 8.7 and 10.6 g m^{-2} respectively.

The pattern of K accumulation by the whole plant and its components of the cultivar C_1 during the year 1978 is presented in Fig.30b. The pattern of K accumulation in the case of cultivars C_2 and C_3 did not show any marked difference between the two years. The amounts of K accumulated in the shoot and the rhizome of cultivar C_1 were remarkably reduced in the second year as compared to the first year. In case of cultivar C_1, the redistribution of K from the shoot as well as its contribution towards the accumulation in the rhizome was higher in the second year. About 64 and 50 per cents of the maximum K accumulated in the shoot of this cultivar was withdrawn in the case of pure and intercropped stands respectively, which contributed about 32 and 39 per cents respectively of the total K accumulated in the rhizome. The total K yield of this cultivar at harvest were 17.8 and 12.8 g m^{-2} under the monoculture and intercropping systems respectively, while the yield by rhizome were 13.2 and 8.9 g m^{-2} under the same respective cropping systems.

7.3. Partitioning of nutrients

The partitioning of elements, N, P and K among the different plant parts at successive stages of plant development as percentages of the total accumulation of each element are illustrated in Figs.31, 32 and 33 respectively. The curves are thus cumulative over time and plant parts so that the vertical distance between the two adjacent lines represents the percentage of the total in a given plant part at a given time.

7.3.1. Nitrogen

The partitioning of N among different plant parts of three turmeric cultivars under pure and intercropped stands during the year 1977 is depicted in Fig.31. The partitioning of N was mainly towards shoot upto 18th week after planting during which the partitioning towards rhizome was considerably less. Beyond 18th week, shoot started to lose accumulated N and partitioning towards rhizome was increased. The partitioning towards root was negligible and did not exceed more than 4 per cent of the total N accumulation at any stage of plant growth.

At maturity, the shoot rhizome and root of the pure stand of the cultivar C_1 contributed about 21, 78 and 1 per cents respectively of the total N accumulation while the intercropped stand correspondingly recorded 24, 75 and 1 per cents respectively. In the case of the pure stand of the cultivar C_2, the shoot, rhizome and root provided about 32, 66 and 2 per cents respectively of the total N yield and the corresponding figures for the intercropped stand of this cultivar were 28, 70 and 2 per cents respectively. In the case of cultivar C_3, the shoot, rhizome and root of the pure stand constituted about 35, 63 and 2 per cents respectively of the total N accumulation while the intercropped stand correspondingly recorded 31, 67 and 2 per cents respectively.

Fig.31. Uptake of nitrogen by various plant parts (expressed as percentage of total) of three turmeric cultivars under pure and intercropped stands.

A. Cls. No.24 (1977)
B. Cls. No.24 (1978)
C. Cll.328 Sugandham (1977)
D. Duggirala (1977)

Rm - Rhizome
St - Shoot
Rt - Root

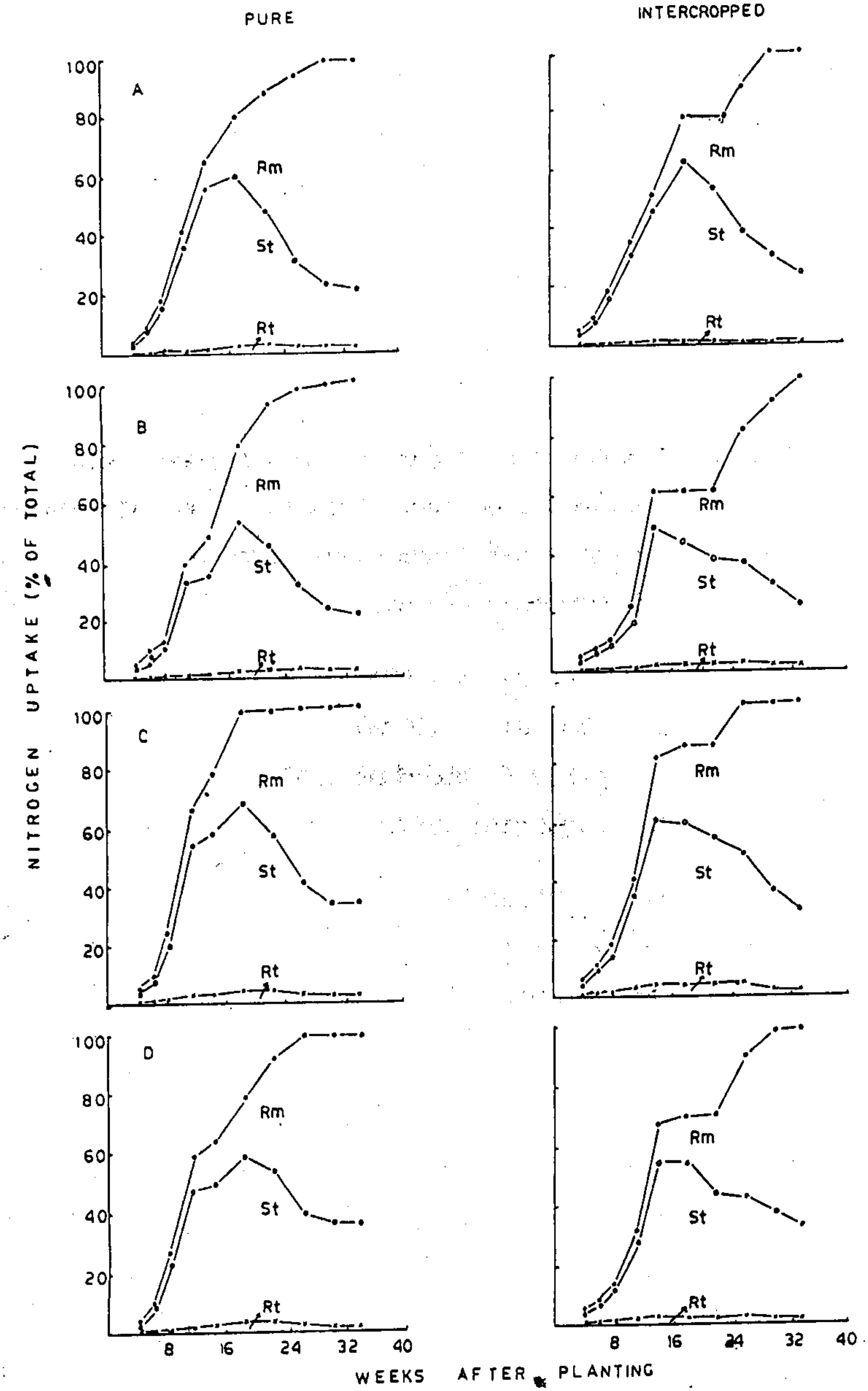

PURE
INTERCROPPED
A
B
C
D
Rm
St
Rt
100
80
60
40
20
8
16
24
32
40
NITROGEN UPTAKE (% OF TOTAL)
WEEKS AFTER PLANTING

FIG. 31

The partitioning of N among different plant parts of the cultivar C_1 during the year 1978 is depicted in Fig.31b. In the case of the cultivars C_2 and C_3 the partitioning of N followed the same trend as that in the first year. In the case of the intercropped stand of the cultivar C_1, partitioning of N towards shoot continued only upto 14th week. At maturity, the shoot, rhizome and root of the cultivar C_1 contributed about 21, 77 and 2 per cents respectively of the total N accumulation without any marked difference between the cropping systems.

7.3.2. Phosphorus

The partitioning of P among different plant parts of three turmeric cultivars under pure and intercropped stands during the year 1977 is depicted in Fig.32. Partitioning of P towards the shoot continued upto the 18th week except for intercropped stand of the cultivar C_2 where it continued only upto 14th week. During this period, partitioning of P towards rhizome was considerably less. Beyond this period, shoot started to lose the accumulated P and the partitioning towards the rhizome was remarkably increased. The partitioning towards root was negligible and it did not exceed more than 4 per cent of the total P accumulation at any stage of plant growth.

Fig.12. Uptake of phosphorus by various plant parts (expressed as percentage of total) of three turmeric cultivars under pure and intercropped stands.

A. Cls. No.24 (1977)
B. Cls. No.24 (1978)
C. Cll.328 Sugandham (1977)
D. Duggirala (1977)

Rm - Rhizome
St - Shoot
Rt - Root

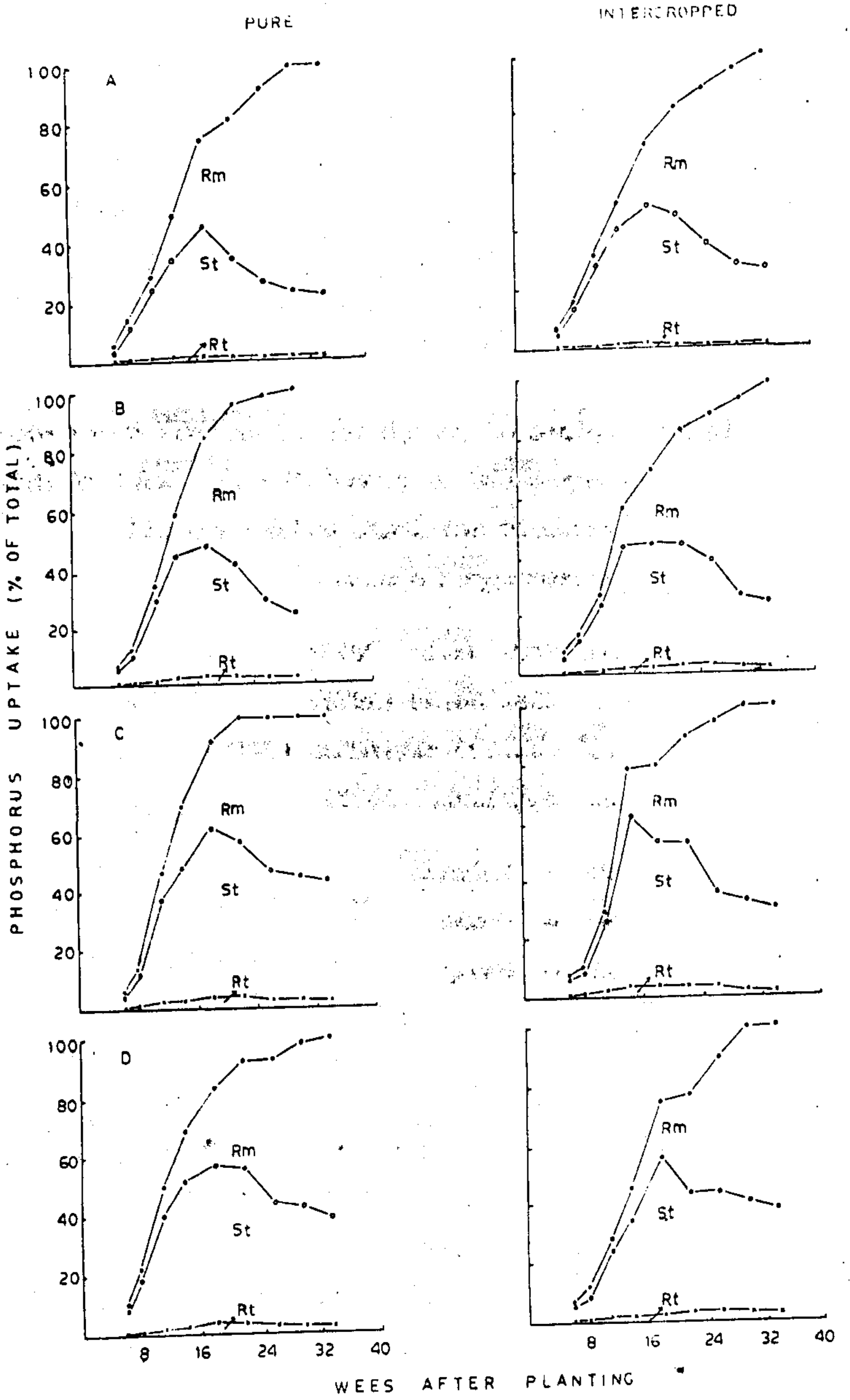

PURE
INTERCROPPED
A
B
C
D
Rm
St
Rt
100
80
60
40
20
8
16
24
32
40
PHOSPHORUS UPTAKE (% OF TOTAL)
WEES AFTER PLANTING

FIG. 32

At maturity, the shoot, rhizome and root of the pure stand of the cultivar C_1 contributed about 21, 78 and 1 per cents of the total P accumulation, while the intercropped stand correspondingly recorded 24, 75 and 1 per cents respectively. In case of the pure stands of the cultivar C_2, the shoot, rhizome and root provided about 41, 57 and 2 per cents respectively of the total P yield and the corresponding figures for the intercropped stand of this cultivar were 29, 69 and 2 per cents respectively. In case of cultivar C_3, the shoot, rhizome and root constituted about 36, 62 and 2 per cents respectively of the total P accumulation without showing any considerable difference between the two cropping systems.

The partitioning of P among different plant parts of this cultivar C_1 during the year 1978 is depicted in Fig.32b. In the case of the cultivars C_2 and C_3, the partitioning of P followed the same trend as that in the first year. In the case of the intercropped stand of the cultivar C_1 a considerable loss of P from the shoot was seen only after 22nd week. At maturity, the shoot, rhizome and root of the pure stand of the cultivar C_1 contributed about 21, 77 and 2 per cents respectively of the total P accumulation and the corresponding figures for the intercropped stand of this cultivar were 24, 74 and 2 per cents respectively.

7.3.3. Potassium

The partitioning of K among different plant parts of three turmeric cultivars under pure and intercropped stands during the year 1977 is depicted in Fig.33. The partitioning of K towards shoot continued upto the period of the 14th to the 18th week. The partitioning of K towards rhizome was considerably less upto 14th week beyond which it markedly increased. The contribution of root K towards the total accumulation was comparitively higher than that of the N and P in the roots, eventhough it did not exceed more than 10 per cent of total K accumulation at any stage of plant growth.

At maturity, the shoot, rhizome and root of the pure stand of cultivar C_1 provided 26, 71 and 3 per cents respectively of the total K accumulation, while the intercropped stand corresponding registered 38, 60 and 2 per cents respectively. In case of cultivar C_2, the shoot, rhizome and root contributed about 32, 64 and 4 per cents respectively of the total K accumulation without any considerable difference between the two cropping systems. In case of the pure stand of the cultivar C_3, the shoot, rhizome and root constituted about 35, 60 and 5 per cents respectively of the total K yield and the corresponding figures for the intercropped stand were about 42, 54 and 4 per cents respectively.

Fig.33. Uptake of potassium by various plant parts (expressed as percentage of total) of three turmeric cultivars under pure and intercropped stands.

A. Cls. No.24 (1977)
B. Cls. No.24 (1978)
C. Cll.328 Sugandham (1977)
D. Duggirala (1977)

Rm - Rhizome
St - Shoot
Rt - Root

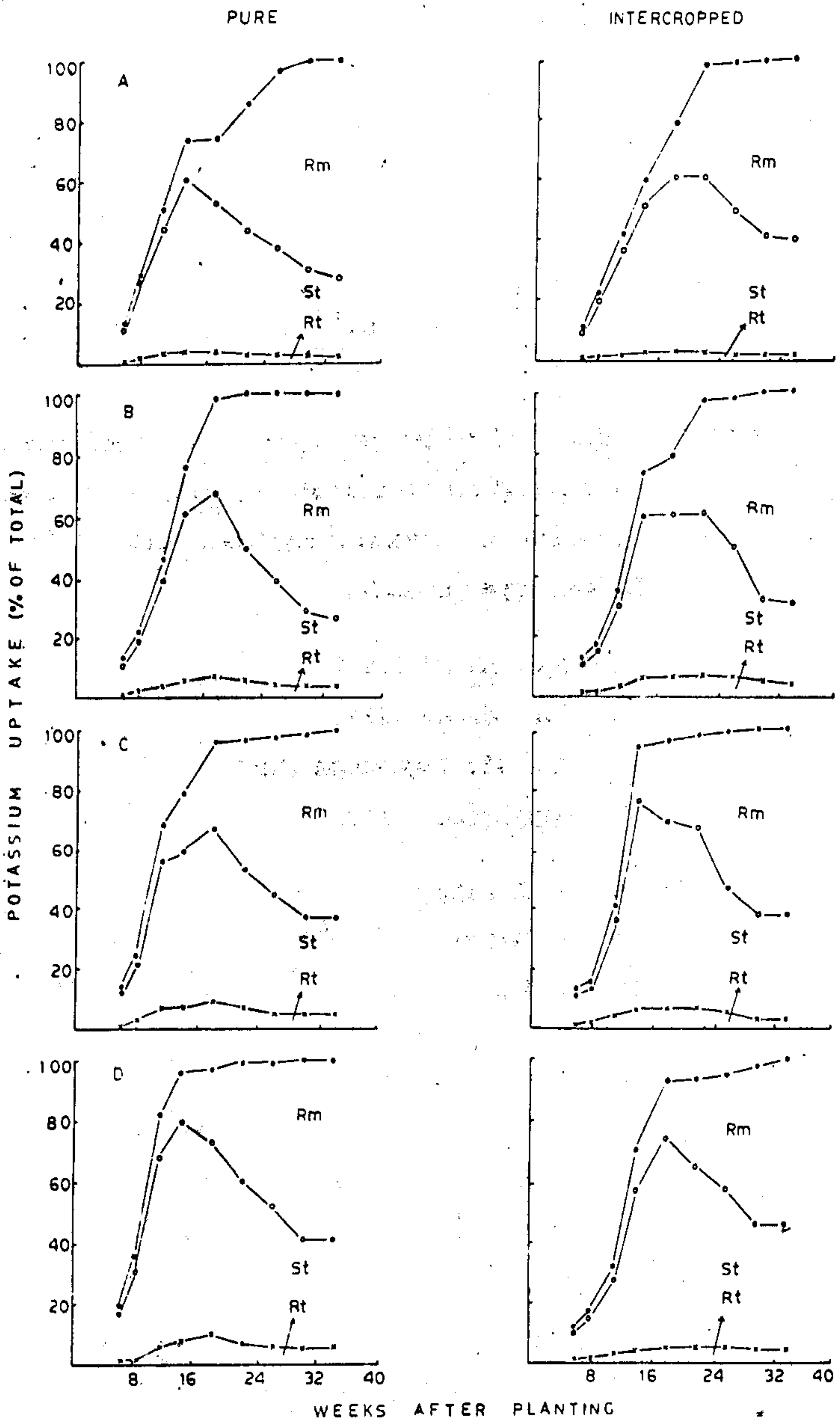

PURE
INTERCROPPED
A
B
C
D
Rm
St
Rt
POTASSIUM UPTAKE (% OF TOTAL)
100
80
60
40
20
8
16
24
32
40
WEEKS AFTER PLANTING

FIG. 33

The partitioning of K among different plant parts of the cultivar C_1 during the year 1978 is depicted in Fig.33b. In case of cultivars C_2 and C_3, the partitioning of K followed the same trend as that in the first year. In case of the pure stand of the cultivar C_1, a considerable loss of K from the shoot was seen only after the 18th week as against the 14th week during the first year. At maturity, the shoot, rhizome and root of the pure stand of the cultivar C_1 contributed about 22, 74 and 4 per cents respectively of the total K accumulation and the corresponding figures for the intercropped stand of this cultivar were about 27, 69 and 4 per cents respectively.

7.4. Nutrient accumulation in relation to growth

The accumulation of N, P and K in relation to the dry matter accumulation (expressed as the percentage of the total) is illustrated in Fig.34 for the cultivar C_1 during the years 1977 (first year) and 1978 (second year) and for the cultivar C_2 and C_3 during the year 1977. Under the intercropping system the accumulation of N and P clearly preceded dry matter production upto 18th week. Under this cropping system, the accumulation of N was negligible during the period of 18th to 22nd week for the cultivar C_1 in the first year of study. This trend was noticed during 14th to 22nd week for the other two cultivars as well as for cultivar C_1 during the second year of study. In the case of P, such a trend under the

Fig.34. Accumulation of N, P and K (expressed as percentage of total) in relation to dry ma accumulation in three turmeric cultivars under pure and intercropped stands.

A. Cls. No.24 (1977)
B. Cls. No.24 (1978)
C. Cll.328 Sugandham (1977)
D. Duggirala (1977)

×——×	Nitrogen
●——●	Phosphorus
▲——▲	Potassium
○- - - -○	Dry matter

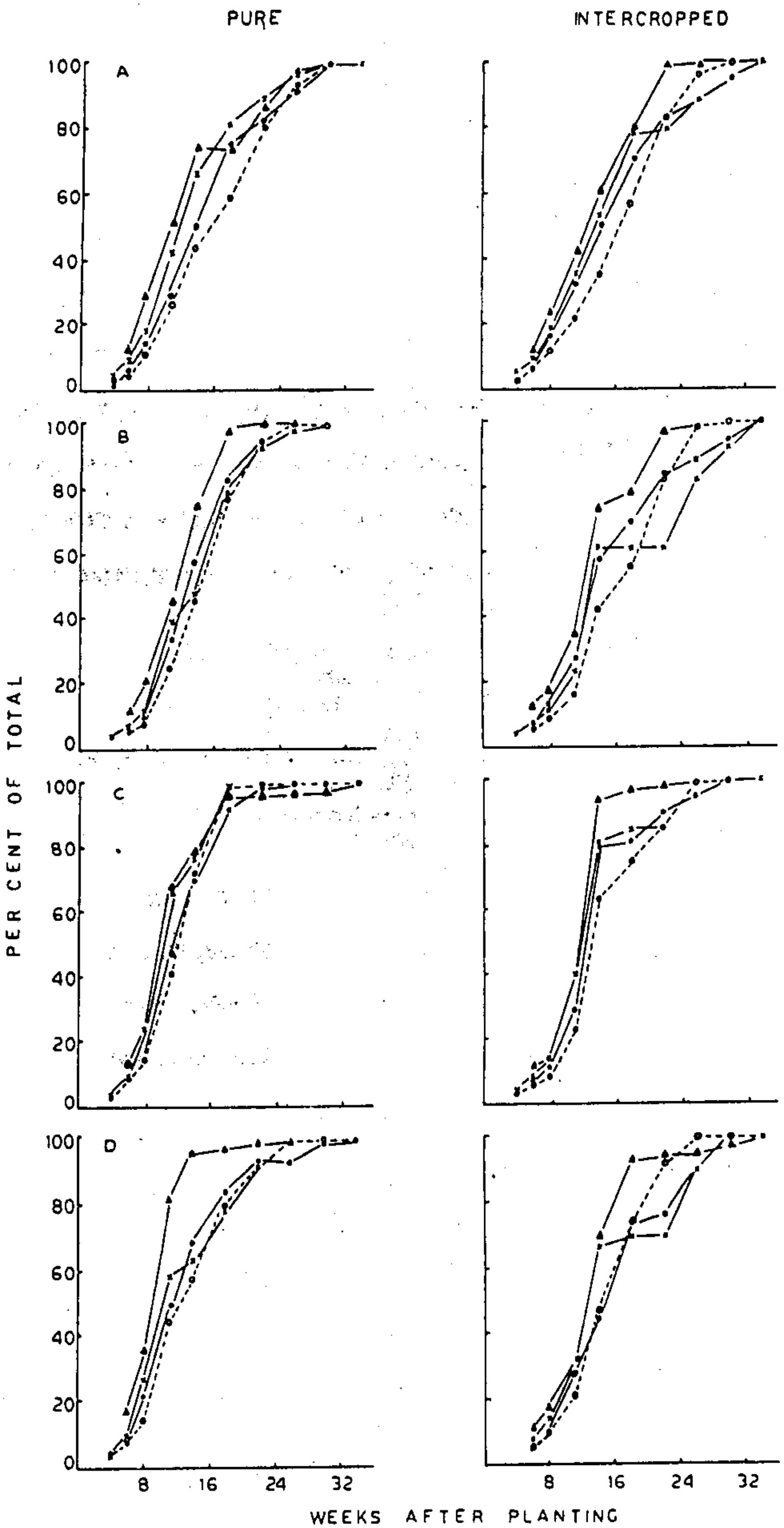

PURE
INTERCROPPED
A
B
C
D
PER CENT OF TOTAL
0
20
40
60
80
100
8
16
24
32
WEEKS AFTER PLANTING

FIG.34

intercropping system was seen during the periods of 14th to 18th and 18th to 22nd weeks for the cultivars C_2 and C_3 respectively. Dry matter accumulation showed a continued increase during this period. Beyond these periods, the accumulation of N and P under the intercropping system further increased upto 30th week. During this period the accumulation curves of N and P lay behind that of dry matter, but followed the same trend as that of the dry matter.

Under the monoculture system, the accumulation of N and P preceded that of dry matter during most periods of growth eventhough it was not pronounced during the later part of growth. The pure stands of the cultivar C_2 and C_3 and that of C_1 during the second year of study had shown lower N accumulation rates than that of dry matter during the period of the 14th to the 18th week. Except for this trend, the accumulation pattern of N and P under the monoculture system followed that of dry matter during most of the growth periods.

The accumulation of K preceded that of dry matter as well as N and P during most parts of the crop growth. The accumulation pattern of K was considerably deviated from that of dry matter in the later half of the crop growth. In the case of the pure stand of the cultivar C_1, the accumulation of K during the period of the 14th to the 18th week was nil during the first year. Under the intercropped stand, the cultivar C_1 did not show any marked accumulation of K beyond 22nd week during the first year. The accumulation of K for this cultivar was practically nil beyond the 18th and the 22nd weeks under pure and intercropped stand respectively during the second year of study. In the case of cultivar C_2, the accumulation of K was negligible beyond 18th and 14th weeks under pure and intercropped stand respectively, while in the case of cultivar C_3, this was insignificant beyond the 14th and the 18th weeks under the same respective cropping systems.

The relative rate of accumulation of N and K was generally higher than that of dry matter upto the 11th and 14th weeks after planting under the monoculture and intercropping systems respectively. The most rapid accumulation of nutrients had taken place during the period of 6th to 14th week. Of the total accumulation of N and P of the cultivar C_1, about 45 to 55 per cent had occurred during this period, while in the case of K the accumulation during this period accounted for 60 per cent of the total seasonal accumulation. Upto the 18th week, the N and P accumulation of this cultivar would account for the 65 to 75 per cent of the total accumulation and that of K would account for the 70 to 80 per cent.

In the case of the cultivar C_2, 70 per cent of the total seasonal accumulation of N and P had occurred during the period of 6th to 14th week, while the accumulation of K during this period accounted for the 80 per cent of the total accumulation. Of the total accumulation recorded in the case of the cultivar C_3, 60 per cent of N and P and 70 per cent of K had occurred during the period of 6th to 14th week after planting.

8. Curcumin and essential oil

Concentration and accumulation of curcumin and essential oil at different stages of growth of three turmeric cultivars grown in monoculture and in association with coconut were investigated.

8.1. Curcumin

8.1.1. Curcumin concentration

I Year. The data on the curcumin concentration in the rhizomes (expressed as percentage of rhizome dry weight) of three turmeric cultivars during the year 1977 are presented in Table 34a and its trend of changes is depicted in Fig.35. For the cultivar C_1, the maximum curcumin concentration was reached during 14th and 18th weeks under pure and intercropped stands respectively. Beyond these periods, it continued to decrease under both the cropping systems. For the cultivar C_2, the values continued to increase upto 14th week under both the cropping systems. During the periods of the 18th and 22nd weeks a reduction in the curcumin concentration was noticed for this cultivar, but again increased by 26th week reaching the maximum. Eventhough the pure stand of this cultivar maintained this maximum value at the time of maturity (30th week), intercropped stand registered a reduction at maturity. In the case of cultivar C_3 also, a reduction in the curcumin

Table 34a. Curcumin concentration (%) of three turmeric cultivars at different stages of growth under pure and intercropped stands during the year 1977

Cropping systems	Cultivars	Weeks after planting								
		4	6	8	11	14	18	22	26	30
Pure	C_1	2.5	3.7	4.1	4.4	7.5	6.1	5.4	5.5	5.1
	C_2	1.2	2.3	3.0	3.3	4.3	3.6	3.3	4.8	4.0
	C_3	2.3	4.2	3.8	4.6	6.5	6.3	7.5	6.9	5.8
Intercropped	C_1	2.0	3.3	4.2	4.1	5.5	7.2	6.0	6.2	5.4
	C_2	1.0	1.6	2.0	1.7	3.2	3.1	3.1	3.8	3.8
	C_3	1.5	3.0	3.1	3.5	6.1	5.6	6.8	8.3	7.2
Mean										
Cultivars										
C_1		2.3	3.5	4.2	4.2	6.5	6.7	5.7	5.9	5.3
C_2		1.1	2.0	2.5	2.5	3.8	3.4	3.2	4.3	3.9
C_3		1.9	3.6	3.5	4.1	6.3	6.0	7.2	7.6	6.5
Mean										
Systems										
Pure		2.0	3.4	3.6	4.1	6.1	5.3	5.4	5.7	5.0
Intercropped		1.5	2.6	3.1	3.1	4.9	5.3	5.3	6.1	5.5
CD (P = 0.05)										
Cultivars (C)		0.38	0.42	0.41	0.38	0.36	0.41	0.40	0.37	0.36
Systems (S)		0.31	0.35	0.33	0.31	0.29	NS	NS	0.30	0.29
C x S		NS	NS	0.58	0.54	0.50	0.58	0.56	0.53	0.50
CV (%)		23.7	15.2	13.1	11.5	7.0	8.4	8.0	6.8	7.4

Table 34b. Curcumin concentration (%) of three turmeric cultivars at different stages of growth under pure and intercropped stands during the year 1978

Cropping systems	Cultivars	Weeks after planting								
		4	6	8	11	14	18	22	26	30
Pure	C_1	2.0	3.1	3.3	3.4	6.3	6.8	5.7	5.7	5.4
	C_2	1.0	2.0	2.8	2.9	4.0	3.5	3.4	5.0	4.0
	C_3	2.0	3.9	3.6	4.3	6.3	6.0	7.8	7.1	6.0
Intercropped	C_1	1.8	3.1	4.1	4.0	5.3	7.8	6.5	6.6	6.1
	C_2	0.9	1.3	2.1	1.8	3.5	3.4	3.3	4.0	4.0
	C_3	1.0	2.9	2.9	3.3	5.6	5.5	7.0	8.6	7.3
Mean Cultivars										
C_1		1.9	3.1	3.7	3.7	5.9	7.3	6.1	6.2	5.8
C_2		1.0	1.6	2.5	2.4	3.8	3.5	3.4	4.5	4.0
C_3		1.5	3.4	3.3	3.8	6.0	5.8	7.4	7.9	6.7
Mean Systems										
Pure		1.7	3.0	3.2	3.5	5.5	5.4	5.6	5.9	5.1
Intercropped		1.2	2.4	3.0	3.0	4.9	5.6	5.6	6.4	5.8
CD (P = 0.05)										
Cultivars (C)		0.36	0.35	0.28	0.30	0.32	0.50	0.38	0.39	0.35
Systems (S)		0.30	0.28	NS	0.31	0.42	NS	NS	0.32	0.29
C x S		0.51	0.49	0.54	0.33	NS	0.84	0.54	0.56	0.50
CV (%)		27.5	13.9	13.3	12.5	10.8	11.7	7.3	6.9	7.0

Fig.35. Concentration of curcumin at different stages of growth in three turmeric cultiv under pure and intercropped stands.

●——●	Cln. No.24 (1977)
●----●	Cln. No.24 (1978)
×——×	Cll.326 Sugandham (1977)
△——△	Duggirala (1977)

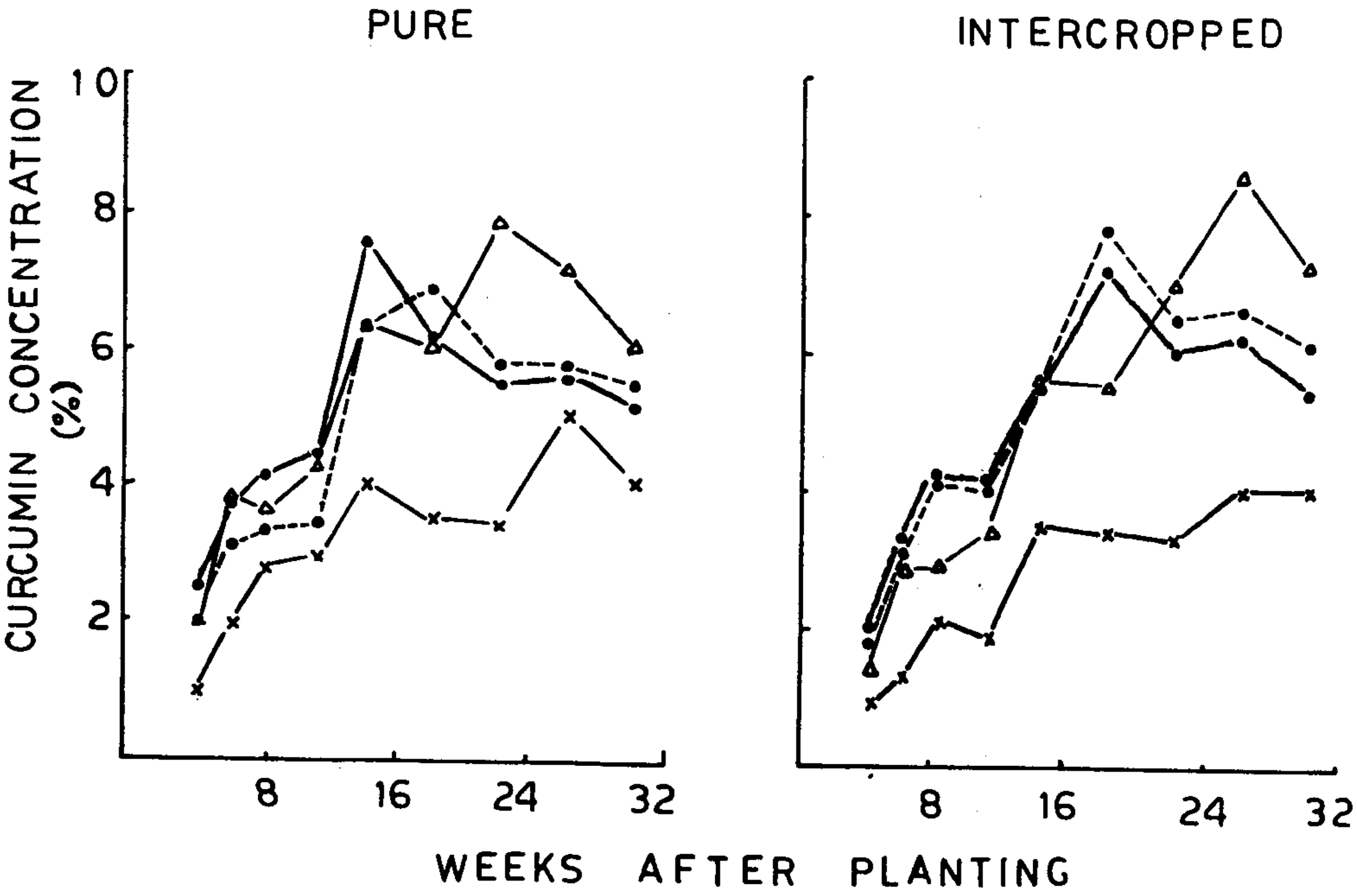

PURE
INTERCROPPED
CURCUMIN CONCENTRATION (%)
10
8
6
4
2
8
16
24
32
8
16
24
32
WEEKS AFTER PLANTING

FIG.35

concentration was noticed at 18th week under both the cropping systems. The maximum curcumin concentration for this cultivar was reached at 22nd and 26th weeks under pure and intercropped stands respectively and showed a considerable reduction at the time of harvest.

Under the pure stand, the maximum curcumin concentration attained by the cultivars C_1 and C_3 was considerably higher than that attained by the cultivar C_2. Under the intercropped stand, the maximum was attained by the cultivar C_3 followed by C_1 and C_2 in that order. At the time of maturity the curcumin concentration for the cultivar C_3 was significantly higher under the intercropped stand than under the pure stand, while for the other two cultivars there was no significant difference between the two cropping systems. The values of curcumin concentration at the time of maturity for the three cultivars under both the cropping systems were in the order, $C_3 > C_1 > C_2$ with significant differences.

<u>II Year</u>. The data on the curcumin concentration during the year 1978 are presented in Table 34b. The seasonal changes in the curcumin concentration for the cultivar C_1 during this year is depicted in Fig.35. The changes in the curcumin concentration for the cultivars C_2 and C_3 were similar during both the years of study. During this year, the maximum curcumin concentration for the

cultivar C_1 was attained by the 18th week under both the cropping systems. Pure stand of this cultivar registered lower values of the curcumin concentration in the second year than in the first year upto 14th week. Under the intercropped stand, the values of curcumin concentration of this cultivar did not show any marked difference between the two years during this period. Beyond 14th week, the values were considerably higher in the second year which was more pronounced under the intercropping system. In contrast to first year, the cultivar C_1 showed significantly higher curcumin concentrations under the intercropped stand than under pure stand at the time of maturity.

8.1.2. Curcumin yield

I Year. The pattern of curcumin accumulation (g m^{-2}) in the rhizomes of the three turmeric cultivars during the year 1977 is depicted in Fig.36. Under the pure stand, cultivar C_1 continued to accumulate curcumin in the rhizome upto maturity, while for the cultivars C_2 and C_3 the maximum accumulation was reached at 26th and 22nd weeks respectively followed by a decline towards maturity. Under the intercropped stand, rhizome continued to accumulate curcumin upto 26th week for all the three cultivars. The intercropped stand of cultivar C_3 showed a reduction in curcumin yield at maturity. Upto 11th week, the accumulation of curcumin in the rhizome was slow beyond which a steady increase was noted under both the cropping systems.

Fig.26. Accumulation of curcumin at different stag
of growth in three turmeric cultivars under
pure and intercropped stands.

●——● Cls. No.24 (1977)

●- - -● Cls. No.24 (1978)

×——× Cll.328 Sugandham (1977)

△——△ Duggirala (1977)

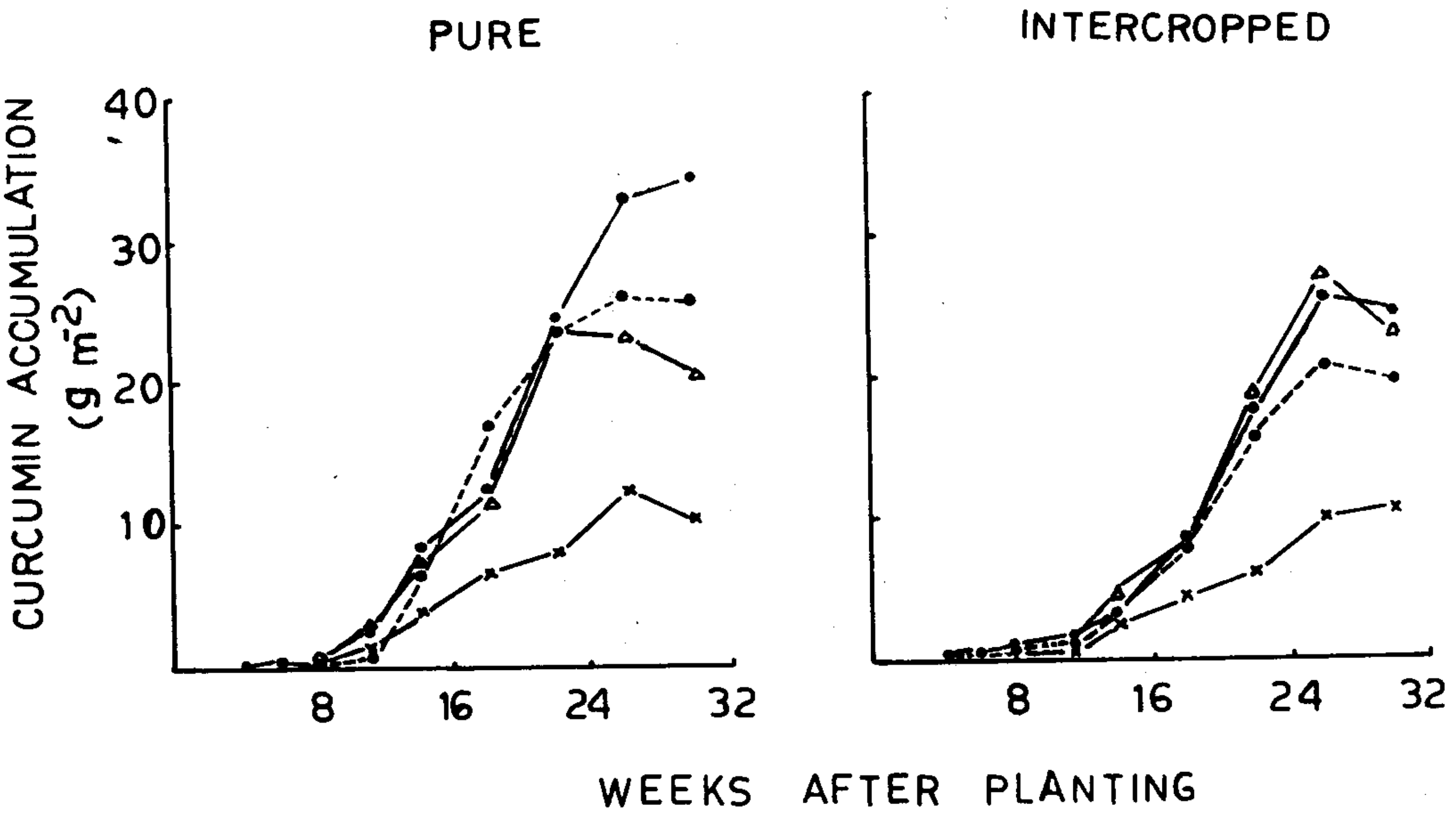

PURE
INTERCROPPED
CURCUMIN ACCUMULATION (g m^{-2})
40
30
20
10
8
16
24
32
8
16
24
32
WEEKS AFTER PLANTING

FIG. 36

The maximum curcumin yield recorded and the curcumin yield at harvest during the year 1977 are presented in Table 36. The maximum curcumin yield was significantly higher under the pure stand than under the intercropped stand for the cultivar C_1, while intercropped stand registered significantly higher curcumin yield for the cultivar C_3. In the case of cultivar C_2, no significant difference was noted for the maximum curcumin yield between the cropping systems. Under the pure stand, the maximum curcumin yield for the three cultivars was in the order, $C_1 > C_3 > C_2$ with significant differences, while under the intercropped stand it was significantly higher for the cultivars C_1 and C_3 than for C_2 without any significant difference between the former two cultivars. The same trend was noticed for the curcumin yield at harvest also.

__II Year__. The accumulation pattern of the total curcumin for the cultivar C_1 during the year 1978 is depicted in Fig.36. The cultivars C_2 and C_3 did not register any marked difference for the accumulation of curcumin between the two years. In contrast to first year, the maximum curcumin accumulation for the pure stand of the cultivar C_1 was attained by 26th week itself and maintained it upto maturity. Intercropped stand of this cultivar followed the same pattern of curcumin accumulation as that of the first year.

The maximum curcumin yield recorded and the curcumin yield at harvest during the year 1978 are presented in Table 36. Both these values had been considerably reduced for the cultivar C_1 in the second year as compared to the first year, which was more pronounced under the pure stand. The cultivars C_2 and C_3 did not show any marked difference for these values between the two years. In spite of the reduction, cultivar C_1 maintained its superiority for the curcumin yield over the other two cultivars under the mono-culture system, but under the intercropping system, C_3 registered significantly higher values followed by C_1 and C_2 in that order.

8.2. Essential Oil

8.2.1. Essential oil concentration

I Year. The data on essential oil concentration in the rhizomes (expressed as percentage of rhizome dry weight) of three turmeric cultivars during the year 1977 are presented in Table 35a and its trend of changes is depicted in Fig.37. The essential oil concentration for the cultivar C_1 had attained the maximum by 14th week under both the cropping systems. In the case of cultivar C_2, the maximum oil concentration was reached at 11th and 8th week under pure and intercropped stands respectively, while in the case of C_3, the maximum was reached at 8th week under both the cropping systems. After reaching the maximum, the oil

Table 33a. Essential oil concentration (%) of three turmeric cultivars at different stages of growth under pure and intercropped stands during the year 1977

Cropping systems	Cultivars	Weeks after planting								
		4	6	8	11	14	18	22	26	30
Pure	C_1	5.3	5.7	6.1	7.0	8.8	7.0	6.3	6.3	5.3
	C_2	5.1	5.5	5.6	5.8	4.8	4.2	4.8	5.1	4.3
	C_3	5.2	5.6	6.2	6.0	5.9	5.0	4.5	6.0	5.0
Intercropped	C_1	4.9	5.4	5.9	6.2	6.6	5.6	5.0	6.2	5.5
	C_2	4.5	5.1	6.1	5.8	6.0	3.8	4.4	5.0	5.0
	C_3	4.4	5.6	6.0	6.0	5.0	4.0	5.3	5.8	5.2
Mean Cultivars										
C_1		5.1	5.6	6.0	6.6	7.7	6.3	5.7	6.3	5.4
C_2		4.8	5.3	5.9	5.8	5.4	4.0	4.6	5.1	4.7
C_3		4.8	5.6	6.1	6.0	5.5	4.5	4.9	5.9	5.1
Mean Systems										
Pure		5.2	5.6	6.0	6.3	6.5	5.4	5.2	5.8	4.9
Intercropped		4.6	5.4	6.0	6.0	5.9	4.5	4.9	5.7	5.2
CD (P = 0.05)										
Cultivars (C)		NS	NS	NS	0.37	0.40	0.37	0.43	0.39	0.40
Systems (S)		0.29	NS	NS	NS	0.32	0.30	NS	NS	0.32
C x S		NS	NS	NS	NS	0.56	0.53	0.60	NS	NS
CV (%)		7.8	8.7	8.0	6.5	6.9	8.2	9.1	7.4	8.5

Table 15b. Essential oil concentration (%) of three turmeric cultivars at different stages of growth under pure and intercropped stands during the year 1978

Cropping systems	Cultivars	Weeks after planting								
		4	6	8	11	14	18	22	26	30
Pure	C_1	5.0	5.5	5.8	5.8	6.0	4.7	4.1	5.0	4.0
	C_2	5.1	5.5	5.3	5.4	4.5	4.2	4.4	4.9	4.2
	C_3	5.1	5.5	5.9	5.8	5.8	4.8	4.5	5.7	5.0
Intercropped	C_1	4.7	5.1	5.7	5.6	5.9	4.7	4.6	5.2	4.4
	C_2	4.3	4.9	5.8	5.5	5.8	3.8	4.1	4.9	5.0
	C_3	4.4	5.3	5.8	5.7	5.0	4.2	5.0	5.6	5.1
Mean Cultivars										
C_1		4.9	5.3	5.8	5.7	6.0	4.7	4.4	5.1	4.2
C_2		4.7	5.2	5.6	5.5	5.2	4.0	4.3	4.9	4.6
C_3		4.8	5.4	5.9	5.8	5.4	4.5	4.8	5.7	5.1
Mean Systems										
Pure		5.1	5.5	5.7	5.7	5.4	4.6	4.3	5.2	4.4
Intercropped		4.5	5.1	5.8	5.6	5.6	4.2	4.6	5.2	4.8
CD (P = 0.05) Cultivars (C)		NS	NS	NS	NS	0.43	0.39	0.35	0.33	0.31
Systems (S)		0.30	0.26	NS	NS	NS	0.32	NS	NS	0.26
C x S		NS	NS	NS	NS	0.61	NS	0.50	NS	NS
CV (%)		8.4	6.6	7.0	9.0	8.5	9.6	8.6	6.8	7.4

Table 36. Yield of curcumin and essential oil of three turmeric cultivars at different stages of growth under pure and intercropped stands during the year 1977 and 1978

Cropping systems	Cultivars	Curcumin yield (g m^{-2})				Essential oil yield (g m^{-2})			
		1977		1978		1977		1978	
		Maximum yield	Yield at harvest	Maximum yield	Yield at harvest	Maximum yield	Yield at harvest	Maximum yield	Yield at harvest
Pure	C_1	34.58	34.58	26.20	25.64	37.88	35.94	22.98	19.02
	C_2	12.22	10.34	12.45	10.12	12.99	10.86	12.20	10.62
	C_3	22.90	20.64	23.16	20.30	19.91	17.22	18.59	16.92
Intercropped	C_1	25.50	24.30	20.59	19.58	25.50	24.76	16.22	14.14
	C_2	10.60	10.60	10.37	10.36	13.26	13.26	12.96	12.96
	C_3	26.68	23.90	26.94	23.52	18.65	16.70	17.54	16.42
Mean									
Cultivars									
C_1		30.04	29.44	23.39	22.61	31.69	30.35	19.60	16.58
C_2		11.42	10.47	11.41	10.24	13.12	12.06	12.58	11.79
C_3		24.79	22.27	25.05	21.91	19.28	16.96	18.07	16.67
Mean									
Systems									
Pure		23.23	21.85	20.60	18.69	23.59	21.34	17.93	15.52
Intercropped		20.93	19.60	19.30	17.82	19.13	18.24	15.58	14.51
CD (P = 0.05)									
Cultivars (C)		1.94	1.95	1.61	1.63	1.80	1.85	1.28	1.36
Systems (S)		1.58	1.50	NS	NS	1.47	1.51	1.04	NS
C x S		2.74	2.75	2.28	2.30	2.54	2.61	1.81	1.93
CV (%)		9.5	10.2	8.7	9.7	9.1	10.1	8.3	9.8

Fig.37. Concentration of essential oil at different stages of growth in three turmeric cultivar under pure and intercropped stands.

●——● Cls. No.24 (1977)

●- - -● Cls. No.24 (1978)

×——× Cll.328 Sugandham (1977)

△——△ Duggirala (1977)

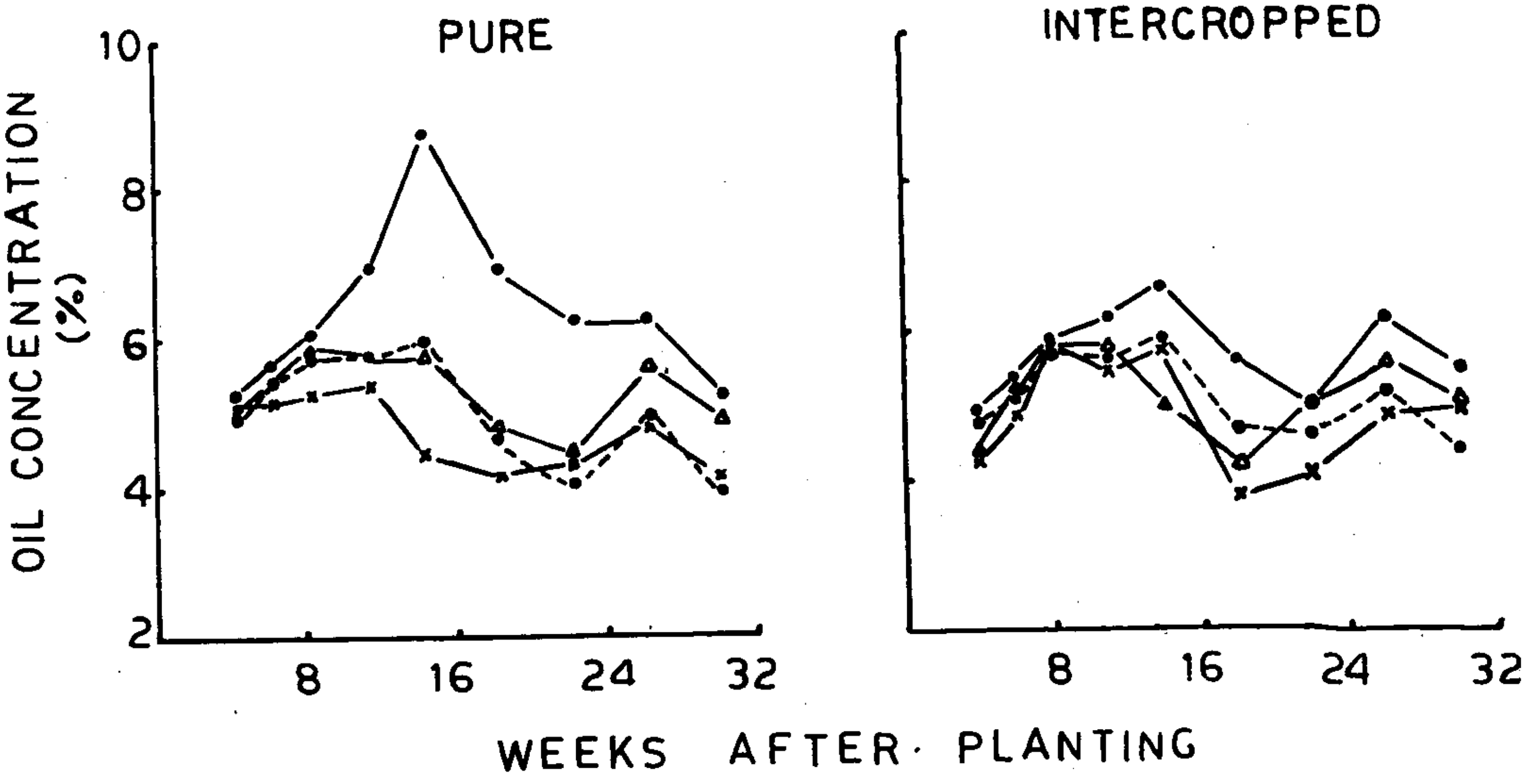

PURE
INTERCROPPED
OIL CONCENTRATION (%)
10
8
6
4
2
8
16
24
32
8
16
24
32
WEEKS AFTER PLANTING

FIG. 37

concentration had steadily decreased for all the three cultivars upto 22nd week. A further rise in oil concentration by the 26th week before dropping again at the time of harvest was noticed except for the intercropped stand of the cultivar C_2.

The maximum oil concentration registered for the cultivar C_1 was significantly higher under the pure stand than under the intercropped stand, while for the other two cultivars, this difference between the two cropping systems was not marked. Upto 8th week, the cultivars did not differ significantly for its oil concentration beyond which cultivar C_1 showed considerably higher values than the other two cultivars under both the cropping systems. At the time of maturity the oil concentration was significantly higher for the cultivars C_1 and C_3 than for C_2 without any significant difference between the former two cultivars. The oil concentration recorded for the intercropped stand of the cultivar C_2 at the time of maturity was higher than that under the pure stand, while for the other two cultivars, there were no considerable difference between the two cropping systems.

<u>II Year</u>. The data on the oil concentration at different stages of growth for three turmeric cultivars under pure and intercropped stands during the year 1978 are presented in Table 35b. The trend of changes in the oil concentration for the cultivar C_1 is depicted in Fig.37. The seasonal

changes in the oil concentration for the other two cultivars were the same during both the years, although the values were comparatively less during the second year. For the cultivar C_1, the values were considerably reduced in the second year as compared to first year throughout the growth period, the reduction being more pronounced under the pure stand than under the intercropped stand. The superiority of this cultivar over the other two cultivars as seen in the first year was not observed in the second year. At the time of maturity, the values of the oil concentration for the three cultivars were in the order, $C_3 > C_2 > C_1$ with significant differences.

8.2.2. Oil yield

<u>I Year</u>. The pattern of accumulation of oil (g m^{-2}) in the rhizomes of the three turmeric cultivars during the year 1977 is depicted in Fig.38. Under the pure stand, all the cultivars continued to accumulate oil in the rhizomes upto 26th week followed by a reduction at the time of maturity. Under the intercropped stand, eventhough cultivar C_2 continued to accumulate oil upto maturity, the maximum accumulation for the other two cultivars was reached by 26th week itself followed by a reduction at the time of maturity. Considerable difference among the cultivars for the oil accumulation was seen beyond 11th week under the pure stand, but such a difference was seen only after the 15th week under the intercropped stand.

Fig.38. Accumulation of essential oil at different stages of growth in three turmeric cultiv under pure and intercropped stands.

●——● Cls. No.24 (1977)
○- - -○ Cls. No.24 (1978)
×——× Cll.328 Sugandham (1977)
△——△ Duggirala (1977)

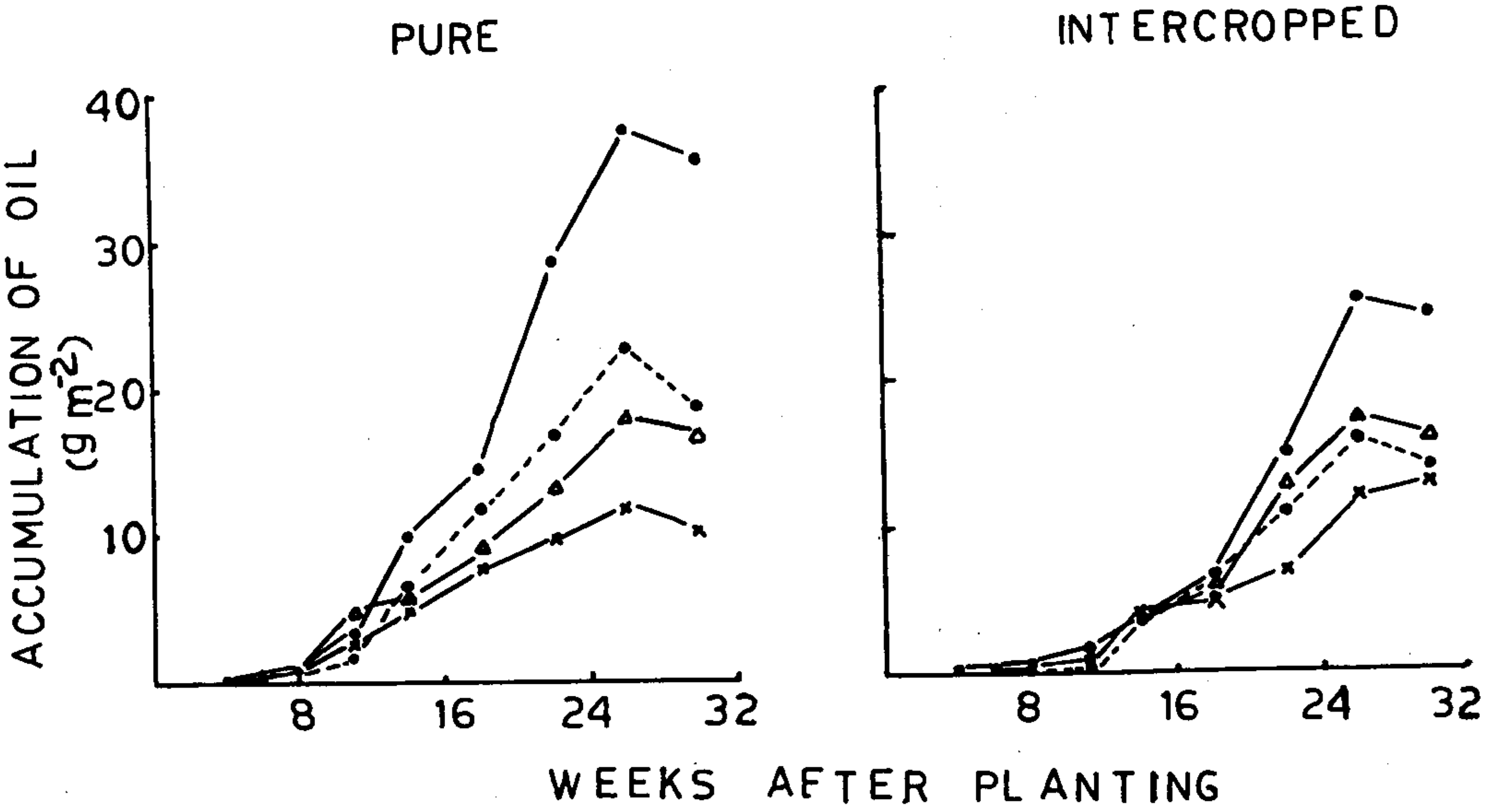

PURE
INTERCROPPED
ACCUMULATION OF OIL
(g m^{-2})
40
30
20
10
8
16
24
32
8
16
24
32
WEEKS AFTER PLANTING

FIG. 38

During these periods the maximum oil accumulation was seen in cultivar C_1 followed by C_3 and C_2 in that order under both the cropping systems.

The maximum yield of essential oil recorded and the oil yield at the time of harvest during the year 1977 are presented in Table 36. The maximum oil yield for the cultivar C_1 was significantly higher under the pure stand than under the intercropped stand, while for the other two cultivars this difference between the two cropping systems was not significant. The maximum oil yield for the three cultivars was in the order, $C_1 > C_3 > C_2$ with significant differences under both the cropping systems. The same trend was seen for the oil yield at harvest also.

<u>II Year</u>. The pattern of the accumulation of oil for the cultivar C_1 during the year 1978 is depicted in Fig.38. Cultivars C_2 and C_3 did not register any marked difference for the oil accumulation between the two years. The pattern of accumulation of oil for the cultivar C_1 followed more or less the same trend as that in the first year, eventhough the values were considerably reduced in the second year. Inspite of this reduction, cultivar C_1 maintained its superiority for the oil accumulation over the other two cultivars under the pure stand, but under the intercropped stand, C_3 was superior.

The maximum oil yield recorded and the oil yield at harvest during the year 1978 are presented in Table 36.

Both these values were considerably reduced for the cultivar C_1 in the second year as compared to the first year under both the cropping systems, while for the other two cultivars this reduction was not marked.

9. Effect of CCC or nitrogen application on growth and productivity

9.1. CCC treatments

The study was undertaken to find out the effect of CCC [(2-chloroethyl) trimethyl ammonium chloride] on the growth and productivity of the turmeric grown in monoculture (pure stand) and in association with coconut (intercropped stand).

Monoculture system. The details of different growth components and dry matter production as influenced by CCC treatments are given in Tables 37 and 38 respectively. It was found that treatments did not show any significant difference for the growth components like height, number of tillers, LAI_{max} and LAD, and also for the dry matter production. But at higher concentration (H_3), there was a tendency for reduced LAI_{max} and LAD which may be resulting in lower biological and rhizome yield.

Intercropping system. The number of tillers produced at different stages of growth are given in Table 39. The tiller production was considerably higher in all the CCC treatments especially for H_1 and H_2. The height of the plant recorded at different stages of growth is presented in Table 40. The maximum height recorded when the shoot

Table 37. Height, number of tillers, LAI_{max} and LAD as influenced by CCC treatments under the pure stand

Treatments	Height (cm)	No. of tillers	LAI_{max}	LAD (weeks)
H_0	92.2	3.8	5.2	65.6
H_1	91.8	3.8	5.1	65.1
H_2	91.3	4.0	5.2	65.9
H_3	90.7	3.8	4.8	63.1
CD (P = 0.05)	NS	NS	NS	NS
CV (%)	3.1	6.3	8.3	7.1

H_0 - Control
H_1 - 2000 ppm CCC
H_2 - 4000 ppm CCC
H_3 - 6000 ppm CCC

Table 38. Dry matter production and harvest index as influenced by CCC treatments under the pure stand

Treatments	Dry weight (gm^{-2})			HI
	Shoot	Rhizome	Whole plant	
H_0	332.4	475.3	836.7	0.560
H_1	330.2	472.0	831.7	0.568
H_2	334.6	478.6	841.8	0.569
H_3	324.6	481.5	806.2	0.559
CD (P = 0.05)	NS	NS	NS	NS
CV (%)	8.5	7.6	7.8	0.040

H_0 - Control
H_1 - 2000 ppm CCC
H_2 - 4000 ppm CCC
H_3 - 6000 ppm CCC

Table 39. Number of tillers produced as influenced by CCC treatments under the intercropped stand

Treatments	Weeks after planting				
	8	11	14	18	22
K_0	0.24	1.12	2.22	2.35	2.92
K_1	0.20	2.40	2.83	3.40	3.52
K_2	0.21	2.64	2.85	3.65	3.62
K_3	0.28	2.00	2.77	3.13	3.37
CD (P = 0.05)	NS	NS	0.50	0.54	0.50
CV (%)	30.2	44.8	13.9	14.0	11.0

K_0 - Control
K_1 - 2000 ppm CCC
K_2 - 4000 ppm CCC
K_3 - 6000 ppm CCC

Table 48. Plant height (cm) as influenced by CCC treatments under the intercropped stand

Treatments	Weeks after planting				
	8	11	14	18	22
E_0	48.0	63.2	84.5	91.3	94.2
E_1	48.4	63.5	83.7	90.7	92.9
E_2	47.7	63.4	83.3	90.4	91.7
E_3	47.8	61.8	82.4	89.4	90.1
CD (P = 0.05)	NS	NS	NS	NS	NS
CV (%)	4.4	4.6	3.4	3.9	5.3

E_0 - Control
E_1 - 2000 ppm CCC
E_2 - 4000 ppm CCC
E_3 - 6000 ppm CCC

reached maturity at 22nd week was found to be reduced in all the CCC concentrations eventhough this difference was not significant. The values of LAI at different stages of growth as influenced by the CCC treatments are shown in Table 41. Treated plants did not show any considerable increase in LAI beyond 18th week, while in control, LAI continued to increase upto 22nd week. Treatments H_1 and H_2 recorded remarkable reduction in LAI at 22nd week. During 18th week, LAI was significantly higher for the treatments H_1 and H_2 than for the control.

The values of rhizome growth rate (RhGR) at different periods of growth as influenced by CCC treatment are given in Table 42. Rhizome growth rate was significantly higher for the treatments H_1 and H_2 than for the control upto 18th week after planting. Beyond 18th week, there was no significant difference between the CCC treatments and control. The shoot growth rate (SGR) as influenced by the CCC treatments is presented in Table 43. Shoot growth rate was considerably higher in the case of all the CCC concentrations during the periods of the 8th to 11th and 14th to 18th weeks. Beyond 18th week, there was no significant difference between the CCC treatments and control, eventhough the values were markedly lower in the case of treatments H_1 and H_2. The effect of CCC treatments on crop growth rate (CGR) at different periods of growth is shown in the Table 44. Crop growth rate was

Table 41. Leaf area index as influenced by CCC treatments under the intercropped stand

Treatments	Weeks after planting					
	8	11	14	18	22	26
E_0	0.79	1.55	3.30	3.77	4.58	1.83
E_1	0.90	2.15	3.94	4.79	4.24	1.16
E_2	0.94	2.32	4.83	4.96	3.87	0.85
E_3	0.89	1.92	3.77	4.48	4.69	1.43
CD (P = 0.05)	NS	NS	NS	0.77	NS	NS
CV (%)	12.4	22.7	12.5	12.8	18.1	49.5

E_0 - Control
E_1 - 2000 ppm CCC
E_2 - 4000 ppm CCC
E_3 - 6000 ppm CCC

Table 42. Rhizome growth rate (g m^{-2} week^{-1}) as influenced by CCC treatments under the intercropped stand

Treatments	Weeks after planting				
	8-11	11-14	14-18	18-22	22-26
E_0	3.9	13.7	12.7	37.8	16.9
E_1	6.4	19.2	21.9	40.7	16.0
E_2	8.1	20.1	34.6	44.5	14.9
E_3	5.2	17.8	18.1	30.0	15.2
CD (P = 0.05)	2.3	3.6	7.0	NS	NS
CV (%)	28.9	15.0	22.8	16.0	22.0

E_0 - Control
E_1 - 2000 ppm CCC
E_2 - 4000 ppm CCC
E_3 - 6000 ppm CCC

Table 43. Shoot growth rate (g m^{-2} week^{-1}) as influenced by CCC treatments under the intercropped stand

Treatments	Weeks after planting			
	8-11	11-14	14-18	18-22
R_0	12.1	30.4	6.7	7.8
R_1	26.3	28.7	13.3	3.7
R_2	30.2	28.0	14.8	1.7
R_3	21.6	29.6	11.8	5.2
CD (P = 0.05)	4.8	NS	6.5	NS
CV(%)	15.7	22.4	27.3	66.7

R_0 - Control
R_1 - 2000 ppm CCC
R_2 - 4000 ppm CCC
R_3 - 6000 ppm CCC

TABLE 44. Crop growth ratio (g m^{-2} week^{-1}) as influenced by CCC treatments under the intercropped stand

Treatments	Weeks after planting				
	8-11	11-14	14-18	18-22	22-26
H_0	17.3	46.4	21.3	47.3	18.9
H_1	34.4	51.6	36.8	46.9	15.8
H_2	40.4	51.6	41.5	48.9	13.5
H_3	28.5	50.4	31.1	45.3	16.2
CD (P = 0.05)	5.7	NS	13.1	NS	NS
CV %	14.0	17.7	22.3	21.2	31.3

H_0 - Control
H_1 - 2000 ppm CCC
H_2 - 4000 ppm CCC
H_3 - 6000 ppm CCC

remarkably higher in all the CCC concentrations during the periods of 8th to 11th and 14th to 18th weeks beyond which no significant difference was noticed. The values of LAD, HI and yield are presented in Table 45. Eventhough the LAD was higher for all the CCC concentrations this difference was not significant. Harvest index was significantly higher for the treatments H_1 and H_2, while no significant difference was noticed between H_3 and control. Eventhough the shoot dry weight was higher for all the CCC treatments, this was not significant. The biological yield as well as rhizome yield were found to be significantly higher for all the CCC concentrations than in the control. The highest biological as well as rhizome yield were registered in the case of the treatment H_2 followed by H_1 and H_3 in that order. The rhizome yield recorded for the treatment H_2 was found to be 32 per cent higher than that for the control.

9.2. Nitrogen application

The study was undertaken to assess the response of turmeric to different doses of nitrogen and also to find out the most effective stage of application when the crop is raised under the monoculture system and in association with coconut (intercropping system).

Monoculture system. The values of LAI_{max}, LAD, HI, and the amount of dry matter accumulated in the shoot, rhizome

Table 45. Leaf area duration (LAD), harvest index (HI) and yield as influenced by CCC treatments under the intercropped stand

Treatments	LAD (weeks)	HI	Dry matter yield (g m^{-2})		
			Shoot	Rhizome	Whole plant
H_0	60.0	0.534	257.3	324.5	607.8
H_1	66.5	0.566	280.6	404.3	714.9
H_2	66.3	0.574	287.4	431.5	751.2
H_3	66.0	0.551	299.8	309.7	706.9
CD (P = 0.05)	NS	0.031	NS	37.8	83.0
CV (%)	7.0	5.3	12.0	7.1	8.5

H_0 - Control
H_1 - 2000 ppm CCC
H_2 - 4000 ppm CCC
H_3 - 6000 ppm CCC

and the whole plant as influenced by the nitrogen treatments are presented in Table 46. Treatment N_2 recorded significantly higher LAI_{max} and LAD than the other treatments. The treatments N_0 and N_4 recorded the lowest LAI_{max} and LAD values. Treatments did not show any significant difference for the harvest indices. The amount of dry matter accumulated in the shoot, rhizome and whole plant were also significantly higher for the treatment N_2 than for the other treatments. As in the case of LAI and LAD, treatments N_0 and N_4 showed the lowest yield of dry matter. Treatment N_2 registered about 20 per cent more rhizome yield than the treatments N_1 and N_3, and 37 per cent more than N_0 and N_4.

Intercropping systems. The values of LAI_{max}, LAD, HI, and the amount of dry matter accumulated in the shoot, rhizome and the whole plant as influenced by the nitrogen treatments are given in Table 47. It was found that the LAI_{max}, LAD and the dry matter yield were higher for the treatments N_1, N_2^* and N_3 than for N_0 and N_4, but the differences were not significant.

Table 46. LAI_{max}, LAD, HI and dry matter production as influenced by nitrogen amendments under the monoculture system

TREATMENTS	LAI_{max}	LAD (weeks)	HI	Dy matter yield ($g m^{-2}$)		
				Shoot	Rhizome	Whole plant
N_0	4.49	59.48	0.561	291.5	414.9	737.3
N_1	5.16	65.55	0.568	332.4	475.3	836.7
N_2	6.23	79.04	0.580	390.9	576.6	991.7
N_3	5.12	66.79	0.572	330.5	485.5	848.8
N_4	4.51	60.11	0.559	308.2	428.7	765.3
CD ($P=0.05$)	0.97	9.25	NS	49.5	88.8	139.2
CV (%)	14.3	10.6	3.4	11.4	16.3	13.4

N_0 - No nitrogen application.
N_1 - Two doses of 15 kg each at 6th and 10th weeks after planting.
N_2 - Two doses of 30 kg each at 6th and 10th weeks after planting.
N_3 - Two doses of 15 kg each at 6th and 10th weeks after planting and another dose of 30 kg at 16th week.
N_4 - Single dose of 60 kg at 16th week after planting.

Table 47. LAI_{max}, LAD, HI and dry matter production as influenced by nitrogen amendments under the intercropping system

TREATMENTS	LAI_{max}	LAD (weeks)	HI	Dry matter yield (gm^{-2})		
				Shoot	Rhizome	Whole plant
N_0	4.35	56.86	0.535	239.6	305.7	571.7
N_1	4.58	60.06	0.532	259.9	321.5	604.8
N_2	4.76	61.76	0.527	270.0	328.1	623.5
N_3	4.82	61.96	0.523	270.9	323.7	620.1
N_4	4.36	57.44	0.536	243.3	306.6	572.7
CD (P=0.05)	NS	NS	NS	NS	NS	NS
CV (%)	16.4	8.9	2.5	15.4	12.7	11.9

N_0 - No nitrogen application

N_1 - Two doses of 15 kg each at 6th and 10th weeks after planting.

N_2 - Two doses of 30 kg each at 6th and 10th weeks after planting.

N_3 - Two doses of 15 kg each at 6th and 10th weeks after planting and another dose of 30 kg at 16th week.

N_4 - Single dose of 60 kg at 16th week after planting.

10. An analysis of yield—and growth components

The relationship between different yield components (size of the mother rhizome, and size/number of fingers, etc.) with the rhizome yield under monoculture and intercropping systems was analysed. The interrelationship of different growth components derived from the growth analytical techniques was examined. The effects of different growth components as well as that of HI on the rhizome yield were examined.

The effect of intercropping on certain rhizome and shoot characters of three turmeric cultivars is presented in Table 48. The size of the mother rhizome of the cultivar C_1 was significantly less under the intercropping system and of cultivar C_3 more under intercropping system than those under monoculture. The cultivar C_2 did not show any significant difference between the cropping systems. All the three cultivars produced less number of fingers under the intercropping system than under monoculture. The length of first order fingers of cultivar C_1 was significantly reduced, while that of the cultivar C_2 was significantly higher under the intercropping system. The length of first order fingers of cultivar C_3 was unaffected by the intercropping practice. The breadth of the first order fingers of

Table 48. Effect of intercropping on rhizome and shoot characters

Cropping systems	Cultivars	Size of the mother rhizome (cm^2) (length x breadth)	Total number of fingers	Length of first order fingers (cm)	Breadth of first order fingers (cm)	Number of tillers	Height (cm)
Pure	C_1	20.9	18.1	4.5	2.3	3.8	92.8
	C_2	22.9	10.3	5.3	2.7	0.7	101.3
	C_3	23.9	12.0	4.8	2.6	2.9	97.7
Intercropped	C_1	17.7	16.5	4.2	1.9	2.6	119.0
	C_2	23.4	9.3	5.6	2.8	0.4	110.9
	C_3	26.7	8.9	4.9	2.8	1.9	116.9
Mean Cultivars							
C_1		19.3	17.3	4.4	2.1	3.2	105.9
C_2		23.1	9.8	5.4	2.8	0.6	106.1
C_3		25.2	10.4	4.8	2.7	2.4	107.3
Mean Systems							
Pure		22.6	13.5	4.8	2.5	2.5	97.3
Intercropped		22.6	11.6	4.9	2.5	1.6	115.6
CD (P = 0.05)							
Cultivars (C)		1.9	1.7	0.2	0.2	0.5	NS
Systems (S)		NS	1.0	NS	NS	0.4	4.0
C x S		2.7	NS	0.3	0.3	0.6	7.0
CV (%)		10.9	12.1	5.9	10.0	28.7	5.0

the cultivar C_1 was also markedly reduced under the intercropping system, compared to that under monoculture. The other two cultivars did not show any significant difference between the cropping system.

The number of tillers produced by the cultivars C_1 and C_3 was significantly less under the intercropping system than those under monoculture. The production of tillers by the three cultivars was in the order, $C_1 > C_3 > C_2$ under both the cropping systems. Maximum height was attained by all the three cultivars under the intercropping system.

Correlation coefficients of different yield components with rhizome yield of the three cultivars under monoculture and intercropping systems are presented in Table 40. The size of the mother rhizome and number of major fingers were significantly and positively correlated with rhizome yield for all the three cultivars under the monoculture system and for the cultivars C_1 and C_3 under the intercropping system. In case of the intercropped stand of cultivars C_2 these parameters did not show significant correlation with rhizome yield. The number of minor fingers registered significant positive correlation with rhizome yield for all the three cultivars under both the cropping system. The length and breadth of major fingers was singnificantly and positively correlated with the rhizome yield for the cultivars C_2 and C_3 under both the cropping systems, but for C_1, this relationship was

Table 49. Correlation coefficients of different yield components on rhizome yield for the three turmeric cultivars under monoculture (S_1) and intercropping (S_2) systems

Independent variables	Correlation coefficients					
	Cls. No. 24		Cll. 326 Sugandham		Duggirala	
	S_1	S_2	S_1	S_2	S_1	S_2
Size of mother rhizome (length x breadth)	0.38*	0.49**	0.66**	0.23	0.48**	0.39*
No. of major fingers (tiller producing ones)	0.63**	0.42**	0.62**	0.30	0.49**	0.52**
No. of minor fingers (other than tiller producing ones)	0.65**	0.45**	0.68**	0.71**	0.63**	0.45**
Length of major fingers	0.53**	0.25	0.59**	0.35*	0.50**	0.60**
Breadth of major fingers	0.45**	0.19	0.64**	0.41*	0.43**	0.64**
Size of minor fingers (length x breadth)	0.12	0.35*	0.52**	0.13	0.55**	0.33

* - Significant at 5% level

** - Significant at 1% level

pronounced only under the monoculture system. There was a significant and positive association between the size of minor fingers and rhizome yield of the cultivars C_2 and C_3, while for the intercropped stands of these cultivars such relationship was not marked. In case of the cultivar C_1, the positive influence of the size of the minor fingers on rhizome yield was pronounced only under the intercropping system.

The relationship among LAI, EAR, CGR, RhGR, LAR and RLGR of the cultivar C_1 at different stages of growth are presented in Table 30. Leaf area index was positively correlated with crop growth rate upto third month of growth under both the cropping systems beyond which no significant association was noticed. A significant positive correlation between LAI and RhGR existed under the monoculture system only during the 3rd month. Economic assimilation rate showed significant positive correlation with crop growth rate from 3rd month onwards and a very close association between these two parameters existed during 5th and 6th months under the monoculture system. Net assimilation rate was positively correlated with crop growth rate as well as rhizome growth rate during this period which was more pronounced during 4th month under the intercropping system and during 5th and 6th months under the monoculture system. Net assimilation rate was negatively correlated with leaf area ratio during the early period of plant growth. A close positive association between

Table 50. Interrelationship among various growth components at different stages of development for the cultivar, Cls. No. 24 under monoculture (S_1) and intercropping (S_2) systems

Variables	Correlation coefficients Months after planting									
	2		3		4		5		6	
	S_1	S_2	S_1	S_2	S_1	S_2	S_1	S_2	S_1	S_2
LAI vs CGR	0.62**	0.72**	0.86**	0.62**	0.59*	0.39	0.41	0.39	0.02	-0.28
LAI vs RhGR	0.23	0.35	0.75**	0.40	0.25	0.31	0.15	0.46	0.20	-0.22
LAR vs CGR	0.44	0.58*	0.72**	0.58*	0.71**	0.69**	0.93**	0.74**	0.90**	0.71**
NAR vs CGR	0.64**	0.84**	0.82**	0.76**	0.84**	0.93**	0.94**	0.85**	0.96**	0.90**
NAR vs RhGR	0.50	0.74**	0.73**	0.74**	0.70**	0.90**	0.85**	0.74**	0.82**	0.67**
NAR vs LAR	-0.81**	-0.26	-0.08	-0.01	-0.74**	-0.36	0.12	0.21	0.45	-0.25
NAR vs RLGR	0.89**	0.73**	0.86**	0.85**	0.73**	0.61**	0.19	0.78**	0.16	0.05

* - Significant at 5% level

** - Significant at 1% level

NAR and RhGR was noticed upto 5th month for the monoculture system and upto 6th month for the intercropping system.

The crop growth rate and rhizome growth rate as a function of cumulative leaf area index for the three cultivars under the monoculture and intercropping systems are shown in Fig.39. During first year of study, pure stand of cultivar C_1 showed a reduction in CGR when LAI exceeded 4.5, while such a reduction was not noticed for the intercropped stand. An increase in RhGR, coincident with the period of maximum LAI, was noticed for the cultivar C_1 under both the cropping systems during the second year of study. In the case of cultivars C_2 and C_3, CGR was reduced when the LAI exceeded the values of 3 to 3.5.

The relationship between dry matter accumulation and the cumulative leaf area duration at several stages of growth upto maturity for the three cultivars under monoculture and intercropping systems is presented in Fig.40. The linear relationship between the dry matter accumulation and the cumulative leaf area duration was more pronounced for cultivar C_1 than that of C_2 or C_3, under both the cropping systems during the two years of study. In case of the intercropped stand of cultivar C_2, the accumulation of dry matter was slower than that of leaf area duration during the period of 14th to 26th week.

Fig.39. Crop growth rate (CGR) and rhizome growth rate (RhGR) as a function of cumulative leaf area index (LAI) in three turmeric cultivars under pure and intercropped stands.

A. Cls. No.24 (1977)
B. Cls. No.24 (1978)
C. Cll.328 Sugandham (1977)
D. Duggirala (1977)

●——● CGR
×——× RhGR

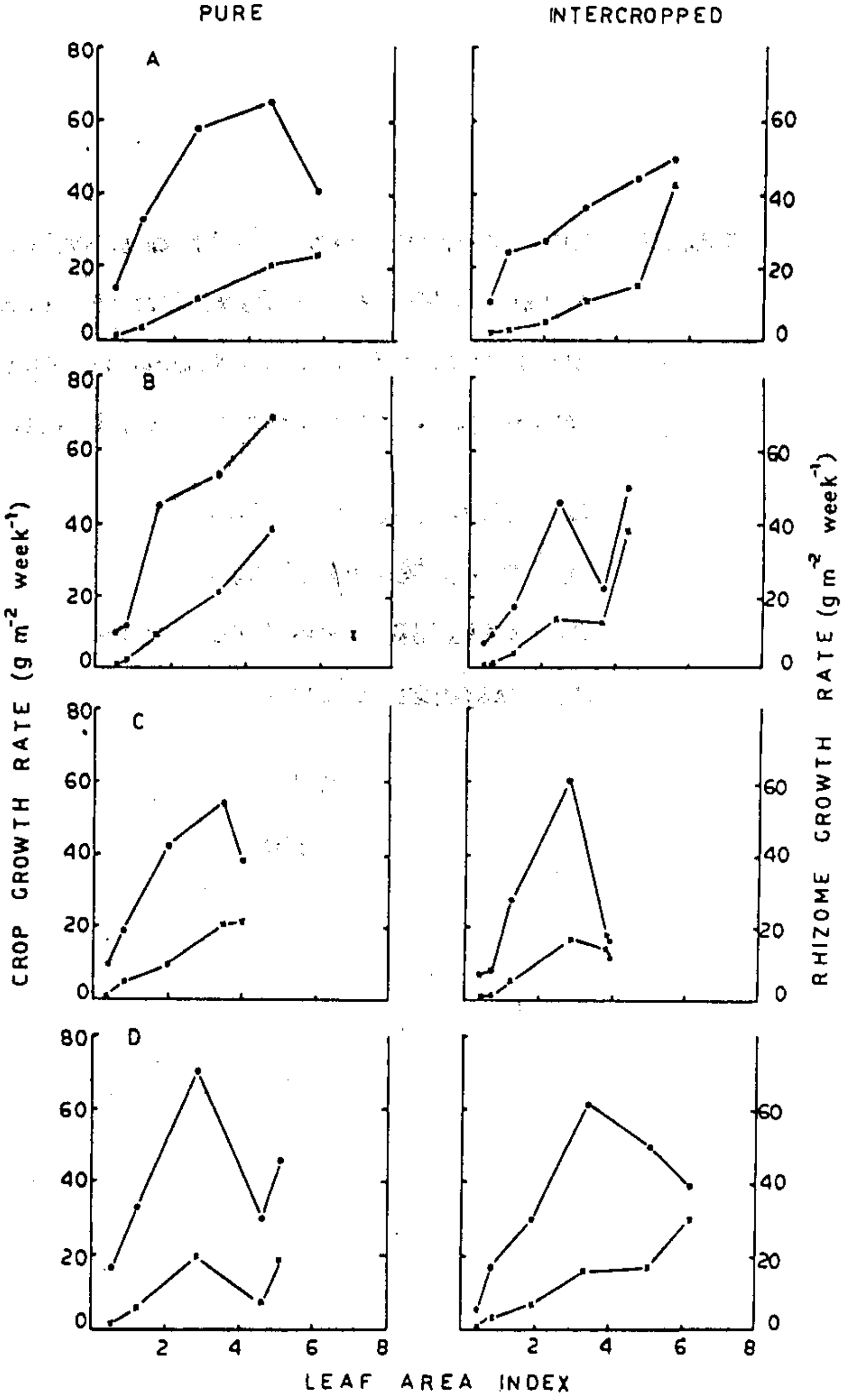

PURE
INTERCROPPED
A
B
C
D
CROP GROWTH RATE (g m^{-2} week^{-1})
RHIZOME GROWTH RATE (g m^{-2} week^{-1})
80
60
40
20
0
2
4
6
8
LEAF AREA INDEX

FIG. 39

Fig.40. Relationship between dry matter accumulati and cumulative leaf area duration (LAD) in three turmeric cultivars under pure and intercropped stands.

A. Cls. No.24

B. Cll.328 Sugandham

C. Duggirala

●——● 1977 } LAD
●- - -● 1978 }

×——× 1977 } Dry matter
×- - -× 1978 }

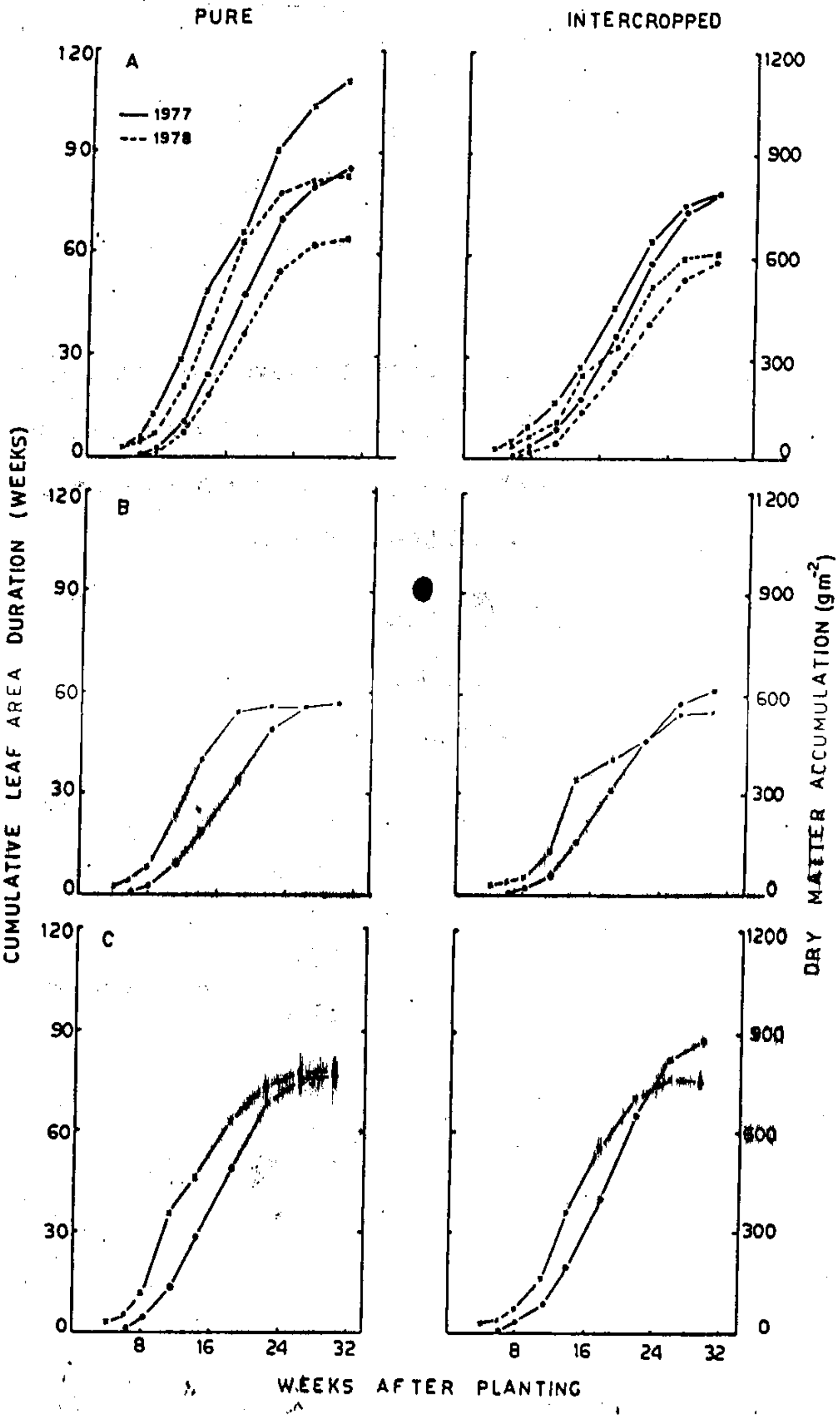

PURE
INTERCROPPED
A
B
C
— 1977
--- 1978
CUMULATIVE LEAF AREA DURATION (WEEKS)
DRY MATTER ACCUMULATION (gm⁻²)
0
30
60
90
120
0
300
600
900
1200
8
16
24
32
WEEKS AFTER PLANTING

FIG. 40

In the case of the intercropped stand of cultivar C_3, the accumulation of dry matter was negligible beyond 22nd week while LAD increased upto 30th week.

The relationship between various growth components at different stages of development and the final rhizome yield for cultivar C_1 under monoculture and intercropping systems is presented in Table 51. Leaf area index and leaf area duration showed significant and positive correlation with final rhizome yield, right from the early growth phases. Such positive relationship could be seen from 3rd to 6th month under the monoculture system, and during 4th and 5th months under the intercropping system. The values of LAI and LAD during 5th month recorded the highest correlation coefficient with the final rhizome yield under both the cropping systems. As in case of LAI and LAD, a positive correlation of shoot dry weight as well as total dry weight with the final rhizome yield could be recorded, from 3rd month onwards under the monoculture system and from 4th month onwards under the intercropping system.

The relationship of LAI_{max}, total leaf area duration, maximum height attained and number of tillers with the final rhizome yield for the cultivar C_1 under the monoculture and intercropping systems is presented in Table 52. The maximum LAI attained and LAD were significantly and positively correlated with the

Table 51. Correlation coefficients of growth components at different stages of development on final rhizome yield for the cultivar, Clo. No. 24 under monoculture (S_1) and intercropping (S_2) systems

Growth characters (independent variables)	Maturity (months after planting)									
	2		3		4		5		6	
	S_1	S_2	S_1	S_2	S_1	S_2	S_1	S_2	S_1	S_2
LAI	0.30	0.36	0.51*	0.46	0.73**	0.54*	0.78**	0.67**	0.63**	0.33
LAD	0.28	0.38	0.55*	0.49	0.69**	0.59*	0.82**	0.74**	0.65**	0.40
Shoot dry weight	0.25	0.31	0.54*	0.50	0.65**	0.55*	0.83**	0.70**	0.85**	0.75**
Total dry weight	0.31	0.34	0.57*	0.52	0.73**	0.65**	0.74**	0.89**	0.88**	0.83**

* - Significant at 5% level

** - Significant at 1% level

Table 52. Relationship of LAI_{max}, LAD (total accumulated weeks), height and number of tillers with the final rhizome yield for the cultivar, Clo. No. 24 under mono-culture (S_1) and intercropping (S_2) systems

	Independent variables							
	LAI_{max}		LAD		Height		No. of tillers	
	S_1	S_2	S_1	S_2	S_1	S_2	S_1	S_2
Correlation coefficients	0.78**	0.57*	0.77**	0.58*	0.66**	0.36	0.67**	0.52*

* - Significant at 5% level

** - Significant at 1% level

rhizome yield, the relationship being more pronounced under the monoculture system than under the intercropping system. The maximum height attained as also positively related with the rhizome yield, the correlation however being significant only under the monoculture system. The number of tillers produced was significantly and positively correlated with the rhizome yield, the correlation coefficient was greater under the monoculture system than under the intercropping system.

The relationship among final shoot dry weight, total dry weight (biological yield), rhizome yield and harvest index for cultivars C_1, C_2 and C_3 are presented in the Tables 53, 54 and 55 respectively. Total dry weight as well as shoot dry weight at harvest was closely correlated with rhizome yield for all the three cultivars under both the cropping systems. The negative correlation between shoot dry weight and harvest index was significant only under the intercropping system for cultivars C_1 and C_2, and under both the cropping systems for cultivar C_3. A linear relationship between the rhizome yield and biological yield was noticed for all the three cultivars under both the cropping systems (Fig.41). There was only a weak correlation between rhizome yield and harvest index of cultivars C_2 and C_3 under both the cropping systems, while a significant correlation was noticed in only the intercropped stand of cultivar C_1.

Table 53. Relationship among final shoot dry weight, total dry weight (biological yield), rhizome yield and harvest index for the cultivar, Cls. No. 24 under monoculture (S_1) and intercropping (S_2) systems

Characters	Correlation coefficients					
	Total dry weight		Rhizome yield		Harvest index	
	S_1	S_2	S_1	S_2	S_1	S_2
Shoot dry weight	0.78**	0.91**	0.71**	0.76**	-0.16	-0.30*
Total dry weight			0.97**	0.93**	0.04	0.01
Rhizome yield					0.27	0.36*

* - Significant at 5% level

** - Significant at 1% level

Table 54. Relationship among final shoot dry weight, total dry weight (biological yield), rhizome yield and harvest index for the cultivar, Cll. 326 Sugandham under monoculture (S_1) and intercropping (S_2) systems

Characters	Correlation coefficients					
	Total dry weight		Rhizome yield		Harvest index	
	S_1	S_2	S_1	S_2	S_1	S_2
Shoot dry weight	0.98**	0.88**	0.89**	0.76**	-0.27	-0.36*
Total dry weight			0.96**	0.94**	-0.07	-0.21
Rhizome yield					0.19	0.15

* - Significant at 5% level

** - Significant at 1% level

Table 55. Relationship among final shoot dry weight, total dry weight (biological yield), rhizome yield and harvest index for the cultivar, Duggirala under monoculture (S_1) and intercropping (S_2) systems

Characters	Correlation coefficients					
	Total dry weight		Rhizome yield		Harvest index	
	S_1	S_2	S_1	S_2	S_1	S_2
Shoot dry weight	0.96**	0.98**	0.69**	0.86**	-0.50**	-0.41*
Total dry weight			0.87**	0.95**	-0.25	-0.22
Rhizome yield					0.22	0.08

* - Significant at 5% level

** - Significant at 1% level

Fig.41. Relationship between biological yield and rhizome yield in three turmeric cultivars under pure and intercropped stands.

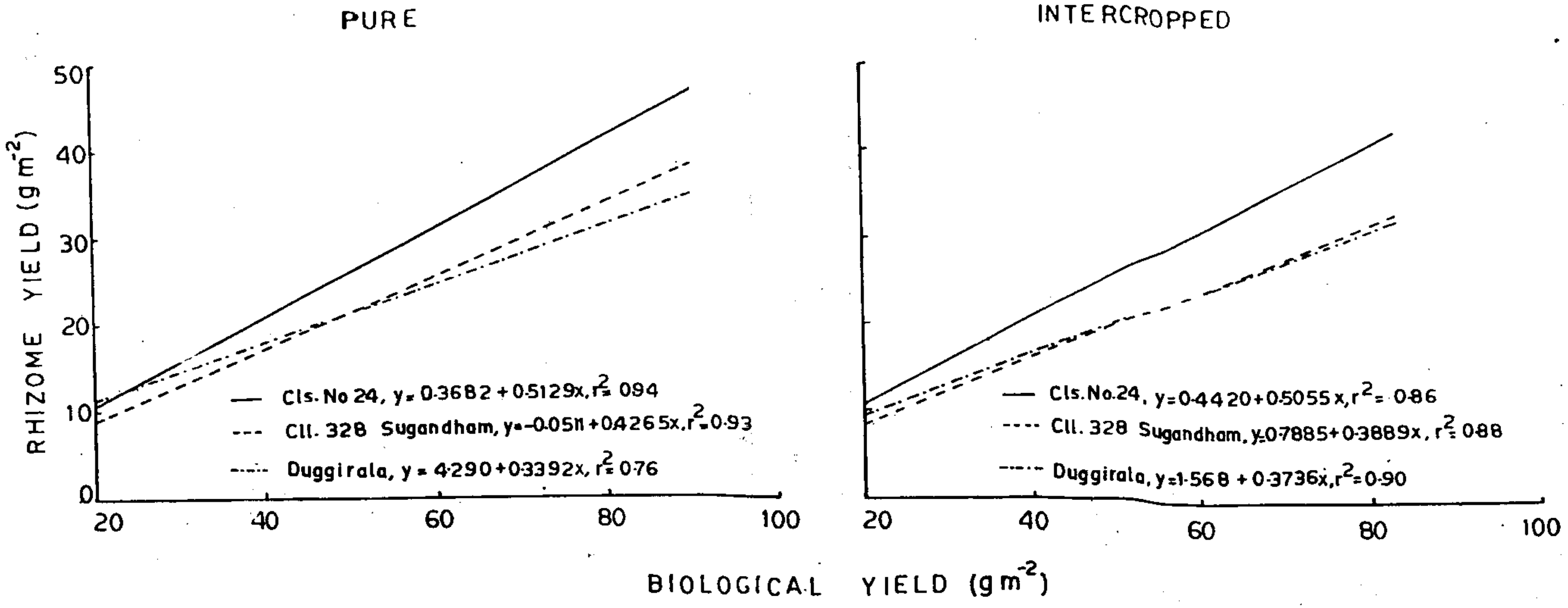
PURE
INTERCROPPED
RHIZOME YIELD (g m-2)
50
40
30
20
10
0
20
40
60
80
100
20
40
60
80
100
BIOLOGICAL YIELD (g m-2)
Cls. No 24, y= 0.3682 + 0.5129x, r2= 0.94
CII. 328 Sugandham, y=-0.0511+0.4265x, r2=0.93
Duggirala, y = 4.290+0.3392x, r2= 0.76
Cls. No.24, y=0.4420+0.5055x, r2= 0.86
CII. 328 Sugandham, y=0.7885+0.3889x, r2= 0.88
Duggirala, y=1.568 + 0.3736x, r2=0.90

FIG. 41

DISCUSSION

Intercropping in coconut gardens has attracted great interest, as the wide spacing of coconut trees offers great scope for raising many annual and perennial crops. Nelliat *et al.* (1974) were the first to highlight this aspect. Bavappa (1975) stressed the significance of intensive cropping system. In the present studies, the development, growth and yield of three cultivars of turmeric in monoculture and as an intercrop in coconut garden were investigated in relation to the prevailing microclimate.

The crops were raised in the cropping seasons (June to December) of 1977 and 1978. In 1977, the sunshine hours as well as PAR were greater than in 1978 during the early period of crop growth (June to September). The precipitation during this period was lower in 1977 than in 1978. During the latter period of crop growth (October and November), the precipitation was higher and PAR input was lower in 1977 than in 1978 (Tables 19 and 25b). There was considerable difference in the solar radiation received between the two cropping systems, viz., as monocrop and as an intercrop. On an average, intercropped stand received about 46 per cent of incoming PAR (Table 20). The only environmental variable found different between the two cropping systems was the solar radiation since the two cropping systems did not differ markedly for the other environmental variables studied (Table 26).

1. Light climate in coconut garden

Although the investigations on intercropping received wide attention in the tropics, in relation to agronomic practices, only very little information was available on the canopy light relationship under the changed environments. The quantification and characterisation of PAR available in the coconut garden during the development of each crop associated with it are highly important for evaluating the advantage of the coconut based intercropping systems.

Characterisation of solar radiation available under tree canopies had, in fact, been widely attempted in forestry (Anderson, 1964a,b; Hutchinson and Matt, 1977; and Swithovski, 1982) and for a few horticultural tree crops like apple (Suckling et al., 1975). The seasonal pattern of PAR transmission in the coconut garden indicated that the PAR transmission by the coconut canopy was more in the early period of turmeric growth than in the later periods. Penetration of radiation into a canopy depends not only on canopy structure but also on relative amounts of direct and diffuse radiation and the angle of elevation (Impens and Lemeur, 1969). Since the leaf area of coconut was fixed in the course of present study, the seasonal changes in the light interception by the coconut canopy were mainly brought about by the changes in sky condition and solar altitude. During the early period of turmeric growth, from June to August, the sunshine duration was comparatively low (5 hours per day), thereby showing the preponderance of overcast sky during this period (Table 25b). Anderson (1964a) cited several instances showing that percentage transmission increased with increase of cloud cover. It was further noticed that in later part of the year, when the solar altitude is lower, cloudless weather prevailed. Palmer and Jackson (1977) found that lower solar altitudes in the later part of the year increased light interception in the case of apple orchards, giving a higher light interception per unit leaf area because of increased shadow lengths from inclined shading structures, which was not apparent under completely cloudy conditions. The present study also revealed that the PAR transmission for the clear day in March was higher than that for the same in December. This can be attributed to the greater contribution of direct light when the sun was higher in the sky. Present studies on diurnal course of PAR transmission demonstrate that the PAR transmission by coconut canopy varies considerably among different seasons of the year.

Nair and Balakrishnan (1976) observed that the peak bright period in the coconut plantation was between 10 to 16 hours. This phenomenon was more pronounced for clear days during the summer months than the other periods.

During heavily overcast days the transmission values were less variable during the day (Fig.10). Clegg *et al*. (1974) had reported that differences between transmission values over a diurnal period were less on cloudy than on clear days indicating more uniform light distribution during cloudy days. The present studies also revealed that high transmission values occur early (6.00 to 7.00 h) and late hours (17.00 to 18.00 h) of the day which may be due to higher proportion of diffuse light during these periods. A higher transmission value during the early morning hours was also reported for rubber plantations in Kerala (Satheesan *et al*., 1983). When there was a marked increase in the total light in the open between 7.30 to 8.30 h, the lowest values of transmission was recorded. Such a reduction was noticed during 16.00 to 17.00 h also.

The greater transmission by coconut canopy between 9 to 16 hours were due to a large contribution of direct light in the form of sunflecks. The higher intensity of sunflecks in the summer month of March as compared to that in December might have caused higher transmission for the clear day in March than that for the same in December. The area under the sunflecks was quite high and reached a maximum of 35 per cent at solar noon. Contribution of sunfleck PAR towards the total PAR available on the plantation floor was also as high as 80 per cent. Bjorkman and Ludlow (1972) found that sunflecks contributed about

70 per cent of the PAR available inside a dense Queensland rain forest. Navithovski (1982) reported that the contribution of sunflecks was between 66 and 89 per cent of the total PAR under poplar plantations. The sunflecks are characterised by their constant movement because of the wind and movement of sun across the sky. Due to this, the intercrops in the coconut plantation are alternately exposed to shady and bright patches of light. Under this situation photosynthesis may be more effective than under an equal amount of PAR of uniform intensity (Wierzbicki, 1980). But such evidences are scarce and some reports did not show any special advantage of flashing light in determining the plant growth. Kriedmann et al. (1973) reported that grape leaves utilised flashing light more effectively. Huxley (1969) did not find any differences in plant growth under shades that covered and uncovered the light source at different rates. Woods and Turner (1971) found that shade-resistant trees showed more rapid stomatal responses to changes in light intensity than shade-sensitive ones. This result indicated that shade-resistant plants showed more adaptation in utilizing the sunflecks than the shade sensitive ones.

Apart from the crop and solar geometry, the distribution of PAR under the plant canopies was also affected by the optical properties of individual leaves. The spectral content of light reflected and transmitted by individual leaves has been examined (Gates *et al.*, 1965; Gausman *et al.*, 1969; and Mc Clure, 1969). The coconut leaves showed maximum reflectance of 16 per cent at around 550 nm and a minimum of 8 per cent in the blue and red regions of the PAR spectrum. These values are somewhat higher than those found for annuals like cotton (Thomas *et al.*, 1967), soybean (Gupta and Woolley, 1971), and blackgram (Jain *et al.*, 1978), and for tree crops like apple (Palmer, 1977), but well within the range of 8 to 21 per cent reported by Federer and Tanner (1966) for typical green leaves. High reflectance of the coconut leaf may be due to the presence of the thick cuticle. Such a high reflectance is advantageous for intercropping in coconut garden, since apart from reflecting the light back to the atmosphere, the dropping leaves at lower levels in the canopy can also reflect light in all directions thereby contributing to the light availability inside the plantation. The transmittance of the coconut leaf was low. The maximum transmittance of 3 per cent was at around 550 nm, while it was negligible at blue and red regions. An efficient filtering off of blue and red wavelengths by the individual leaves had been reported for a number of tree species (Loomis, 1965; and Stoutjesdijk, 1972). This depletion of critical blue and red wavelengths by the coconut leaves could reduce the photosynthetic efficiency of the intercrops and makes the sunflecks in the coconut garden all the more important. Since sunflecks retain the spectrum of sunlight (Horn, 1971), they can alleviate the qualitative imbalance of the transmitted PAR.

Thus under coconut canopy, the light environment was considerably modified in intensity, quality as well as periodicity. Photosynthetic as well as morphogenetic adaptation to a distinct environment determined by the dominant crop has been found necessary for successful performance of turmeric cultivars, when they are grown as an intercrop in the coconut plantation.

In tropical and subtropical regions the annual energy conversion can be greatly increased by the practice of multiple cropping. During the early period of growth, most of the crops do not have enough leaf area to intercept most of the incoming radiation. This is a serious drawback of annual crops resulting in lower efficiency of energy conversion and is the most important physiological limitation to the dry matter production (Watson, 1971). This becomes relevant for turmeric which has got a prolonged juvenile period during which the LAI is below one.

An increased productivity by the practice of intercropping obtained through efficient spatial use of light had been reported by many workers (Schepers and Sibma, 1976; Willey, 1979a; and Sivakumar and Virmani, 1980). The crop combination of turmeric + coconut was superior to the pure stand of coconut in PAR interception throughout the period of study (Table 23a). This is expected since in a coconut based intercropping system where coconut shows complete domination, the understorey components intercept the light that was not otherwise utilised.

2. Growth and development of intercrop

Three distinct stages of development could be distinguished during the growth cycle of turmeric in the autotrophic phase. The first phase (Phase I) represents upto the 8th week during which there is a complete domination of shoot growth. The second phase (Phase II) is ranging from 8th to 18th week during which the initiation of fingers takes place. During this period, while the rhizome showed only slow growth rate, the shoot attained the maximum growth rate. Beyond 18th week (Phase III) when the shoot growth declined sharply, rhizome growth dominated. Generally in root and tuber crops, there is a gradual decrease in the growth of parts above the soil as the underground storage organs increase in size (Kawakami, 1978). The maximum values of RGR, RLGR, NAR and LAR were noticed during the early period of growth upto 8th week. Changes in these growth indices during this early period are important while analysing the effect of environment on plant growth since the changes due to the ontogenetic drift are minimum during this early period (Phase I) of growth (Hunt, 1978).

2.1. Leaf area development

2.1.1. Leaf area index and leaf area duration

Blackman (1956) reported an increase in leaf area with decrease in solar energy input as a typical response of many plants. But this may not be so in areas of high radiation levels. Ampofo and Lawson (1972) suggested that below a certain threshold of light intensity, leaf area would reduce. Considerable cultivar difference in LAI was found when turmeric was intercropped in coconut garden under which the energy input was only 46 per cent of the open (Table 2). Cultivar C_1 showed considerable reduction in LAI under the intercropping system as against a marked increase for C_3. Under both systems, C_2 had lowest LAI and did not register any difference between the two cropping systems. During the period when LAI was declining higher LAI was maintained by cultivar C_1. Slow decline of leaf area during leaf senescence is important since this period coincides with maximum rates of tuber bulking (Haynes *et al.*, 1967). Under monoculture, all the cultivars registered maximum LAI by 18th week, under the intercropping it was postponed to 22nd week.

Due to an early decline in LAI under monoculture, cultivar C_1 did not show any significant difference in LAD between the cropping systems; eventhough its LAI was higher under the monoculture system. Birke (1965) and Bremner *nd Taha (1966) established high correlation between LAD* d yield, in sugarbeet and potato, respectively. yi (1972) showed that in lesser yam, tuber yield was ghly and positively correlated with LAD. The importance duration of assimilatory apparatus in determining the oductivity of crop need not be emphasised. Cultivar C_1 hibited a significant positive correlation of rhizome eld with LAD, particularly under the monoculture system able 52). But the higher rhizome yield of this cultivar der the monoculture system than under the intercropping stem cannot be explained on the basis of LAD since the D of this cultivar did not show any significant fference between the two cropping systems. But greater I of this cultivar under monoculture than under the tercropping system suggests that actual amount of leaf ea produced can be more important than the length of af growth period. As in the case of LAI, cultivar C_1 d C_3 had higher LAD than that of C_2

The present investigation revealed a close linear lationship between cumulative LAD and dry matter cumulation (Fig.40). This relationship appears to be ttle affected by cultivars, cropping systems, stages of velopment and the years of study. Consequently the dry tter accumulation appears to be a direct time function leaf area. Thus, any factor that increases either af area or the duration of the green leaves will result in greater dry weights. Such close correlation between LAD and dry matter accumulation had been reported also for other crops like corn (Eik and Hanway, 1966), and Barley (Power *et al*., 1967). During the second year of study both LAI and LAD of cultivar C_1 was reduced as compared to first year which may be one of the reasons for lower yield obtained for this cultivar during this year.

2.1.2. Relative leaf growth rate

The response of cultivars to changed environmental conditions is reflected in the RLGR also (Table 4). While in cultivar C_1, the higher dry matter production is preceded by the attainment of higher RLGR under the mono-cropping system than under the intercropping system, in cultivar C_2, no such difference was noted. The greater RLGR of cultivars C_1 and C_3, than that of the cultivar C_2 may be one of the reasons for former's high dry matter production especially under monoculture system. Kaplan and Koller (1977) and Ibrahim and Buxton (1981) found that the leaf expansion rates were more important than CO_2 exchange rates, as a determinant of crop growth rate.

Littleton *et al*. (1979a) reported that in cowpeas, the leaf growth rate increased linearly with temperatures but solar radiation appeared to have little effect. But Dennett *et al*. (1979) found that in field beans, both variables were correlated with leaf growth rate.

In cassava, Keating *et al.* (1982b) had shown that 89 per cent of variation in CGR brought about by various planting dates can be explained in terms of mean air temperature or solar radiation and LAI. But temperature and solar radiation were highly correlated and it was therefore not possible to distinguish their separate effects on CGR. In the present study, much of the changes in RLGR as well as LGR and consequently in CGR as influenced by the cropping systems can be attributed to differences in solar energy input since the other environmental variables did not show any appreciable difference between the two cropping systems (Table 26). Further, in the second year of study, when the solar energy input was considerably reduced during the early period of crop growth RLGR and LGR of cultivar C_1 were considerably low as compared to the first year. This may be one of the reasons for the lower growth rate of this cultivar during the second year of study. The significance of high RLGR during early growth period is further evident from the high correlation of NAR with RLGR (Table 50). Wilhelm and Nelson (1978) reported that among tall fescue genotypes, the RLGR of genotypes with high CO_2 exchange rates was greater than those, with low rates of CO_2 assimilation. Incidentally, turmeric cultivars C_1 and C_3 which had recorded higher RLGR had recorded higher NAR values also. In many annual crops, like in potato or sugarbeet the rate of attainment of a closed canopy is a serious limitation to production (Watson, 1971). Hence, the selection for rapid expansion of leaf surface becomes an important breeding objective (Wareing, 1971). The early reduction in RLGR noted for the cultivar C_1 as compared to the other cultivars would result in higher duration of bulking of rhizome.

2.1.3. Leaf area index vs crop growth rate

In the case of cultivar C_1 an optimum LAI at which CGR is maximum i.e. about 4.0 to 4.5 was attained under the monoculture while under intercropping such optimisation was not observed. This may be because under monoculture the rapid bulking (Phase III) is initiated after the attainment of maximum LAI whereas under the intercropping the attainment of LAI_{max} was simultaneous with active bulking. An overlapping of active bulking with the period of LAI_{max} was noticed for cultivar C_1 under both the cropping systems during the second year of study (Fig.39). In the case of tapioca, Enyi (1973b) reported an optimum LAI during the period when bulking of tuberous roots and leaf area development were simultaneous. In turmeric, attainment of optimisation of LAI in cultivar C_1 was altered under the intercropping system where CGR approached asymptotic values at high LAI (Fig.39). In the case of other two cultivars, C_2 and C_3, the optimisation of LAI in the range of about 3 to 3.5 showed a clear trend unlike in C_1, under both cropping systems. Watson (1958) was able to get an optimum LAI in Kale, but later workers failed to get a clear cut optimum LAI (Pearce et al., 1965; Williams et al., 1965b; and Buttery, 1970). Yoshida (1972) cited several examples which disagree with the existence of an optimum LAI. Optimum LAI values at which CGR is maximum will be different from the LAI values required to obtain highest economic yield (Nichiporovich et al., 1961; and Medanova, 1967). Mc Collum (1978) was able to get an optimum LAI at which tuber growth rate was maximum in potato.

The LAI showed a high correlation with rhizome growth rate only at the period of 8th to 11th week when the initiation of fingers began in the monoculture (Table 50). At the other stages of growth in monoculture and in all stages of growth under intercropping no such correlation was obtained. This may be because the initiation of fingers in C_1 under the monoculture system requires a minimum leaf area. Moorby and Milthorpe (1975) have reported that rate of bulking in tubers in potato is determined at the time of tuber initiation itself and is related to the amount of leaf area then supplying them with the photosynthate, a smaller leaf area resulting in a slower rate of bulking. Thus, in the case of C_1 the relationship obtained under monoculture is highly significant in that such relationship was not obtained under intercropping where the final yield was also less. These results also indicate that the bulking of the rhizome is independent of LAI during most periods of growth.

The LAI showed a significant positive association with CGR upto third month of growth beyond which no significant correlation was noticed (Table 50). Several workers found a positive correlation between LAI and CGR during initial period of crop growth which is proportional to the total radiation interception. (Williams et al., 1965a; Shibles and Weber ,1965 ; and Biscoe and Gallagher ,1977). Aso (1978) reported a positive correlation between leaf area and dry matter in wheat upto the 5th growth stage when the tillering was complete, but beyond which no relationship could be established. Vegetative growth in the early stage of development may be more dependent on the rate of leaf expansion, but when the leaf expansion ceases, the more important factor determining the yield may be the photosynthetic rate (Krishnamoorthy et al., 1973 and Sharma et al., 1982). In the present study there was no association between CGR and LAI during the Phase III, but CGR and NAR were highly and positively correlated (Table 50).

2.2. Dry matter production

2.2.1. Crop growth rate as influenced by net assimilation rate and leaf area index

The differential behaviour of the cultivars under the two cropping systems is reflected in several facets.

While the maximum CGR, SGR and RhGR attained by the pure stand of cultivar C_1 were significantly higher than those attained by its intercropped stand, cultivars C_2 and C_3 did not register any marked difference between the two cropping systems for these parameters as well as in their rhizome or biological yield. Another major difference noted between the two cropping systems is in the attainment of maximum SGR. All the cultivars exhibited remarkable delay in the attainment maximum SGR which was more pronounced in cultivar C_1 (Fig.6b). It should specially be noted that cultivar C_3 showed a continued shoot growth upto 26th week and the rhizome yield of this cultivar was considerably reduced as compared to the cultivar C_1, eventhough it was able to maintain a fairly high biological yield (Table 33). In the case of root, tuber and rhizomatous crops, once a closed canopy was established, further leaf growth is required only to maintain that canopy, and the maximum amount of assimilates should be transferred to the relevant storage sink. Spence (1970) found that slow turnover of leaves after maximum LAI has been attained, is advantageous for high yield in tannia. Gibson and Schertz (1977) reported that in the case of Sorghum hybrids, the growth of leaves and stems started to decline several days earlier than it did in the parents, and a complete transfer of assimilates to grain production shortly after anthesis is evident in contrast to the continued vegetative growth of the parents. Under intercropping, there is a marked delay in the onset of higher RhGR due to delayed initiation of fingers (Fig.6c). Early initiation and cellular development of underground storage organs are essential to create an active sink for assimilate (Lowe and Wilson, 1974; 1975a,b). But Wholey and Cock (1974) reported that in tapioca, differences in root yield after seven months were caused by variations in rate of root bulking, and were not associated with differences in onset of root bulking.

The present study revealed that in turmeric the maximum NAR as well as LAR were recorded during the Phase I, thereby resulting in maximum RGR during this period. While NAR declined only subsequently upto the end of the Phase II, LAR recorded steady decline throughout the growth cycle. A decrease in NAR concomitant with increase in LAI and CGR recorded in turmeric is similar to previous observations with other crops (Watson et al., 1963; Buttery, 1969; and Dyson and Watson, 1971). One of the reasons for the decline in NAR in the Phase II is the self-shading of leaves. The decline in LAR may be due to the progressive reduction in assimilate distribution towards area expansion eventhough the LAI increased upto 18th and 22nd weeks under pure and intercropped stands, respectively. The cultivar C_1 showed a further remarkable increase in NAR in the Phase III under the monoculture systems, but not under the intercropping system (Fig.17). Both the pure and intercropped stands of the cultivar C_3 as well as pure stand of cultivar C_2 did not register such an increase. But it is interesting to note that cultivar C_2 recorded a further increase in NAR beyond 22nd week under the intercropping system which is reflected in the slightly higher yield of rhizome for this cultivar under the intercropping system (Table 33). Under the monoculture, the cultivar C_1 showed a pronounced secondary peak in CGR and a levelling of RGR early in the Phase III (Fig.6a and 7a). This trend noticed during the period when LAI and LAR were decreasing is the result of the increased NAR (Fig.17). The cultivar C_1 under the intercropping as well as the other two cultivars under both the cropping systems did not show such a pronounced secondary peak in CGR during the Phase III. The increase in NAR during the Phase III is interpreted as a response of the photosynthetic apparatus to an increased demand for assimilates. The increased demand for assimilates was due to the rapid bulking of the rhizome during this period. The massive shift in sink towards the rhizome began at this stage of growth (Fig.6). The phenomenon of photosynthate utilization influencing the photosynthetic activity had been reported in several crop plants like peas (Eastin and Gritton, 1969), potato (Burt, 1964; Nosberger and Humphries, 1965; Collins, 1977b), soybean (Koller <u>et al</u>., 1970; and Scott and Batchler, 1979), and sweet potato (Spence and Humphries, 1972; and Hahn, 1977).

2.2.1.1. Net assimilation rate and 'sink' effect

While analysing the basis of yield variation between the cultivars as influenced by the cropping system, it can be noticed that cultivar C_2 and C_3 attained a fairly high CGR and RGR during the initial stage of growth and the maximum CGR during this period was of cultivar C_3 under both the cropping system. But this advantage established during the initial stage when the dry matter production is related to the leaf area growth, disappeared in Phase III, eventhough cultivar C_3 maintained a large LAI throughout the season. The intercultivar differences occurred in CGR during the third phase of growth, mainly because of differences in NAR, were reflected in the rhizome yields. At this time, the major portion of the photosynthate was transported to the rhizomes and the cultivar differences in rhizome yield can be traced to variation in their NAR. The difference in NAR among the cultivars noticed during the Phase III can at least partially be explained from the inability of their rhizome to receive assimilate, i.e. their 'sink-strength'. The direction of the relationship is however, uncertain, for small NAR might as easily have been the cause rather than the consequence of poor rhizome growth or alternatively, could represent inefficient translocation of assimilate from the leaves as noted in the case of sugar-beet (Leach, 1970). Williams (1972) reported that in tapioca, higher rates of assimilation and greater development of total dry matter as well as tubers are at least partly brought about by a higher demand for assimilates by developing tubers. But San Jose and Mayobre (1982) found that the storage root does not act as a 'sink' for large amount of assimilates, and differences in growth response were mainly a result of morphology, development and function of leaves in the cassava canopy ('source' activity).

The role of sink in controlling the net assimilation rate is further evidenced while analysing the basis of yield variation for the cultivar C_1 between the two years of study. While cultivars C_2 and C_3 did not show any considerable difference in the growth and productivity between the two years of study, cultivar C_1 recorded marked difference in its growth rhythm as well as productivity between these years. During second year, the SGR of cultivar C_1 was considerably reduced as compared to first year mainly due to a lower solar energy input in the early part of crop growth. This was seen reflected in the RhGR as well as NAR values especially under monoculture system. In the second year, the NAR values during the Phase I were lower as compared to first year, but higher in Phase II and remarkably reduced in the Phase III. Eventhough the maximum RhGR under the monoculture was attained early during the second year, due to a reduced competition by top growth, the poor RhGR during the Phase III was the result of low NAR values during this period in the second year as compared to the first year. Eventhough the rise in NAR in the Phase III during the first year of study can be partly attributed to increase in solar energy input during this period as compared to the earlier periods, the absence of such an increase during the second year under more or less the same environmental conditions is mainly due to the reduction in rate of bulking of rhizome, thereby showing the importance of 'sink' strength in controlling the 'source' activity. Moorby and Milthorpe (1975) reported that in potato, encouragement of haulm growth retarded the tuber initiation, but after the initiation, a large haulm surface maintained a higher tuber growth rate for a longer time. Another interesting factor which has emerged from the second year data is that when the rhizome initiation takes place, a rise in NAR was noticed for the cultivar C_1 under both the cropping systems. Collins (1977a) found that NAR increased as canopy size decreased, and the demands of the developing tubers exerted the greatest influence on NAR. The present results had also revealed that when the shoot growth was reduced beyond a limit as seen under the intercropping system as compared to monoculture, it did not exert any influence on RhGR as well as NAR at any stage of growth.

The increase in NAR obtained towards the end of the growing season in the case of potato (Moorby, 1970; and Sale 1973a) and in tomatoes, peas and soybeans (Milthorpe and Moorby, 1974) can be attributed to an increase in the photosynthetic rate of the leaves. But the experiments conducted by Frier (1977) with potato had shown that leaf area was still increasing at the end of the period of measurement and NAR was still falling. He concluded that the increase in NAR at the end of the growth period described by other workers was attributable to the cessation in the increase, and then decrease, of leaf area while total dry weight was still increasing, rather than to an increase in photosynthesis by the remaining leaves. Eventhough there is some doubt about the physiological significance of drifts in NAR during the late growth stages, the early-season trends have important implications regarding the source-sink relationship. In this context, the results obtained in the second year of study for the cultivar C_1 are of particular importance. When the solar energy input was low in the early period of growth as compared to first year, the rhizome bulking proceeds at the expense of shoot growth resulting in a upward trend in NAR. These results establish the importance of 'sink' strength in turmeric, which has a partial control over the photosynthetic activity of the leaves.

Gifford and Evans (1981) reported that the factors determining the setting up and relative activity of 'sinks' will influence the pattern of assimilates distribution. Milthorpe and Moorby (1967) reported that in the case of potato the gain in weight of the crop was dependent primarily on the strength of the photosynthetic 'sink' exerted by the developing tubers, which was determined at the time of tuber initiation. Factors controlling sink strength in turmeric have not clearly been identified eventhough the three cultivars showed considerable difference in the expression of rhizome characters between the two cropping systems. The size of mother rhizome was either drastically reduced under intercropping as in the case of cultivar C_1, or the rhizome was large as in C_3, while no significant difference was observed in cultivar C_2. Such differences are noted in the length and breadth of first order fingers also. However, a consistent feature was reduction in number of fingers under the intercropping system in all the cultivars (Table 48) and in the reduction of number of tillers in the cultivar C_1 and C_3. Higher production efficiency of C_1 as compared to C_2 and C_3 may be due to a higher number of fingers which may be a varietal character. The number of fingers formed have shown a high correlation with final yield in this cultivar.

Sale (1973a,b) found that shading during 2 or 3 weeks following the onset of tuber initiation, caused a remarkable reduction in the number of tubers formed. Shade also delayed the onset of the rapid tuber-bulking, and also reduced the maximum bulking rate achieved (Sale, 1976). In turmeric, eventhough the shade cast by coconut delayed the onset of rapid bulking in all the cultivars, its effect on the rate of bulking was well pronounced only for cultivar C_1 which had shown a lower rate under intercropping throughout the growth cycle (Table 12). In other crop plants such as wheat, shade during the filling of the storage organ has resulted in decrease in yield (Willey and Holliday, 1971b), but in barley such a reduction was not noticed (Willey and Holliday, 1971a). Fischer (1975) reported that in spring wheat, the period of rapid spike growth showed greatest sensitivity to shading resulting in fewer number of spikes and reduced grain yield. But Keating <u>et al</u>. (1982a) reported that in cassava, the extent and timing of storage root initiation were relatively unaffected by the different temperatures, solar radiation and photoperiod conditions associated with different planting dates.

2.2.2. The relative growth rate as influenced by net assimilation rate and leaf area ratio

Since RGR is the product of NAR and LAR, an effect on growth rate can be expected whenever any factor affects either on the net efficiency of photosynthetic apparatus or on the relative size of the photosynthetic apparatus, or on both. Since many factors have opposite effect on NAR and LAR, the ultimate RGR reflects the interaction of the two. This interaction is most conspicuous with respect to shading and stand density (Blackman, 1961; Mac Coll and Cooper, 1967). Blackman _et al_. (1955) and Blackman and Black (1959a) found that NAR and LAR were related linearly to the logarithm of percentage light intensity; in the case of LAR this relationship was an inverse one. The relationship of LAR to NAR is brought out very clearly from the present studies. Under the intercropping system where there is about 50 per cent reduction in PAR, the RGR of the three cultivars were considerably reduced (Table 13). Eventhough the LAR is high under the intercropping system, the marked reduction in NAR is mainly responsible for this reduction in RGR. Thornley and Hurd (1974) found that when tomato was grown under various combinations of irradiance, day length and CO_2 concentration, the difference in RGR could best be accounted for difference in NAR. Patterson _et al_. (1978b) reported that when cotton was grown under three levels of irradiance, RGR was better correlated with NAR than with LAR. Potter and Jones (1977) compared different species of crop plants grown in three different temperature regimes and found that differences in RGR were not well correlated with NAR, but closely correlated with leaf area partition coefficient (LAP). In the present study, since the major difference between the two cropping systems is in the solar energy input, the differences in RGR could therefore be explained by the variation in NAR. This fact is further emphasised when the performance of the cultivar C_1 in two years of study was compared. The lower solar energy input in the second year as compared to the first year in the Phase I has caused a reduction in RGR of cultivar C_1 in the second year (Table 13b). A marked reduction in NAR is responsible for this reduction in RGR, eventhough the LAR is comparatively high during this period. The degree of negative relationship between NAR and LAR was pronounced under the monoculture system (Table 50). Meyling (1973) found that the low LAR values were associated with high values of NAR, RGR and rate of leaf appearance, at increasing light intensity. The highes leaf growth rate recorded under the monoculture system is associated with a lower LAR. Hegde and Saraf (1982a) found that the reduction in CGR of pigeonpea when intercropped with other legumes, was not associated with the reduction in NAR. But Gardiner and Craker (1981) noticed that when beans were intercropped with maize there was a decrease in NAR and an increase in LAR of beans growing in the intercrop as compared with the monocrop, which was mainly due to the fact that light available to beans is reduced by 50 per cent in the intercrop canopy as compared with the monocrop bean canopy.

There were significant differences among the RGR values of cultivars. During the Phase I when the highest RGR values were recorded, the cultivars C_2 and C_3 were superior to C_1 under both the cropping systems. But during most of the later periods of crop growth, cultivars C_2 and C_3 behaved similarly in their significantly higher RGR values under the intercropping than under the monoculture, whereas cultivar C_1 showed higher values under the monoculture system. Charles Edwards (1978) pointed out that due to a negative correlation between maximum photosynthetic rate and leaf area ratio, the apparent advantage of a large LAR for intercepting light during the formation of the canopy would be partly offset by a slow maximum rate of growth when light interception reached a constant maximum value. This aspect has been clearly brought out in the present study. The results indicate that cultivar C_1 is reacting more to the higher radiation than C_2 and C_3. During second year of study, while the RGR values of cultivars C_2 and C_3 are similar to those of first year, the values of cultivar C_1 are considerably reduced in the second year as compared to first year during the Phase I. As already mentioned, the amount of solar energy input was considerably reduced in Phase I of second year as compared to first year.

The two components of LAR are the specific leaf area (SLA), a measure of the leafiness of the plant on an area/weight basis and the leaf weight ratio (LWR), an index of the leafiness of the plant on a weight basis. The former is more sensitive to environmental change and more prone to ontogenetic drift (Hunt, 1978). As in the case of LAR, maximum values of SLA and LWR were recorded in the Phase I, and cultivars C_2 and C_3 showed higher values than C_1 during this period (Tables 17 and 18). In all the cultivars the SLA was more under the intercropped stand than under the pure stand throughout the growth period, but in the case of LWR this trend was not seen during the Phase I. Evans (1972) had drawn a list of environmental factors the changes of which hardly affected the values of LWR, but considerably influenced that of SLA; the most important among them was the light intensity. Deep shade caused large increase in SLA and such leaves were thin (Hughes and Evans, 1962).

2.2.3. Light interception and solar energy conversion

Differences in dry weight between crops not only depend on the incident solar radiation but also on the fraction of this radiation intercepted and the efficiency with which it is used (Monteith, 1977; Littleton *et al.*, 1979b; and Wilson, 1981). Trenbath (1981) pointed out that the light use efficiency (LUE) of the canopy is the product of interception efficiency (I_1/I_0) and conversion efficiency (P_n/I_i). The present study revealed that the PAR interception efficiency of the pure and intercropped stands of the three cultivars of turmeric followed the same pattern as that of LAI. The interception efficiency reached above 90 per cent by 14th week itself under both the cropping systems (Table 23b). The increase in interception efficiency was seen only upto an LAI of about 4 (Fig.16). A further increase in LAI caused a reduction in CGR unless the period of maximisation of LAI overlapped with that of rapid bulking. As in the case of dry matter production cultivar C_1 showed higher efficiency of solar energy conversion than other two cultivars under both the cropping systems, the values for the entire growth period ranging from 0.7 to 1.4 per cent under the monoculture cropping system and 1.5 to 2.1 per cent under the intercropping system (Table 24). The values recorded under the monoculture system are lower than those reported for other crops (Hall, 1976), like potato (2.3 per cent), cassava (2.0 per cent), maize (2.7 per cent), sugar cane (3.8 per cent) and rice (2.9 per cent). All the three cultivars showed a higher conversion efficiency under the intercropping system than under the monoculture system. This trend was more pronounced for cultivars C_2 and C_3 where the conversion efficiency almost doubled under the intercropping system. These results show that eventhough the total available energy under the coconut canopy was only half of that under monoculture system, it was used by the plant more efficiently. Another interesting aspect brought out by this study is that the conversion efficiency of all the three cultivars under both the cropping system was increased during the active rhizome bulking period as compared to that for total crop growth period. Wassink (1968) pointed out that, although 2 per cent conversion efficiency is not normally exceeded by crop plants over the whole growing season, higher efficiencies are likely to occur for a period in the season once crop canopy has closed, as shown by Gaastra (1958) for sugarbeet. In a potato crop in North-West Europe, an yield of 12 to 15 t/ dry matter in the tubers gave a conversion efficiency of 1 per cent of the annual energy input, but this efficiency was as high as 2.5 per cent during the bulking period (Thorne, 1971 and Watson, 1971).

2.3. Photosynthesis and chlorophyll pigments

Considerable intervarietal differences exist in light saturated net photosynthesis of several crop plants, but correlation between rate of apparent photosynthesis and yields is generally low (Irvine, 1975; Bhagsari _et al_., 1977; Mauney _et al_., 1978; and Buenemen _et al_., 1979). The results from the present investigation brought out the intimate relationship between the productivity of three cultivars and their light-saturated rates of photosynthesis under both the cropping systems. While the rate of photosynthesis of cultivar C_1 was significantly higher when grown under the monoculture than under the intercropping, the other two cultivars did not show any significant difference between the two cropping systems (Table 28). In the case of cultivar C_2, the rate was slightly more when grown under the intercropping. Gaskel and Pearce (1981) found that among maize hybrids, those having higher photosynthetic rates recorded higher leaf area development and dry matter production also, but exported excess assimilates to non-productive parts thereby nullifying any yield advantage attributed to high photosynthetic activity. In the present study this was the case for the cultivar C_3 which had only a limited capacity of assimilate partitioning towards rhizome eventhough it was able to maintainea fairly high photosynthetic rate under both the cropping systems. The differences among cultivars in photosynthetic efficiency as influenced by the cropping system noted from gas exchange studies was in agreement with the results from growth analytical studies (NAR). Such a close association is of rare occurrence (Wilhelm and Nelson, 1978).

The photosynthetic rate of a leaf may vary depending on the conditions towards which it is more acclimatised.

Plants are classified into 'sun' and 'shade' plants depending on their adaptability to a selected light intensity (Bjorkman, 1968). This adaptability was also dependent on the genetic adaptation to the light environment prevailing in the native habitat (Boardman, 1977). While cultivar C_1 registered remarkably higher photosynthetic rate when grown under monoculture than under intercropping, cultivar C_2 showed higher values under intercropping thereby showing the existence of specific adaptation among the turmeric cultivars to varied light climates. Bjorkman and Holmgren (1963, 1966), Gauhl (1976) and Clough *et al.* (1979) had shown that ecological races of same species from exposed and shaded habitats differ markedly in the adaptation of their photosynthetic response to light intensity. Patterson *et al.* (1978a) had shown that the quantitative changes in the photosynthetic apparatus accounted for the photosynthetic adaptation to irradiance. The high adaptability of cultivar C_2 towards the low light intensity is reflected in its chlorophyll content also (Table 28). This cultivar had shown a significantly higher chlorophylls, both *a* and *b* (per unit fresh weight) under the intercropping system than under the monoculture system which is consistent with the sun-shade difference reported for other plants (Boardman, 1977). Incidently the highest chlorophyll *b* concentration was recorded for the intercropped stand of the cultivar C_2. All the cultivars had shown higher chlorophyll b and lower chlorophyll a/b ratio under the intercropping system. Chlorophyll b forms a large part of the light harvesting pigment for photosystem II. In light limiting conditions ability to harvest a large per cent of available energy is advantageous (Lewandowska et al., 1976). Lower chlorophyll a/b ratios are typical of shade ecotypes and may enable more efficient absorption of light under shaded conditions due to differences in the absorption spectra of chlorophyll a and b and the variance in the light quality in the understorey (Boardman, 1977; and Young and Smith, 1980).

The results also revealed an increase in the leaf air space volume of all the cultivars when grown under intercropping. Fails et al. (1982) reported that shade grown leaves have more widely spaced veins, and greater propotion of intercellular space in spongy parenchyma. The air space volume, which is a measure of tissue density, was higher for cultivar C_2 than for C_1 and C_3. In a survey on the distribution of air space volume in C_3 and C_4 plant species, Byott (1976) observed significantly higher leaf air space volume in C_3 species than in C_4 species which is related to their photosynthetic efficiency. In fact the higher air space volume in cultivar C_2 is not surprising as this cultivar recorded.lowest rate of photosynthesis under both the cropping systems.

2.4. The carbohydrates

Since growth of turmeric rhizomes depend on the carbohydrate supply from the foliage, a continued supply of carbohydrates from the leaves to the rhizome over a prolonged growth period of the crop is necessary to ensure maximum rhizome growth. Moorby (1970) found that in the case of potato there was a gradual turn over of stored ethanol-insoluble material in the haulm and that this was transferred to the tubers. The results of the present study demonstrate that in turmeric, the stage of maximum rhizome growth rate coincides with a drastic reduction in starch/sugar ratio, in leaves (Fig.23). Giaquinta *et al.* (1980) had shown that in soybeans, a decrease in leaf starch/sucrose ratio during the pod filling caused an increase in the dry matter accumulation in seeds indicating that partitioning of assimilates between starch and sucrose may be an important determinant of assimilate translocation to the seeds. Judel and Mengel (1982) noted that the mobilisation of storage carbohydrate such as fructosans and starch is a major process, which may limit grain production. Huber (1981) concluded that the rate of translocation of assimilates which is at least partially controlled by sink demand can influence the starch accumulation in the leaves. In view of these findings it is interesting to note that cultivar C_1 showed a marked reduction in leaf starch/sugar ratio for prolonged period of 14th to 22nd week as compared to other cultivars where a decrease was only for the period of 18th to 22nd period. Such a marked reduction in starch/sugar ratio recorded by the cultivar C_1 may be due to the high sink demand of this cultivar which cause high rate of translocation of assimilates and thereby influence the starch accumulation in leaves. Several authors have reported that photosynthetic rates declined when leaf starch content increased (Milford and Pearman, 1975; Nafziger and Koller, 1976; and Mauney *et al.*, 1979). The results suggested that cultivar C_1 was more efficient in the translocation of photosynthates than C_2 and C_3, which have a positive influence on the rate of photosynthesis of this cultivar. The cultivar C_1 showed higher concentration as well as accumulation of starch in the leaves than the other two cultivars under the monoculture system (Figs.19 and 20). The accumulation of polysaccharides like starch and fructosans in leaves implies a high rate of net photosynthesis (Schlubach, 1961; and Walker, 1980). Generally, the amount of starch accumulated in the leaves was considerably higher under monoculture than under intercropping, which was more pronounced in the case of cultivar C_1. This finding is in consistent with the concept that in shaded plants, the level of storage carbohydrates would be lower than in unshaded plants due to reduced photosynthesis (Kremer and Moss, 1975; and Fischer, 1975).

2.5. Partitioning of dry matter

Eventhough the dry weight increase of a crop arises directly from the process of photosynthesis, the most important determinant of economic yield is always not the total crop photosynthesis, but the manner in which assimilates are partitioned among various plant parts (Donald, 1968; Nichiporovich, 1969, 1970). All the three cultivars of turmeric had a similar pattern of partitioning *i.e.*, the partitioning was mainly towards shoot upto 18th week beyond which a steady increase in the partitioning towards rhizome occurred (Fig.24). However, cultivars differed in the quantum of assimilates partitioned between the two cropping systems. Cultivar C_1 under intercropping showed relatively more partitioning towards shoot than under monoculture, while for other two cultivars such difference was not noted. Gruber *et al.* (1983) found that in radish, the distribution of assimilates to leaves and storage organs varied under different light regimes with long photoperiods and high irradiance producing the largest storage organs. Nosberger and Humphries (1965) found that 60 per cent shade reduced tuber growth more than the top growth which is in accordance with the view that when photosynthesis is restricted, carbohydrates are preferentially used by shoots, and growth of underground parts was slowed down.

In cultivar C_2, higher partitioning towards rhizome was commenced earlier, and almost completed by 18th week. The further growth of rhizome noted for this cultivar under the monoculture system when there was no net increase in dry weight may be due to a continued translocation of assimilates from the shoot. Such residual translocation had been reported in crops having underground storage organs like potato (Mc Collum, 1978). The environmental influence on the partitioning of assimilates in case of cultivar C_1 is further evidenced by the observation that when the solar energy input reduced during second year as compared to first year in the early part of crop growth, this cultivar showed an early completion of partitioning of assimilates towards rhizome thereby resulting in a reduced duration of bulking and reduced yield. Estimation of partition coefficient is a more sensitive measure of short term changes in assimilate partitioning is noteworthy (Keating et al., 1982a). When used in conjunction with NAR, economic assimilation rate (EAR) is a useful indicator of partitioning efficiency (Fig.18), but partitioning coefficient (Table 31) is the parameter of ultimate interest to production agronomists (Mc Collum, 1978). The values of rhizome/shoot ratio support the results of assimilate partitioning already mentioned in the three cultivars. The cultivar differences in the amount of assimilates partitioned among plant parts were reflected in similar rhizome/shoot ratios (Table.32). The highest ratio attained beyond 18th week was for cultivar C_1 followed by C_2 and C_3 in that order with significant differences.

2.5.1. The Harvest index

Harvest index defined by Donald (1962) is one of the indices currently used to evaluate partitioning efficiency of the crops. The cultivars differed significantly among them and in their response towards the cropping systems for the harvest indices. The higher HI noted for the cultivar C_1 than the other two cultivars showed the higher partitioning efficiency of this cultivar. Also it showed higher efficiency under the monoculture system than the intercropping system. While cultivars C_2 and C_3 did not register any marked difference between the two years of study for the harvest indices, in case of cultivar C_1 HI was considerably reduced in the second year as compared to first year. The behaviour of cultivar C_1 confirms the findings of Anon (1969, 1972) that for a particular crop cultivar, HI could vary between seasons. Cultivar C_1 showed maximum dry matter production and highest partitioning efficiency whereas the HI of cultivar C_3 was considerably low eventhough it was able to maintain a fairly high biological yield. Cultivar C_2 was inferior in the biological yield as well as HI. These changes are reflected in the differences in rhizome yield observed among the cultivars (Table 33).

2.6. Growth components

Understanding the relationship between the yield and different components influencing it, is essential for achieving improved yields by incorporating high yielding attributes in selection and breeding programmes. It also helps in examining whether the selection strategy for one cropping system would hold good for another system also. It has been widely recognised by plant breeders that selection for terminal yield components alone may not be sufficient to achieve yield improvement and that growth analytical techniques also need be employed. In the present study, the LAI and LAD together with the shoot dry weight and total dry weight showed a significant positive correlation with final rhizome yield from very early growth phase (Table 51). This association of leaf area as well as dry matter production in the early stages of growth with the final rhizome yield is in contrast with cereals where the grain yield is mainly determined by the concurrent photosynthesis during the grain fill period, the rate of grain fill and length of the grain fill period (Evans and Wardlaw, 1976). In turmeric, where the economically important part is the underground storage organ, this association is definitely useful, since it can be developed as an important tool for prediction of yield at an early stage of crop growth. Ashley *et al.* (1965) reported that in cotton, there is a close relationship between yield and the quantity of leaves present on the plants in the early season.

Harvest index is one of the important criteria used by plant breeders for identifying promising genotypes and predicting the yields (Nass, 1973; Fischer and Kertesz, 1976; and Deloughery and Crookston, 1979). Economic yield of a crop can be expressed as the product of biological yield and harvest index. Tahlan *et al*. (1979) indicated that differences in dry matter production would extend to final yields. In all the three cultivars of turmeric studied, a linear relationship between rhizome yield and biological yield existed. Due to this close association of biological yield and rhizome yield, the correlation between rhizome yield and HI was low. From Fig.41, it is clear that within a cultivar, higher rhizome yield requires higher biological yield. However, harvest index is an important criteria for the comparison among the cultivars, since cultivars differed significantly for this character. The excessive production of vegetative dry matter did not always reduce economic yields, since better partitioning of dry weight could result in higher yields (Shibles and Weber, 1966). This may be the case for cultivar C_3 where the rhizome yield was less eventhough it maintained high biological yield. Johnson and Major (1979) reported that in soybeans, variability for harvest index among cultivars existed, but there was a proportionate increase in seed yield as biological yield increased thereby maintaining the same harvest index. In the present study the HI of cultivar C_1 was significantly reduced under the intercropping system, compared to the monoculture system. This may be one of the reasons for reduction in yield of this cultivar under the intercropping system. This cultivar recorded a weak but significantly positive correlation between HI and rhizome yield under the intercropping systems, but not under the monoculture system. DeLoughery and Crookston (1979) reported that in corn, HI and grain yield exhibited high positive correlation in the stress environment, but this was not pronounced under non-stress environment. Baker and Gebeyehou (1982) showed that relationship among grain yield, biological yield and harvest index may vary from one level of productivity to another.

2.7. Effect of growth retardant

Thus the cultivar C_1 showed a poor productivity under the intercropping system which was partly due to the low HI. An attempt was therefore made to modify and divert the assimilate partitioning of this cultivar towards the rhizome by the application of growth retardant, CCC. Beneficial effects on yields have been reported from foliar application of CCC in starch producing crops like potato (Dyson, 1965; and Humphries and Dyson, 1967) and cassava (Dasgupta, 1976). A higher rhizome yield, in fact, was obtained by the application of CCC under the intercropping system. A concentration of 4000 ppm was found to be most effective which also registered significantly higher HI. These results show the possibility of realising higher yields from this cultivar under the intercropping system by the application of CCC. El-Fouly (1973) reported that application of growth retardants will help to keep the balance between shoot and storage root growth and favour accumulation of more and more reserves in the storage organ. Dasgupta (1972) reported that treatments of sugar beet plants with growth substances, which could increase the cambial activity of roots, may increase yield. The application of such growth retardants is important under conditions of low light intensity which favours the production of more auxin, depressing the growth of storage organs. Tolbert (1960) found that the growth pattern obtained after the application of growth retardant, CCC was similar to growth in high light intensity.

2.8. Effect of N application

Both the shoot dry matter and total biomass production were closely and positively associated with economic yield, while the correlation between harvest index and rhizome yield was low. Based on these findings an attempt was made to get more rhizome yield by bringing about a higher size of the plant by the application of higher dose of nitrogen. The studies conducted using cultivar C_1 showed that a higher dose of N applied in the early period of crop growth was able to produce higher LAI, LAD and total biomass followed by a higher rhizome yield under the monoculture system. Consequently these cultural practices did not change the harvest index. Donald and Hamblin (1976) cited examples to show that when higher doses of nitrogen were applied, the increase in biological yield greatly exceeded the decline in harvest index, so that a rise in grain yield occurred. In the present study, the HI was unaffected by the application of higher doses of nitrogen, and there was a proportionate increase in rhizome yield with the increase in biological yield.

A higher dose of nitrogen applied during the early stage of growth resulted in a higher LAI_{max}, LAD and yield. When this was split between early and later stages of growth, the leaf area development and dry matter production were considerably reduced. Thorne and Watson (1955) found that under temperate conditions, early and late nitrogen applications had the same effect on grain yield. But Khalifa (1973) concluded that under tropical conditions, the period of photosynthesis was not long enough after ear emergence to show the effect of late nitrogen application.

The intercropped stand did not respond for the higher doses of N where the increase in leaf area development and dry matter production obtained by the N application over the zero N was not significant thereby showing a serious limitation by light of nitrogen utilisation. This may be due to the low activity under the shaded condition of nitrate reductase enzyme, which is a key step in the conversion of nitrate to ammonia. Several workers reported decreased nitrate reductase activity under low light intensities (Hageman et al., 1961; Nicholas et al., 1976; and Udayakumar et al., 1981).

2.9. Nutrient uptake and redistribution

Although nutrient uptake is genetically determined, environmental variables or cultural practices can also influence the same. Selection of genotype for higher efficiency in nutrient use under different cropping systems would be useful in improving crop productivity. The knowledge of total nutrient absorption of plants throughout the growing season is the basis for understanding the nutrient requirement of a crop. Data on the total nutrient demand, nutrient removal in the harvested and nonharvested products, and the rate of nutrient accumulation at different stages of growth are needed for each component in a multiple cropping system to understand the rate, time and placement of various nutrients (Nair, 1979). Information on how and to what degree the data from the intercropping system deviate from those of the monoculture system will give a better idea about the adaptability of different genotypes to specific intercropping systems. The results obtained in the present study cannot be directly used to make a precise fertiliser recommendation. However, three important factors of nutrient uptake dealt with in this study, do have a bearing on fertiliser management, viz., the amount of nutrient required to produce the crop, the rate of uptake at various growth stages, and the proportion which moves into the harvested portion of the crop.

The present study revealed that there was no marked difference between the pure and intercropped stands of turmeric for the concentration of N, P and K. The reduced accumulation of nutrients by the intercropped stand of turmeric was more a consequence of decreased dry matter production than of nutrient concentration. Hegde and Saraf (1982b) reported that in pigeonpea, the intercropping did not cause significant effect on the nutrient concentration. During the Phase I, the accumulation rates were slow, but increased rapidly beyond this period. During Phase I and II the accumulation of nutrients was mainly in the shoot, but during Phase III it was mainly in the rhizome. The maximum concentration of N, P and K in the leaves was during Phase I, prior to the initiation of fingers. The nutrient levels decreased through most of the bulking phase, suggesting that the extent of translocation of nutrients to rhizome exceeded the uptake during tuber bulking.

The present study established that redistribution of nutrients made substantial contribution towards the nutrient accumulation in rhizome. In cereals and seed crops the redistribution of nutrients is of practical importance since it can make a substantial contribution to seed filling (Hocking and Pate, 1978, and Pyare Lal *et al.*, 1978). In turmeric after 18th week there was a rapid loss of nutrients from the leaves, following the onset of the active bulking of rhizome. Since there was no physical loss of leaves this downward trend in the nutrients in the vegetative tissue could have occurred through translocation. About 41 to 66 per cent of N accumulated in leaves was redistributed which constituted about 33-61 per cent of total N accumulation in the rhizome. The maximum redistribution of N was recorded for cultivar C_1 followed by C_2 and C_3 in that order which is an indication of their translocation efficiency. In the case of P about 30 to 50 per cent in the leaves was redistributed which contributed about 28 to 44 per cent of total P accumulation in rhizome. The cultivar C_3 showed lesser efficiency for translocation of P also. About 34 to 55 per cent of leaf K was redistributed which constituted about 33 to 62 per cent of total K accumulation in the rhizome. Influence of the cropping systems is more pronounced in the redistribution of K than on other nutrients. The translocation of N from leaves to tubers may reduce leaf N concentration and accelerate the leaf senescence (Dyson and Watson, 1971; and Christensen *et al.*, 1981).

Hocking and and Steer (1983) was of the opinion that withdrawal of P from leaves may also be an important restriction to continued leaf functioning.

The results indicated that the nutrient accumulation preceded dry matter accumulation which was more pronounced in the case of K than in other nutrients (Fig.34). When the active bulking of rhizome starts during the period of 18th to 22nd week, the total accumulation of N and P under the intercropping system, was practically nil eventhough the dry matter accumulation continued. Sale and Campbell (1980) and Hocking (1982) found that nutrient movement is not coupled directly to photosynthetic transport and that some nutrients were transported within the plant independently of each other.

The most rapid period of nutrient accumulation in turmeric was during 6th to 14th week. The accumulation of K was more rapid than other nutrients and about 80 per cent of the total K accumulation was attained by 18th week after planting. Thus, during the active rhizome bulking period in the Phase III when the K is much needed, the rhizome might be solely depending on the translocation from the shoot. Such an effect during the reproductive phase had been reported for sorghum (Roy and Wright, 1974) and cotton (Halevy, 1976). Halvey (1969) found that K was absorbed by reproductive parts from vegetative ones, especially when the amount of available K in the soil was low.

2.10. Curcumin and essential oil

Turmeric is valued principally for its yellow-orange colouring power which is due to the presence of a pigment, curcumin. Apart from the colouring power, turmeric possesses specific aroma and flavour owing to the presence of a significant quantity of essential oil. Pigment and essential oil content of turmeric can differ considerably among cultivars (Rama Rao *et al*., 1975; Krishnamurthy *et al*., 1975; 1976; and Mathai, 1976). The present study revealed that the maximum pigment concentration in the rhizome was attained prior to maturity of rhizome. At maturity, curcumin concentration of cultivar C_3 under the intercropping system was significantly higher than under the monoculture system; but no such difference was noticed for the other two cultivars. The maximum curcumin yield for cultivars C_2 and C_3 occurred during the period of 22nd to 26th week followed by a reduction at harvest (30th week). Krishnamurthy *et al*. (1975) found that the pigment content of turmeric increased to a peak and then declined during the maturation of rhizome and implied that optimum time for harvesting can differ according to a particular cultivar and the location of cultivation.

The maximum oil concentration in the rhizome was attained earlier in the growth cycle, between 8th to 14th week after planting. The concentration decreased upto 22nd week followed by a further rise during 26th week. All the cultivars showed a drop in the oil concentration at the time of harvest. At maturity, the oil concentration of cultivar C_2 under the intercropped stand was higher than under the pure stand, while no such marked difference was noticed for the other two cultivars. A reduction in oil yield at the time of harvest was recorded for all the cultivars under the monoculture system and for cultivar C_3 under the intercropping system. The results indicated that cultivars differed markedly in their curcumin as well as oil contents in the rhizome and their response towards the cropping system.

A study on the growth and development of three turmeric cultivars viz., Cls. No.24 (C_1), Cll.328 Sugandham (C_2) and Duggirala (C_3) in monoculture and as an intercrop in coconut garden was conducted for two years. The results obtained are discussed in relation to the light climate in coconut garden.

1. In adult coconut garden, only about 46 per cent of incoming PAR is available for intercrops. The adult coconut garden is characterised by large proportions of sunflecks, contributing to nearly 80 per cent of the available PAR inside the plantation.

2. The coconut leaf let showed a maximum of 16 per cent reflectance at about 550 nm and 8 per cent at blue and red regions of the spectrum. The large number of sunflecks and high reflectance of leaves are advantageous to intercrops in coconut garden. The transmittance of coconut leaf let is only 3 per cent at about 550 nm and negligible at red and blue regions.

3. The turmeric crop showed three distinct stages in growth and development viz., the first phase representing growth upto 8th weeks after planting, and is dominated by shoot growth; the second phase in the period of 8th to 18th week is characterised by initiation of fingers and maximisation of shoot growth; and the third phase,

characterised by dominant rhizome growth. The three cultivars of turmeric showed differential response to the changed environment under coconut canopy as compared to the monoculture.

4. Under the monoculture, all the cultivars registered maximum LAI by 18th week, while under intercropping it was postponed to 22nd week. Cultivar C_1 showed considerable reduction in LAI under the intercropping system as against a marked increase for C_3. Under both systems, cultivar C_2 had lowest LAI and did not register any difference between the two cropping systems. The LAI of cultivar C_1 showed high positive correlation with rhizome growth rate during the period of initiation of fingers under the monoculture system. This relationship was not obtained for the intercropped stand of this cultivar where the final yield was also less. The LAI showed a significant positive association with CGR upto third month of growth. During the Phase III, there was no association between CGR and LAI, but CGR and NAR were highly and positively correlated. The attainment of optimisation of LAI in cultivar C_1 was altered under the intercropping system where CGR approached asymptotic values at high LAI.

5. There was a close linear relationship between cumulative LAD and dry matter production. This relationship appears to be little affected by cultivars, cropping systems,

stages of development and the years of study. Cultivar C_1 exhibited a significant positive correlation of rhizome yield with LAD. But higher rhizome yield of this cultivar under the monoculture system than under the intercropping can be well explained on the basis of differences in LAI than those in LAD.

6. In cultivar C_1, the higher dry matter production is preceded by the attainment of higher RLGR under the monoculture system than under the intercropping system. In cultivar C_2, no such difference was noted. The greater RLGR of cultivars C_1 and C_3 than that of cultivar C_2 had resulted in former's high dry matter production. The early reduction in RLGR noted for the cultivar C_1 as compared to the other cultivars resulted in higher duration of bulking of rhizome. Much of the changes in RLGR as well as LGR and consequently in CGR as influenced by the cropping systems can be attributed to differences in solar energy input, since the other environmental variables did not show any appreciable difference between the two cropping systems.

7. While the maximum CGR, SGR and RhGR attained by the pure stand of cultivar C_1 were significantly higher than those attained by its intercropped stand, cultivars C_2 and C_3 did not register any marked difference between the two cropping systems for these parameters as well as in their rhizome or biological yield. Cultivar C_3 showed

a continued shoot growth upto 26th week, and the rhizome yield of this cultivar was considerably reduced as compared to the cultivar C_1, eventhough it was able to maintain a fairly high biological yield. Under the intercropping, there is a marked delay in the onset of higher RMR due to delayed initiation of fingers.

8. The maximum NAR as well as LAR were recorded during the Phase I, thereby resulting in maximum RGR during this period. Cultivar C_1 showed a further remarkable increase in NAR in the Phase III under the monoculture system which had resulted in a secondary peak in CGR and a levelling of RGR during this period. This trend noticed during the period when LAI and LAR were decreasing is the result of the increased NAR. The increase in NAR is interpreted as a response of the photosynthetic apparatus to an increased demand for assimilates caused by the rapid bulking of the rhizome.

9. During the initial stages of growth, the dry matter production was determined by the rate at which the leaf area was developed, but this effect did not persist upto final harvest. The cultivar differences in final rhizome yield can be well explained by the differences in CGR during the Phase III, which in turn is influenced by the NAR. During second year, when the solar energy input was low in the early period of growth as compared to first year, the rhizome bulking proceeded at the expense of shoot growth resulting .

in a upward trend in NAR, thereby showing the importance of 'sink' strength in turmeric, which has a partial control over the photosynthetic activity of the leaves.

10. Factors controlling sink strength in turmeric have not clearly been identified eventhough the three cultivars showed considerable difference in the expression of rhizome characters between the two cropping systems. The size of mother rhizome was either drastically reduced under intercropping as in the case of cultivar C_1, or the rhizome was large as in C_3, while no significant difference was observed in cultivar C_2. Higher production efficiency of C_1 as compared to C_2 and C_3 may be due a higher number of fingers which may be a varietal character.

11. The RGR of the three cultivars were considerably reduced under the intercropping system. Eventhough LAR was high under this cropping system, the marked reduction in NAR was mainly responsible for this reduction in RGR. Cultivar C_1 reacted more to the higher radiation than C_2 and C_3. During the second year, when the amount of solar energy input was considerably reduced in Phase I as compared to first year, the RGR values of cultivar C_2 and C_3 were similar to those of first year, but those of cultivar C_1 were considerably reduced. Specific leaf area was found to be more sensitive to changes in environmental conditions than leaf weight ratio.

12. The PAR interception efficiency of the pure and intercropped stands of the three cultivars of turmeric followed the same pattern as that of LAI. The increase in interception efficiency was seen only upto an LAI of about 4. All the three cultivars showed a higher efficiency of solar energy conversion under the intercropping system than under the monoculture system. Cultivar C_1 showed higher conversion efficiency than the other two cultivars under both the cropping systems. Conversion efficiency of all the three cultivars under both the cropping systems was increased during the rhizome bulking period as compared to that for total crop growth period.

13. The intimate relationship between the productivity of three cultivars and their light-saturated rates of photosynthesis had been brought out. While the rate of photosynthesis of cultivar C_1 was significantly higher when grown under the monoculture than under intercropping, cultivar C_2 showed higher values under intercropping thereby showing the existence of specific adaptation among the turmeric cultivars to varied light climates. Cultivar C_2 had shown significantly higher chlorophylls, both *a* and *b* (per unit fresh weight) under the intercropping system than under the monoculture system. The leaf air space volume, which is a measure of tissue density was higher for cultivar C_2 than for C_1 and C_3.

14. The stage at which maximisation of rhizome growth occurred, coincided with a drastic reduction in starch/sugar ratio in leaves. Cultivar C_1 showed a marked reduction in starch/sugar ratio for a prolonged period as compared to other cultivars. This marked reduction in starch/sugar ratio of cultivar C_1 may be due to the high sink demand of this cultivar which caused high rate of translocation of assimilates towards rhizome.

15. The cultivars differed significantly among them and in their response towards the cropping systems for the harvest indices. The higher HI noted for the cultivar C_1 than the other two cultivars showed higher partitioning efficiency of this cultivar. Also it had higher efficiency under the monoculture system than the intercropping system. Cultivar C_1 showed maximum dry matter production and highest partitioning efficiency, whereas the HI of cultivar C_3 was considerably low eventhough it was able to maintain a fairly high biological yield. Cultivar C_2 was inferior in biological yield as well as HI. These changes are reflected in the differences in rhizome yield observed among the cultivars.

16. The LAI and LAD together with the shoot dry weight and total dry weight showed a significant positive correlation with final rhizome yield from very early

growth phase. In turmeric, where the economically important part is the underground storage organ, this association is definitely useful, since it can be developed as an important tool for prediction of yield at an early stage of crop growth.

17. In all the three cultivars of turmeric studied, a linear relationship between rhizome yield and biological yield existed. Due to this close association between biological yield and rhizome yield, the correlation between rhizome yield and HI was low. Within a cultivar, higher rhizome yield requires higher biological yield. However, HI is an important criteria for the comparison among cultivars, since cultivars differed significantly for this character.

18. A higher rhizome yield was obtained for the cultivar C_1 under intercropping system by the application of CCC. A concentration of 4000 ppm was found to be most effective which also registered significantly higher HI. These results showed the possibility of realising higher yields from this cultivar under the intercropping system by the application of CCC.

19. The studies conducted using cultivar C_1 showed that a higher dose of nitrogen applied in the early period of crop growth was able to produce higher LAI, LAD and total biomass followed by a higher rhizome yield under

the monoculture system. The HI was unaffected by the application of higher doses of nitrogen, and there was a proportionate increase in rhizome yield with the increase in biological yield.

20. There was no marked difference between the pure and intercropped stands of turmeric for the concentration of N, P and K. The reduced accumulation of nutrients by the intercropped stand of turmeric was more a consequence of decreased dry matter production than of nutrient concentration. The redistribution of nutrients made substantial contribution towards the nutrient accumulation in rhizome. Nutrient accumulation preceded dry matter accumulation which was more pronounced in case of K than in other nutrients. The most rapid period of nutrient accumulation in turmeric was during 6th to 14th week. The accumulation of K was more rapid than other nutrients.

21. Cultivars differed markedly in their curcumin and essential oil contents in the rhizome and their response towards the cropping system. The maximum curcumin as well as oil concentration attained prior to the maturity of rhizome.

REFERENCES

Agata, W. 1982. The characteristics of dry matter and yield production in sweet potato under field conditions. In: Villareal, L. and Griggs, T.D. (eds). *Sweet Potato*. *Proc*. *First Inter*. *Symp*. Asian Vegetable Research and Development Center, Shanhua, Tainan, Taiwan, China.

Agboola, A.A. and Fayemi, A.A. 1972. Fixation and excretion of nitrogen by tropical legumes. *Agron*. *J*. **64**: 409-412.

Aiyer, A.K.Y.N. 1949. Mixed cropping in India. *Indian* *J*. *Agric*. *Sci*. **19**: 439-543.

Allen, E.J. and Scott, R.K. 1980. An analysis of growth of potato crop. *J*. *Agric*. *Sci*. Camb. **94**: 583-606.

Allen, L.H.Jr., Sinclair, T.R. and Lemon, E.R. 1976. Radiation and microclimate relationships in multiple cropping systems. In: Papendick, R.I., Sanches, R.A. and Triplett, G.B. (eds). *Multiple* *Cropping*. Am. Soc. Agron., Madison, Wisconsin, pp. 171-200.

Allen, L.H.Jr., Stewart, D.W. and Lemon, E.R. 1974. Photosynthesis in plant canopies.. Effect of light response curves and radiation source geometry. *Photosynthetica* **8**: 184-207.

American Spice Trade Association. 1968. *Official* *Analytical* *Methods*. 2nd Edn, New York.

Ampofo, S.T. and Lawson, G.W. 1972. Growth of seedling of *Afromosia elata* harms. in relation to light intensity. *J. Appl. Ecol.* *9*: 301-306.

Anderson, M.C. 1964a. Studies of the woodland light climate. 1. The photographic computation of light conditions. *J. Ecol.* *52*: 27-41.

Anderson. M.C. 1964b. Studies of the woodland light climate. 2. Seasonal variation in the light climate. *J. Ecol.* *52*: 643-663.

Anderson, M.C. 1964c. Light relation of terrestrial plant communities and their measurement. *Biol. Rev.*, Cambridge. Phil. Soc. *39*: 425-486.

Andrews, D.J. 1972. Intercropping with sorghum in Nigeria. *Exp. Agric.* *8*: 139-150.

Andrews, D.J. 1974. Responses of sorghum varieties to intercropping. *Exp. Agric.* *10*: 57-63.

Andrews, D.J. and Kassam, A.H. 1976. The importance of multiple cropping in increasing world food supplies. In: Papendick, R.I., Sanchez, P.A. and Triplett, G.B. (eds) *Multiple Cropping*. *Am. Soc. Agron.*, Madison, Wisconsin. pp. 1-10.

Anon. 1969. *Photosynthesis and utilization of solar energy. Level I Experiments.* Report II, J.I.B.P., Tokyo.

Anon. 1972. *Photosynthesis and utilization of solar energy. Level I Experiments.* Report V. J.I.B.P., Tokyo.

Armitage, A.M. and Vines, H.M. 1982. Net Photosynthesis, diffusive resistance and chlorophyll content of shade and sun-tolerant plants grown under different light regimes. *Hort Sci*. *17*: 342-343.

Arnon, D.I. 1949. Copper enzymes in isolated chloroplasts. Polyphenoloxidase in *Beta vulgaris*. *Plant Physiol*. *24*: 1-15.

Ase, J.K. 1978. Relationship between leaf area and dry matter in winter wheat. *Agron*. *J*. *70*: 563-565.

Ashley, D.A., Doss, B.D. and Bennett, O.L. 1965. Relation of cotton leaf area index to plant growth and fruiting. *Agron*. *J*. *57*: 61-64.

Baker, E.F.I. 1981. Population, time and crop mixtures. In: *Proc*. *Int*. *Workshop on Intercropping*, ICRISAT, Hyderabad, 10-13 January, 1979, pp. 52-60.

Baker, R.J. and Gebeyehou, G. 1982. Comparative growth analysis of two spring wheats and one spring barley. *Crop Sci*. *22*: 1225-1229.

Balakrishnan, T.K., Nair, P.K.R. and Nelliatt, E.V. 1976. Microclimate of coconut varieties and cacao and cinnamon grown as mixed crops with coconut. *Indian J*. *Met*. *Hydrol*. *and Geophys*. *27*: 71-74.

Bavappa, K.V.A. 1975. Intensive cropping possibilities in plantation crops. *Planters' Chronicle*. *69* (9): 260-262.

Bavappa, K.V.A. and Jacob, V.J. 1981. A model for mixed cropping. *Ceres* (May-June): 44-46.

Beets, W.C. 1977. Multiple cropping of maize and soybean under a high level of crop management. *Neth. J. Agric. Sci.* *25*: 95-102.

Beste, C.E. 1976. Co-cropping sweet corn and soybeans. *Hort Sci.* *11*: 236-238.

Bhagsari, A.S., Ashley, D.A., Brown, R.H. and Boerma, H.R. 1977. Leaf Photosynthetic characters of determinate soybean cultivars. *Crop Sci.* *17*: 929-932.

Bingham, J. 1969. The physiological determinants of grain yield in cereals. *Agric. Prog.* *44*: 30-42.

Birke, J. 1965. Uber die Abhangigkeit des Zuckerrubenertrages von der Entwicklung des Assimilations-apparatus. *Albrecht-Thaer-Arch.* *9*: 715-729.

Biscoe, P.V. and Gallagher, J.N. 1977. Weather, dry matter production and yield. In: Landsberg, J.J. and Cutting, C.V. (eds). *Environmental effects on Crop Physiology*. Academic Press, New York, pp. 75-100.

Björkman, O. 1968. Carboxymutase activity in shade-adapted and sun-adapted species of higher plants. *Physiol. Plant.* *21*: 1-10.

Björkman, O. and Holmgren, P. 1963. Adaptability of the photosynthetic apparatus to light intensity in ecotypes from exposed and shaded habits. *Physiol. Plant.* *16*: 889-914.

Björkman, O. and Holmgren, P. 1966. Photosynthetic adaptation to light intensity in plants native to shaded and exposed habitats. *Physiol. Plant.* *19*: 854-859.

Björkman, O. and Ludlow, M.M. 1972. Characterisation of the light climate in the floor of Queensland rain-forest. *Carnegie Institute of Washington Year Book*. *7*: 85-94.

Blackman, V.H. 1919. The compound interest law and plant growth. *Ann*. *Bot*. *33*: 353-360.

Blackman, G.E. 1956. Influence of light and temperature on plant growth. *Proc*. *3rd Easter Sch*. *Agric*. *Sci*. *Univ*. *Nott*. pp. 152-167.

Blackman, G.E. 1961. Responses to environmental factors by plants in the vegetative phase. In: Zarrow, M.X. (ed). *Growth in Living Systems*. Basic Books Inc., New York. pp. 525-556.

Blackman, G.E. 1968. The application of the concepts of growth analysis to the assessment of productivity. In: Eckardt, F.E. (ed). *Functioning of Terrestrial Ecosystems at the Primary Production Level*. UNESCO, Paris. pp. 243-259.

Blackman, G.E. and Black, J.N. 1959a. Physiological and ecological studies in the analysis of plant environment. XI. A further assessment of the influence of shading on the growth of different species in the vegetative phase. *Ann*. *Bot*. N.S. *23*: 51-63.

Blackman, G.E. and Black, J.N. 1959b. Physiological and ecological studies in the analysis of plant environment. XII. The role of light factor in limiting growth. *Ann*. *Bot*. N.S. *23*: 131-145.

Blackman, G.E., Black, J.N. and Kemp, A.W. 1955. Physiological and ecological studies in the analysis of plant environment. X. An analysis of the effects of seasonal variations in day light and temperature on the growth of *Helianthus annuus* in the vegetative phase. *Ann. Bot.* N.S. *19*: 527-548.

Blackman, G.E. and Wilson, G.L. 1951. Physiological and ecological studies in the analysis of plant environment. VI. The constancy for different species of a logarithmic relationship between assimilation rate and light intensity and its ecological significance. *Ann. Bot.* N.S. *15*: 63-94.

Blackman, G.E. and Wilson, G.L. 1954. Physiological and ecological studies in the analysis of plant environment. IX. Adaptive changes in vegetative growth and development of *Helianthus annuus* induced by an alteration of light level. *Ann. Bot.* N.S. *18*: 71-94.

Boardman, N.K. 1977. Comparative photosynthesis of sun and shade plants. *Ann. Rev. Pl. Physiol.* *28*: 355-377.

Bremner, P.M. and Radley, R.W. 1966. Studies in potato agronomy. II. The effects of variety and time of planting on growth, development and yield. *J. Agric. Sci.* *66*: 253-262.

Bremner, P.M. and Taha, M.A. 1966. Studies in potato agronomy. I. The effects of variety, seed size and spacing on growth, development and yield. *J. Agric. Sci.* *66*: 241-252.

Briggs, G.E., Kidd, F. and West, C. 1920. Quantitative analysis of plant growth. Ann. Appl. Biol. 7: 103-123.

Bunce, J.A. 1983. Photosynthetic characteristics of leaves developed at different irradiance and temperatures: an extension of the current hypothesis. Photosynthesis Res. 4: 87-97.

Burt, R.L. 1964. Carbohydrate utilization as a factor in plant growth. Aust. J. Biol. Sci. 17: 867-877.

Burt, R.L. 1966. Some effects of temperature on carbohydrate utilization and plant growth. Aust. J. Biol. Sci. 19: 711-714.

Buttery, B.R. 1969. Analysis of growth of soybeans as affected by plant population and fertiliser. Can. J. Plant Sci. 49: 675-684.

Buttery, B.R. 1970. Effects of variations in leaf area index on growth of maize and soybeans. Crop. Sci. 10: 9-13.

Buttery, B.R. and Buzzell, R.I. 1972. Some difference between soybean cultivars observed by growth analysis. Can. J. Plant. Sci. 52: 13-20.

Byott, G.S. 1976. Leaf air space systems in C_3 and C_4 species. New Phytol. 76: 295-299.

Charles-Edwards, D.A. 1978. An analysis of the photosynthesis and productivity of vegetative crops in the United Kingdom. Ann. Bot. 42: 717-731.

Christensen, L.E., Below, F.E. and Hageman, R.H. 1981. The effect of ear removal on senescence and metabolism of maize. Plant Physiol. 68: 1180-1185.

Clarke, J.M. and Simpson, G.M. 1978. Growth analysis of *Brassica napus* cv. Tower. *Can. J. Plant Sci.* *58*: 587-595.

Clegg, D.M., Biggs, W.W., Eastin, D.J., Maranville, W.J. and Sullivan, Y.C. 1974. Light transmission in field communities of sorghum. *Agron. J.* *66*(4): 471-476.

Clough, J.M., Albert, R.S. and Teeri, J.A. 1979. Photosynthetic adaptation of *Solanum dulcamara* L. to sun and shade environments. *Plant Physiol.* *64*: 25-30.

Collins, W.B. 1977a. Comparison of growth and tuber development in three potato cultivars with diverse canopy size. *Can. J. Plant Sci.* *57*: 797-801.

Collins, W.B. 1977b. Analysis of growth in Kennebec with emphasis on the relationship between stem no. and yield. *Am. Potato J.* *54*(1): 33-40.

Constable, G.A. and Gleeson, A.C. 1977. Growth and distribution of dry matter in cotton (*Gossypium hirsutum* L.). *Aust. J. Agric. Res.* *28*: 249-256.

Cooper, C.S. 1972. Growth analysis of two Sainfoin (*Onobrychis viciaefolia* Scop.) growth types. *Agron. J.* *64*(5): 611-613.

Cooper, J.P. 1970. Potential production and energy conversion in temperate and tropical grasses. *Herb. Abstr.* *40*: 1-15.

Cooper, J.P. 1975. Control of photosynthetic production in terrestrial systems. In: Cooper, J.P. (ed). *Photosynthesis and productivity in different environments*. Cambridge Univ. Press, Cambridge, pp. 593-621.

Cordero, A. and Mc Collum, R.E. 1979. Yield potential of interplanted annual food crops in Southeastern U.S. *Agron. J.* *71*: 834-842.

Craker, L.E., Seilbert, M. and Clifford, J.T. 1983. Growth and development of radish (*Raphanus sativus* L.) under selected light environments. *Ann. Bot.* N.S. *51*: 59-64.

Crookston, R.K. 1976. Intercropping, a new version of an old idea. *Crops Soil Mag.* *28*: 7-9.

Dalal, R.C. 1974. Effects of intercropping maize with pigeon peas on grain yield and nutrient uptake. *Exp. Agric.* *10*: 219-224.

Das Gupta, D.K. 1972. Developmental physiology of sugar beet. IV. eEffects of growth substances and differential root and shoot temperatures on subsequent growth. *J. exp. Bot.* *23*: 103-113.

Das Gupta, D.K. 1976. Effect of Cycocel on crop plants in Sierra Leone. II. Cassava (*Mannihot esculenta*). *Exp. Agric.* *12*: 321-328.

Daynard, T.B., Tanner, J.W. and Duncan, W.G. 1971. Duration of grain filling period and its relation to grain yield in corn. *Crop Sci.* *11*: 45-48.

De Loughery, R.L. and Crookston, R.K. 1979. Harvest index of corn affected by population density, maturity rating and environment. *Agron. J.* *71*: 577-580.

Dennet, M.D., Elston, J. and Milford, J.R. 1979. The effect of temperature on the growth of individual leaves of *Vicia faba* L. in the field. *Ann. Bot.* *43*: 197–208.

de Wit, C.T. 1965. Photosynthesis of leaf canopies. *Agric. Res. Rep. 63*. Inst. Biol. and Chem. Res. on Field Crops and the Herbage, Wageningen.

Donald, C.M. 1963. Competition among crop and pasture plants. *Adv. Agron.* *15*: 1–118.

Donald, C.M. 1962. In Search of yield. *J. Aust. Inst. Agric. Sci.* *28*: 171–178.

Donald, C.M. 1968. The breeding of crop ideotypes. *Euphytica* *17*: 385–403.

Donald, C.M. and Hamblin, J. 1976. The biological yield and harvest index of cereals as agronomic and plant breeding criteria. *Adv. Agron.* *28*: 361–405.

Dubois, M., Gilles, K.A., Hamilton, J.K., Rebers, P.A. and Smith, F. 1956. Colorimetric method for determination of sugars and related substances. *Anal. Chem.* *28*: 350–356.

Duncan, W.G. 1972. SIMCOT: A simulator of cotton growth and yield. In: Murphy, C. *et al.* (eds). *Proc. Workshop on Tree Growth Dynamics and Modeling*. Duke Univ., Oct. 1971. pp. 115–118.

Duncan, W.G., Loomis, R.S., Williams, W.A. and Hanau, R. 1967. A model for simulating photosynthesis in plant communities. *Hilgardia* *38*: 181–205.

Dunsmore, J.R. and Ngui, T.S.T. 1970. The prospects for cocoa in Sarawak, Malaysia. In: Blencowe, E.K. and Blencowe, J.W. (eds). *Crop diversification in Malaysia*. pp. 275-285.

Dyson, P.W. 1965. Effect of gibberellic acid and 2-chloroethyl-trimethyl-ammonium chloride on potato growth and development. *J. Sci. Fd. Agric.* *16*: 542-549.

Dyson, P.W. and Watson, D.J. 1971. An analysis of the effects of the nutrient supply on the growth of potato crops. *Ann. Appl. Biol.* *69*: 47-63.

Eastin, J.A. and Gritton, E.T. 1969. Leaf area development, light interception and growth of canning peas (*Pisum sativum* L.) in relation to plant population and spacing. *Agron. J.* *61*: 612-615.

Eik, K. and Hanway, J.J. 1966. Leaf area in relation to yield of corn grain. *Agron. J.* *58*: 16-18.

El-Fouly, M.M. 1973. Beneficial effects of chlormequat (CCC) in root crops under Egyptian field conditions. *Proc. 3rd Symp. Inter. Soc. Trop. Root Crops*, Ibadan, Nigeria, 2-9th December.

Enyi, B.A.C. 1972. The effects of seed size and spacing on growth and yield in lesser yam (*Dioscorea esculenta*). *J. Agric. Sci.* Camb. *78*: 215-225.

Enyi, B.A.C. 1973a. Effects of intercropping maize or sorghum with cowpeas, pigeon peas or beans. *Exp. Agric.* *9*: 83-90.

Enyi, B.A.C. 1973b. Growth rates of three cassava varieties (*Manihot esculenta* Crantz.) under varying population densities. *J. Agric. Sci.* *81*: 15-28.

Evans, A.C. 1960. Studies of intercropping. I. Maize or sorghum with groundnuts. *East African Agric. For. J.* *26*: 1-10.

Evans, G.C. 1972. *The Quantitative Analysis of Plant Growth*. Blackwell Sci. Pub. Oxford.

Evans, L.T. 1975a. The Physiological basis of crop yield. In: Evans, L.T. (ed). *Crop Physiology: Some Case Histories*. Cambridge Univ. Press, Cambridge. pp. 327-355.

Evans, L.T. 1975b. Beyond photosynthesis - the role of respiration, translocation and growth potential in determining productivity. In: Cooper, J.P. (ed). *Photosynthesis and Productivity in Different Environments*. Cambridge Univ. Press, Cambridge. pp. 501-507.

Evans, L.T. and Dunstone, R.L. 1970. Some physiological aspects of evolution in wheat. *Aust. J. Biol. Sci.* *23*: 725-741.

Evans, L.T. and Wardlaw, I.F. 1976. Aspects of comparative physiology of grain yield in cereals. *Adv. Agron.* *28*: 301-359.

Fails, B.S., Lewis, A.J. and Barden, J.A. 1982. Net photosynthesis and transpiration of sun and shade-grown *Ficus benjamina* leaves. *J. Amer. Soc. Hort. Sci.* *107*(5): 758-761.

Federer, C.A. and Tanner, C.B. 1966. Spectral distribution of light in the forest. *Ecology* *47*: 555-560.

Fisher, N.M. 1975. Investigations into the competitive relations of maize and beans in mixed crops. *Techn. Commun.* *14*, *Dept. Crop Sci.* University of Nairobi, Kenya.

Fisher, N.M. 1977a. Studies in mixed cropping. I. Seasonal differences in relative productivity of crop mixtures and pure stands in the Kenya Highlands. *Exp. Agric.* *13*: 177-184.

Fisher, N.M. 1977b. Studies in mixed cropping. II. Population pressures in maize/bean mixtures. *Exp. Agric.* *13*: 185-191.

Fischer, R.A. 1975. Yield potential in a dwarf spring wheat and the effect of shading. *Crop Sci.* *15*: 607-613.

Fischer, R.A. and Kertesz, A. 1976. Harvest index in spaced population and grain weight in microplots as indicators of yielding ability in spring wheat. *Crop Sci.* *16*: 55-59.

Forsyth, F.R. and Hall, I.V. 1965. Effect of leaf maturity, temperature, CO_2 concentration and light intensity on rate of photosynthesis in clonal lines of low bush blueberry, *Vaccinium angustifolium* Ait. under laboratory conditions. *Can. J. Bot.* *43*: 893.

Francis, C.A., Flor, C.A. and Temple, S.R. 1976. Adapting varieties for intercropped systems in the tropics. In: Papendick, R.I., Sanchez, P.A. and Triplett, G.B. (eds). *Multiple Cropping*. Am. Soc. Agron. Madison, Wisconsin. pp. 235-253.

Francis, C.A., Prager, M. and Tejada, G. 1982. Effects of relative planting dates in bean (*Phaseolus vulgaris* L.) and maize (*Zea mays* L.) intercropping patterns. *Field Crops Res*. *5*: 45-54.

Francis, C.A. and Sanders, J.H. 1978. Economic analysis of bean and maize systems: monoculture versus associated cropping. *Field Crops Res*. *1*: 319-335.

French, S.A.W. and Humphries, E.C. 1977. The effect of partial defoliation on yield of sugar beet. *Ann*. *Appl*. *Biol*. *87*: 201-212.

Freyman, S. and Venkateswarlu, J. 1977. Intercropping on rainfed red soils of the Deccan Plateau, India. *Can*. *J*. *Plant*. *Sci*. *57*: 697-705.

Frier, V. 1977. The relationship between photosynthesis and tuber growth in *Solanum tuberosum* L. *J*. *exp*. *Bot*. *28*: 999-1007.

Gaastra, P. 1958. Light energy conversion in field crops in comparison with the photosynthetic efficiency under laboratory conditions. *Meded*. *Landb* *Hoogesch*., Wageningen. *58*: 1-12.

Gallagher, J.N. and Biscoe, P.V. 1978. Radiation absorption, growth and yield of cereals. *J. Agric. Sci.* *91*: 47-60.

Gardiner, T.R. and Craker, L.E. 1981. Bean growth and light interception in a bean-maize intercrop. *Field Crops Res.* *4*: 313-320.

Gaskel, M.L. and Pearce, R.B. 1981. Growth analysis of maize hybrids differing in photosynthetic capacity. *Agron. J.* *73*: 817-821.

Gates, D.M., Keegan, H.J., Schleter, J.C. and Weidner, V.R. 1965. Spectral properties of plants. *Appl. Optics* *4*: 11-17.

Gauhl, E. 1976. Photosynthetic response to varying light intensity to ecotypes of *Solanum dulcamara* L. from shaded and exposed habitats. *Oecologia* *22*: 275-286.

Gausmann, H.W., Allen, W.A. and Meyers, V.I. and Cardenas, R. 1969. Reflectance and internal structure of cotton leaves, *Gossypium hirsutum* L. *Agron. J.* *61*: 374-376.

Giaquinta, R.T., Quebedeaux, B. and Wittenbach, V. 1980. Alternation in photosynthesis and assimilate partitioning between starch and sucrose in soybean leaves during seed filling. In: *Photosynthesis.* Vol. IV. Regulation of carbon Metabolism. *Proc. Fifth Inter. Congr. Photosynthesis*, September 7-13, 1980. Halkidiki, Greece.

Gibson, P.T. and Schertz, K.F. 1977. Growth analysis of a sorghum hybrid and its parents. *Crop Sci.* *17*: 387-391.

Gifford, R.M. and Evans, L.T. 1981. Photosynthesis, carbon partitioning and yield. *Ann. Rev. Pl. Physiol.* *32*: 485-509.

Gomez, A.A. and Gomez, K.A. 1983. "*Multiple Cropping in the Humid Tropics of Asia*". Ottawa, Ont. IDRC, 1983. 248 p.

Gregory, F.G. 1917. *Physiological conditions in cucumber houses*. Third Ann. Rep. Exp. and Res. Stn., Cheshunt (England), pp. 19-28.

Gupta, K.R. and Woolley, J.T. 1971. Spectral properties of soybean leaves. *Agron. J.* *63*: 123-126.

Hageman, R.H., Flesher, D. and Gitter, A. 1961. Diurnal variations and other effects influencing the activity of nitrate reductase and nitrogen metabolism in corn. *Crop Sci.* *1*: 201-204.

Hahn, S.K. 1977. A quantitative approach to source potentials and sink capacities among reciprocal grafts of sweet potato varieties. *Crop. Sci.* *17*: 559-562.

Halevy, J. 1969. *Factors affecting the efficiency of K uptake by cotton* (Hebrew with English Summary). Ph.D. Thesis, Hebrew Univ. of Jerusalem, Faculty of Agric., Rehovot, Isreal.

Halevy, J. 1976. Growth rate and nutrient uptake of two cotton cultivars grown under irrigation. *Agron. J.* *68*: 701-705.

Hall, D.O. 1976. Photobiological energy conversion. *FEBS Lett.* *64*: 6-16.

Hamblin, J., Rowell, J.G. and Redden, R. 1976. Selection for mixed cropping. *Euphytica* *25*: 47-106.

Harrison, S.A., Boerma, H.R. and Ashley, D.A. 1981. Heritability of canopy-apparent photosynthesis and its relationship to seed yield in soybeans. *Crop Sci*. *21*: 222-226.

Haynes, P.H., Spence, J.A. and Walter, C.J. 1967. The use of physiological studies in the agronomy of root crops. *Proc*. *Int*. *Symp*. *Trop*. *Root Crops*, Ist, 1970. 1: 1-17.

Hearn, A.B. 1969. The growth and performance of cotton in a desert environment. II. Dry matter production. *J*. *Agric*. *Sci*. Cambridge. 73: 75-86.

Hegde, D.M. and Saraf, C.S. 1982a. Growth analysis of pigeon pea (*Cajanus cajan* (L.) Muth) in pure and intercropped stands with different other grain legumes in relation to phosphorus fertilization. *Z*. *Acker-und Pflanzenbau*. *151*: 49-61.

Hegde, D.M. and Saraf, C.S. 1982b. Effect of intercropping and phosphorus fertilization on nitrogen, phosphorus and potassium concentration and uptake and productivity of pigeon pea (*Cajanus cajan* (L.) Muth). *Z*. *Acker-und Pflanzenbau*. *151*: 302-314.

Highkin, H.R. and Frenkel, F. 1962. Studies on growth and metabolism of barley mutant lacking chlorophyll *b*. *Plant Physiol*. *37*: 314-320.

Hocking, P.J. 1982. Accumulation and distribution of nutrients in fruits of casterbean (*Ricinus communis* L.) *Ann*. *Bot*. N.S. *49*: 51-62.

Hocking, P.J. and Pate, J.S. 1978. Accumulation and distribution of mineral elements in the annual lupins (*Lupinus alba* L.). *Aust*. *J*. *Agric*. *Res*. *29*: 280-297.

Hocking, P.J. and Steer, B.T. 1983. Uptake and partitioning of selected mineral elements in sunflower (*Helianthus annuus* L.) during growth. *Field Crops Res*. *6*: 93-107.

Hodanova, D. 1967. Development and structure of foliage in wheat stands of different density. *Biol*. *Plant*. *9*: 424-438.

Horn, H.S. 1971. *The Adaptive Geometry of Trees*. Princeton Univ. Press, Princeton, N.J. 144 p.

Hozyo, Y. and Park, C.Y. 1971. Plant production in grafting plants between wild type and improved variety in *Ipomoea*. *Bull*. *Nat*. *Inst*. *Agric*. *Ser*. D No. 12, Tokyo, Japan.

Huber, S.C. 1981. Inter and intra-specific variation in photosynthetic formation of starch and sucrose. *Z*. *Pflanzenphysiol*. *101*: 49-54.

Hughes, A.P. and Evans, G.C. 1962. Plant growth and the aerial environment. II. Effects of light intensity on *Impatiens parviflora*. *New Phytol*. *61*: 154-174.

Hughes, A.P. and Freeman, P.R. 1967. Growth analysis using frequent small harvests. *J*. *Appl*. *Ecol*. *4*: 553-560.

Huett, D.O. and O'Neill, G.H. 1976. Growth and development of short and long season sweet potatoes in subtropical Australia. *Exp. Agric.* **12** (4): 385.

Humphries, E.C. and Dyson, P.W. 1967. Effects of growth regulators, CCC and B_9 on some potato varieties. *Ann. Appl. Biol.* **60**: 333–341.

Humphries, E.C. and French, S.A.W. 1969. Effect of seedling treatment on growth and yield of sugar beet in the field. *Ann. Appl. Biol.* **64**: 385–393.

Hunt, R. 1978. *Plant Growth Analysis*. *Studies in Biology* No. 96. Edward Arnold (Publishers) Limited, London.

Hunt, R. 1982. Plant growth analysis: Second derivatives and compounded second derivatives of splined plant growth curves. *Ann. Bot.* **50**: 317–328.

Hunt, R. and Evans, G.C. 1980. Classical data on the growth of maize. Curve fitting with statistical analysis. *New Phytol.* **86**: 155–180.

Hunt, L.A., Wholey, D.W. and Cock, J.H. 1977. Growth physiology of Cassava (*Manihot esculenta* Crantz). *Field Crops Abstr.* **30** (2): 77–91.

Hutchinson, B.A. and Matt, D.R. 1977. The annual cycle of solar radiation in a deciduous forest. *Agric. Meteorol.* **18**: 255–265.

Huxley, P.A. 1969. The effect of fluctuating light intensity on plant growth. *J. Appl. Ecol.* **6**: 273–276.

Ibrahim, M.E. and Buxton, D.R. 1981. Early vegetative growth of cotton as influenced by leaf type. *Crop Sci*. **21** (5): 639-643.

Impens, I. and Lemeur, R. 1969. Extinction of net radiation in different crop canopies. *Arch*. *Meteorol*. *Geophys*. *Bioklimatol*. *Ser*. B **17**: 403-412.

Irvine, J.E. 1975. Relation of photosynthesis rates and leaf and canopy characters to sugarcane yield. *Crop Sci*. **15**: 671-676.

Jackson, M.L. 1958. *Soil Chemical Analysis*. Prentice-Hall Inc., Englewood Cliffs, N.J., U.S.A.

Jain, S., Chaddha, G. and Pandey, R.K. 1978. Reflectance and transmittance of the leaves of black gram and green gram at 500-700 nm. *Indian J*. *Agric*. *Sci*. **48**: 650-654.

Johnson, D.R. and Major, D.J. 1979. Harvest index of soybeans as affected by planting date and maturity rating. *Agron*. *J*. **71**: 538-541.

Jones, J.W., Hesketh, J.D., Kamprath, E.J. and Bowen, H.D. 1974. Development of a nitrogen balance for cotton growth models - a first approximation. *Crop Sci*. **14**: 541-546.

Joshi, L.K. and Sharma, N.D. 1982. Diseases of ginger and turmeric. *Proc*. *National Seminar on "Ginger and Turmeric"*, CPCRI, 8-9 April, 1980, Calicut, India. pp 104-119.

Judel, G.K. and Mengel, K. 1982. Effect of shading on nonstructural carbohydrates and their turnover in culms and leaves during the grain filling period of spring wheat. Crop Sci. 22 (5): 958-962.

Kanwar, J.S. 1970. Multiple cropping: trends and problems. Indian Fmg. 20 (7): 5-7.

Kaplan, S.L. and Koller, H.R. 1977. Leaf area and CO_2 exchange rate as determinants of the rate of vegetative growth in soybean plants. Crop Sci. 17: 35-38.

Kassam, A.H. and Stockinger, K. 1973. Growth and nitrogen uptake of sorghum and millet under mixed cropping. Samaru Agric. News Lett. 15: 89-91.

Kawakami, K. 1978. Physiology of yield of underground storage organs. In: Gupta, V.S. (ed). Crop Physiology. Oxford and IBH Publishing Co., New Delhi.

Khalifa, M.A. 1973. Effects of nitrogen on leaf area index, leaf area duration, net assimilation rate and yield of wheat. Agron. J. 65: 253-256.

Keating, B.A., Evenson, J.P. and Fukai, S. 1982a. Environmental effects of growth and development of cassava (Manihot esculenta Crantz.). I. Crop Development. Field Crops Res. 5: 271-281.

Keating, B.A., Evenson, J.P. and Fukai, S. 1982b. Environmental effects of growth and development of cassava (Manihot esculenta Crantz.). II. Crop growth rate and biomass yield. Field Crops Res. 5: 283-292.

Keating, B.A., Evenson, J.P. and Fukai, S. 1982c. Environmental effects of growth and development of cassava (*Manihot esculenta* Crantz.). III. Assimilate distribution and storage organ yield. *Field Crops Res*. 5: 293-303.

Koller, H.R., Nyquist, W.E. and Chorush, I.S. 1970. Growth analysis of the soybean community. *Crop Sci*. 10: 407-412.

Krenzer, E.G. and Moss, D.N. 1975. Carbon dioxide enrichment effects upon yield and yield components in wheat. *Crop Sci*. 15: 71-74.

Kriedmann, P.E., Torokfalvy, E. and Smart, R.E. 1973. Natural occurrence and photosynthetic utilisation of sunflecks by grape vine leaves. *Photosynthetica* 7: 18-27.

Krishnamurthy, N., Mathew, A.G., Nambudiri, E.S., Shivashankar, S., Lewis, Y.S. and Natarajan, C.P. 1976. Oil and oleoresin of turmeric. *Trop*. *Sci*. 18: 37-45.

Krishnamurthy, N., Padma Bai, R., Natarajan, C.P. and Kuppuswamy, S. 1975. Colour content of turmeric varieties and studies of its processing. *J*. *Food*. *Sci*. *Technol*. (India) 12: 12-14.

Krishnamurthy, K., Rajashekara, B.G., Jagannath, M.K., Bomme Gowda, A., Raghunatha, G. and Venugopal, N. 1973. Photosynthetic efficiency of sorghum genotypes after head emergence. *Agron*. *J*. 65 (6): 858-860.

Kueneman, E.A., Wallace, D.H. and Ludford, P.M. 1979. Photosynthetic measurements of field grown dry beans and their relation to selection for yield. *J. Amer. Soc. Hort. Sci.* *104* (4): 480-482.

Kundu, A.L. and Chatterjee, B.N. 1982. Growth analysis of turmeric as a sole crop and in mixture with other crops. *Indian J. Agric. Sci.* *52*: 584-589.

Kvet, J., Ondok, J.P. Necas, J. and Jarvis, P.G. 1971. Methods of growth analysis. In: Sestak, Z., Catsky, J. and Jarvis, P.G. (eds). *Plant Photosynthetic Production. Manual of Methods.* Dr. W. Junk Publishers, The Hague. pp. 343-391.

Lewandowska, M., Hart, J.W. and Jarvis, P.G. 1976. Photosynthetic electron transport in plants of *Sitka spruce* subjected to different light environments during growth. *Physiol. Plant.* *37*: 269-274.

Lima, A.F. and Lopes, L.H.O. 1981. Plant population and spatial arrangement study on the intercropping of maize and beans (*Phaseolus vulgaris* L.) in Northeast Brazil. In: *Proc. Int. Workshop on Intercropping*, 10-13 January, 1979, ICRISAT, Hyderabad, India. pp. 41-45.

Littleton, E.J., Dennett, M.D., Elston, J. and Monteith, J.L. 1979a. The growth and development of cow peas (*Vigna unguiculata*) under tropical field conditions. 1. Leaf area. *J. Agric. Sci.* Cambridge, *93*: 291-307.

Littleton, E.J., Dennett, M.D., Monteith, J.L. and Elston, J. 1979b. The growth and development of cow peas (*Vigna unguiculata*) under tropical field conditions. 2. Accumulation and partition of dry weight. *J. Agric. Sci.* Cambridge, *93*: 309-320.

Loach, K. 1970. Analysis of differences in yield between six sugar beet varieties. *Ann. Appl. Biol.* *66*: 217-223.

Loomis, W.E. 1965. Absorption of radiant energy by leaves. *Ecol.* *46*: 14-17.

Loomis, R.S. and Gerakis, P.A. 1975. Productivity of agricultural ecosystems. In: Cooper, J.P. (ed) *Photosynthesis and Productivity in Different Environments*. Cambrdige Univ. Press, Cambridge. pp. 145-172.

Loomis, R.S., Williams, W.A. and Hall, A.E. 1971. Agricultural Productivity. *Ann. Rev. Pl. Physiol.* *22*: 431-468.

Lowe, S.B. and Wilson, L.A. 1974. Comparative analysis of tuber development in six sweet potato (*Ipomoea batatas* (L.) Lam.) cultivars. 1. Tuber initiation, tuber growth and partition of assimilate. *Ann. Bot.* N.S. *38*: 307-317.

Lowe, S.B. and Wilson, L.A. 1975a. Yield and yield components of six sweet potato cultivars. 1. Contribution of yield components to tuber yield. *Exp. Agric.* *11*: 39-48.

Lowe, S.B. and Wilson, L.A. 1975b. Yield and yield components of six sweet potato (*Ipomoea batatas*) cultivars. II. Variability of possible sources of variation. *Exp. Agric.* **11**: 49-58.

Mac Coll, D. and Cooper, J.P. 1967. Climate variations in forage grasses. III. Seasonal changes in growth and assimilation in climatic races of *Lolium*, *Dactylis* and *Festuca*. *J. Appl. Ecol.* **4**: 113-127.

Maestri, M. and Barros, R.S. 1977. Coffee. In: Alvin, P.deT. and Kozlowski, T.T. (eds). *Ecophysiology of tropical crops*. Academic Press, New York.

Mahapatra, I.C., Leeuwrik, D.M., Singh, N.K. and Dayanand. 1973. Green revolution through multiple cropping in India. *Agric. Mech. in Asia. Spring.* 37-42.

Mathai, C.K. 1976. Variability in turmeric (*Curcuma* Species) germplasm for essential oil and curcumin. *Qual. Plant-Pl. Fds. Hum. Nutr.* **25**: 227-230.

Mauney, J.R., Fry, K.E. and Guinn, G. 1978. Relationship of photosynthetic rate to growth and fruiting of cotton, soybean, sorghum and sunflower. *Crop Sci.* **18**: 259-263.

Mauney, J.R., Guinn, G., Fry, K.E. and Hesketh, J.D. 1979. Correlation of photosynthetic carbon dioxide uptake and carbohydrate accumulation in cotton, soybean, sunflower and sorghum. *Photosynthetica* **13**: 260-266.

Mc Clure, W.F. 1969. Spectral characteristics of tobacco in the near infra-red region from 0.6 to 2.6 microns. *Tob. Sci.* **13**: 232-235.

Mc Collum, R.E. 1978. Analysis of potato growth under different P regimes. II. Time by P-status interactions for growth and leaf efficiency. *Agron. J.* **70**(1): 58-67.

Mead, R. and Willey, R.W. 1980. The concept of a 'land equivalent ratio' and advantages in yields from intercropping. *Exp. Agric.* **16**: 217-228.

Meyling, H.D.G. 1973. Effect of light intensity, temperature and day-length on the rate of leaf appearance of maize. *Neth. J. Agric. Sci.* **21**: 68-76.

Milford, G.F.J. and Pearman, I. 1975. The relationship between photosynthesis and the concentrations of carbohydrates in the leaves of sugar beet. *Photosynthetica* **9**: 78-83.

Milthorpe, F.L. and Moorby, J. 1967. The growth of the potato. *Proc. 3rd Trienn. Conf. Eur. Ass. Potato. Res., Zurich,* 1966. pp. 51-70.

Milthorpe, F.L. and Moorby, J. 1974. *An Introduction to Crop Physiology.* Cambridge Univ. Press, Cambridge. pp. 92-98.

Monteith, J.L. 1977. Climate and the efficiency of crop production in Britain. *Phil. Trans. Royal Soc. London,* B, **281**: 277-294.

Monteith, J.L. 1981. Does light limit crop production. In: Johnson, C.B. (ed). *Physiological Process Limiting Plant Productivity*. Butterworths, London, pp. 23-38.

Moorby, J. 1968. The influence of carbohydrates and mineral nutrient supply on the growth of potato tubers. *Ann. Bot.* *32*: 57-68.

Moorby, J. 1970. The production, storage and translocation of carbohydrates in developing potato plants. *Ann. Bot.* *34*: 297-308.

Moorby, J. and Milthorpe, F.L. 1975. Potato. In: Evans, L.T. (ed). *Crop Physiology - Some Case Histories*. Cambridge University Press, Cambridge. pp. 225-257.

Nafziger, E.D. and Koller, H.R. 1976. Influence of leaf starch concentration on CO_2 assimilation in soybeans. *Plant Physiol.* *57*: 560-563.

Nair, M.R.G.K. 1982. Pests of ginger and turmeric. *Proc. National Symp. on Ginger and Turmeric*. CPCRI 8-9 April, 1980, Calicut, India. pp. 102-103.

Nair, P.K.R. 1979. *Intensive Multiple Cropping with coconuts in India: Principles, Programmes and Prospects*. Verlag Paul Parey, Berlin, and Hamburg.

Nair, P.K.R. and Balakrishnan, T.K. 1976. Pattern of light interception by canopies in a coconut+cacao crop combination. *Indian J. Agric. Sci.* *46*: 453-462.

Nair, P.K.R. and Balakrishnan, T.K. 1977. Microclimate of a coconut+cacao crop combination on the west coast of India. *Agric. Meteorol.* *18*: 455-462.

Nass, H.G. 1973. Determination of characters for yield selection in spring wheat. Can. J. Plant. Sci. 53: 755-762.

Nasyrov, Y.S. 1978. Genetic control of photosynthesis and improving of crop productivity. Ann. Rev. Pl. Physiol. 29: 215-237.

Natarajan, M. and Willey, R.W. 1980. Sorghum-pigeon pea intercropping and the effect of plant population density. 2. Resource use. J. Agric. Sci., Camb. 95: 59-65.

Necas, J. 1965. Application of growth analysis to potatoes in field culture and some specific features of potato growth. Biol. Plant. 7: 180-193.

Necas, J. 1968. Growth analytical approach to the analysis of yielding capacity of potato varieties. Photosynthetica 2: 85-100.

Nelliat, E.V., Bavappa, K.V.A. and Nair, P.K.R. 1974. Multistoreyed cropping - new dimension of multiple cropping in coconut plantations. World Crops. 26: 262-266.

Nichiporovich, A.A. 1969. The role of plants in the bio-regenerative systems. Ann. Rev. Pl. Physiol. 20: 185-208.

Nichiporovich, A.A. 1970. Biological bases of plant productivity. In: Stubbe, H. (ed). Die Kulturpflanze. Akademie-Verlag, Berlin. pp. 73-108.

Nichiporovich, A.A., Strogonova, L.E., Chimova, S.N. and Vlasova, M.P. 1961. Fotosinteticheskoye Deyatel 'nost' Rastenii *v* Posevakh. (Photosynthetic Activity of Plants in Crops). *Izdat Akad*. *Nauk*. SSSR, Moskva.

Nicholas, J.C., Harper, J.E. and Hageman, R.H. 1976. Nitrate reductase activity in soybean (*Glycine max* (L.) Merr). 1. Effects of light and temperature. *Plant Physiol*. *58*: 731-735.

Nosberger, J. and Humphries, E.C. 1965. The influence of removing tubers on dry matter production and net assimilation rate of potato plants. *Ann*. *Bot*. N.S. *29*: 579-588.

Ołech, K. and Blamowski, Z.K. 1978. Formation of the assimilation area and biomass by sugar beet plants. *Acta*. *Agrobot*. *31*: 21-32.

Palmer, J.W. 1977. Light transmittance by apple leaves and canopies. *J*. *Appl*. *Ecol*. *14*: 505-513.

Palmer, J.W. and Jackson, J.E. 1977. Seasonal light interception and canopy development in hedgerow and bed system apple orchards. *J*. *Appl*. *Ecol*. *14*: 539-549.

Pandey, R.K., Saxena, M.C. and Singh, V.B. 1978. Growth analysis of black gram genotypes. *Indian* *J*. *Agric*. *Sci*. *48* (8): 466-473.

Papendick, R.I., Sanchez, P.A. and Triplett, G.B. (eds). 1976. *Multiple Cropping*. Am. Soc. Agron. Madison, Wisconsin.

Patterson, D.T., Duke, S.O. and Hoagland, R.E. 1978a. Effects of irradiance during growth on adaptive photosynthetic characteristics of velvet leaf and cotton. *Plant Physiol*. *61*: 402-405.

Patterson, D.T., Meyer, C.R. and Quimby, Jr. P.C. 1978b. Effects of irradiance on relative growth rates, net assimilation rates and leaf area partitioning in cotton and three associated weeds. *Plant Physiol*. **62**: 14-17.

Pearce, R.B., Brown, R.H. and Blaser, R.E. 1965. Relationship between leaf area index, light interception and net photosynthesis in orchard grass. *Crop Sci*. **5**: 553-556.

Peet, M.M., Bravo, A., Wallace, D.H. and Ozbun, J.L. 1977. Photosynthesis, stomatal resistance and enzyme activities in relation to yield of field-grown dry bean varieties. *Crop Sci*. **17**: 287-293.

Potter, J.R. and Jones, J.W. 1977. Leaf area partitioning as an important factor in growth. *Plant Physiol*. **59**: 10-14.

Power, J.F., Willis, W.O., Grunes, D.L. and Reichman, G.A. 1967. Effect of soil temperature, phosphorus and plant age on growth analysis of barely. *Agron. J.* **59**: 231-234.

Pushparajah, E. and Wong, W.P. 1970. Cultivation of groundnuts and maize as intercrops in rubber. In: Blencowe, E.K. and Blencowe, J.W. (eds). *Crops Diversification in Malaysia*. pp. 53-65.

Pyare Lal, Reddy, G.G. and Modi, M.S. 1978. Accumulation and redistribution pattern of dry matter and N in triticale and wheat varieties under water stress conditions. *Agron. J.* **70**: 623-626.

Radford, P.J. 1967. Growth analysis formulae, their use and abuse. *Crop Sci*. *7*: 171-174.

Rama Rao, M., Ramakrishna Reddy, K. and Subbarayudu, M. 1975. Promising turmeric types of Andhra Pradesh. *Indian Spices*. *12*: 2-5.

Rao, M.R. and Willey, R.W. 1980. Evaluation of yield stability in intercropping: Studies on sorghum/pigeon pea. *Exp*. *Agric*. *16*: 29-40.

Rao, M.R. and Willey, R.W. 1983. Effects of genotype in cereal/pigeon pea intercropping on the alfisols of the semi-arid tropics of India. *Exp*. *Agric*. *19*: 67-78.

Rawson, H.M. and Evans, L.T. 1971. The contribution of stem reserves to grain development in a range of wheat cultivars of different height. *Aust*. *J*. *Agric*. *Res*. *22*: 851-863.

Roy, R.N. and Wright, B.C. 1974. Sorghum growth and nutrient uptake in relation to soil fertility. II. N, P and K uptake pattern by various plant parts. *Agron*. *J*. *66*: 5-10.

Sale, P.J.M. 1973a. Productivity of vegetable crops in a region of high solar input. I. Growth and development of potato. *Aust*. *J*. *Agric*. *Res*. *24*: 733-749.

Sale, P.J.M. 1973b. Productivity of vegetable crops in a region of high solar input. II. Yields and efficiencies of water use and energy. *Aust*. *J*. *Agric*. *Res*. *24*: 751-762.

Sale, P.J.M. 1976. Effect of shading at different times on the growth and yield of the potato. *Aust. J. Agric. Res. 27*: 557-566.

Sale, P.W.G. and Campbell, L.C. 1980. Patterns of mineral nutrient accumulation in soybean seed. *Field Crops Res. 3*: 157-163.

San Jose, J.J. and Mayobre, F. 1982. Quantitative growth relationships of cassava (*Manihot esculenta* Crantz): Crop development in a Savanna wet season. *Ann. Bot. 50*: 309-316.

Santa-Cecilia, F.C. and Vieira, C. 1978. Associated cropping of beans and maize. I. Effects of bean cultivars with different growth habits. *Turrialba 28*: 19-23.

Satheesan, K.V. Gururaja Rao, G., Sethuraj, M.R. and Raghavendra, A.S. 1983. Canopy photosynthesis in rubber (*Hevea brasiliensis*): Characteristics of leaves in relation to light interception. *Proc. Sixth Int. Congr. Photosynthesis*, Brussels, 1983. (in press).

Schepers, A. and Sibma, L. 1976. Yield and dry matter content of early and later potatoes as affected by monoculture and mixed cultures. *Potato Res. 19*: 73-90.

Schlubach, H.H. 1961. Der Kohlenhydratstoffwechsel in Roggen und Weizen. *Fortschr. Chem. Org. Naturst. 19*: 291-315.

Scott, H.D. and Batchelor, J.T. 1979. Dry weight and leaf area production rates of irrigated determinant soybeans. *Agron*. *J*. *71*(5): 776-782.

Searle, P.G.E., Comudom, Y., Shedden, D.C. and Nance, R.A. 1981. Effect of maize + legume intercropping systems and fertilizer nitrogen on crop yields and residual nitrogen. *Field Crops Res*. *4*: 133-145.

Sestak, Z. 1971. Determination of chlorophyll *a* and *b*. In: Sestak, Z., Catsky, J. and Jarvis, P.G. (eds). *Plant Photosynthetic Production*. *Manual of Methods*. Dr. W. Junk Publishers, The Hague. pp. 672-701.

Sharma, A.K., Singh, B.B. and Singh, S.P. 1982. Relationships among NAR, LAI and yield in soybean (*Glycine max* (L.) Merrill) genotypes. *Photosynthetica* *16* (1): 115-118.

Shibles, R.M. and Weber, C.R. 1965. Leaf area, solar radiation interception and dry matter production by soybeans. *Crop Sci*. *5*: 575-577.

Shibles, R.M. and Weber, C.R. 1966. Interception of solar radiation and dry matter production in various soybean planting patterns. *Crop Sci*. *6*: 55-59.

Sibma, L. 1968. Growth of closed green crop surfaces in the Netherlands. *Neth*. *J*. *Agric*. *Sci*. *16*: 211-216.

Sibma, L. 1970. Relation between total radiation and yield of some field crops in the Netherlands. *Neth*. *J*. *Agric*. *Sci*. *18*: 125-131.

Sivakumar, M.V.K. and Shaw, R.H. 1978. Methods of growth analysis in field grown soybeans. Ann Bot. 42 (177): 213-222.

Sivakumar, M.V.K. and Virmani, S.M. 1980. Growth and resource use of maize, pigeon pea and maize/pigeon pea intercrop in an operational research watershed. Exp. Agric. 16: 377-386.

Sivaraman Nair, P.C. 1982. Agronomy of ginger and turmeric. Proc. Natn. Seminar on Ginger and Turmeric, 8-9 April, 1980, CPCRI, Calicut, India. pp. 63-68.

Smith, H. 1981. Adaptation to shade. In: Johnson, C.B. (ed). Physiological Processes Limiting Plant Productivity, Butterworths, London. pp. 159-173.

Spence, J.A. 1970. Growth and development of tannia (Xanthosoma spp.). Proc. Int. Symp. Trop. Root. Tuber Crops. 2nd, 1970. 1: 47-52.

Spence, J.A. and Humphries, E.C. 1972. Effect of moisture supply, root temperature and growth regulators on photosynthesis of isolated root leaves of sweet potato (Ipomoea batatas). Ann. Bot. N.S. 36: 115-121.

Spiertz, J.H.J. 1974. Grain growth and distribution of dry matter in the wheat plant as influenced by temperature, light energy and ear size. Neth. J. Agric. Sci. 22: 207-220.

Stewart, G.A. 1970. High potential productivity of the tropics for cereal crops, grass forage crops and beef. J. Aust. Inst. Agric. Sci. 36: 85-101.

Stoutjesdijk, P.H. 1972. Spectral transmission curves of some types of leaf canopies with a note on seed germination. *Acta Bot. Neerl.* *21*: 185-191.

Suckling, P.W., Davies, J.A. and Proctor, J.T.A. 1975. The transmission of global and photosynthetically active radiation within a dwarf apple orchard. *Can. J. Bot.* *53*: 1428-1441.

Swaminathan, M.S. 1970. New varieties for multiple cropping. *Indian Fmg.* *20*(7): 9-13.

Tarhalkar, P.P. and Rao, N.G.P. 1975. Changing concepts and practices of cropping systems. *Indian Fmg.* *25*: 3-15.

Tehlan, R.S., Singh, R.K. and Sharma, S.C. 1979. Impact of growth and dry matter production pattern on yield of wheat. *Proc. 5th Int. Wheat Genet. Symp.* New Delhi. pp. 1004-1009.

Thomas, J.R., Wiegand, C.L. and Myers, V.I. 1967. Reflectance of cotton leaves and the relation to yield. *Agron. J.* *59*: 551-554.

Thorne, G.N. 1971. Physiological factors limiting the yield of arable crops. In: Wareing, P.F. and Cooper, J.P. (eds). *Potential Crop Production*. Heinemann, London. pp. 143-158.

Thorne, G.N. and Evans, A.F. 1964. Influence of tops and roots on net assimilation rate of sugar beet and spinach beet and grafts between them. *Ann. Bot.* *28*: 499-508.

Thorne, G.N. and Watson, D.J. 1955. The effect on yield and leaf area of wheat of applying nitrogen as a top dressing in April or in sprays at ear emergence. *J. Agric. Sci. 46*: 449-456.

Thornley, J.H.M. and Hurd, R.G. 1974. An analysis of the growth of young tomato plants in water culture at different light integrals and CO_2 concentrations. II. A mathematical model. *Ann. Bot. 38*: 389-400.

Tolbert, N.E. 1960. (2-Chloroethyl) trimethyl ammonium chloride and related compounds as plant growth substances. II. Effect on growth of wheat. *Plant Physiol. 35*: 380-385.

Trenbath, B.R. 1974. Biomass productivity of mixtures. *Adv. Agron. 26*: 177-210.

Trenbath, B.R. 1981. Light-use efficiency of crops and the potential for improvement through intercropping. *Proc. Int. Workshop on Intercropping*, ICRISAT, 10-13 January, 1979, Hyderabad, India. pp. 141-154.

Trenbath, B.R. and Angus, J.F. 1975. Leaf inclination and crop production. *Field Crops Abstr. 5*: 231-244.

Tsuno, Y. 1971. *Sweet Potato : Nutrient Physiology and Cultivation*. Int. Potash Inst. Berne, Switzerland.

Tsuno, Y. and Fujise, K. 1965a. Studies on dry matter production of sweet potato. *Bull. Nat. Inst. Agric. Sci.* D. *13*: 1-131, Tokyo, Japan.

Tsuno, Y. and Fujise, K. 1965b. Studies on the dry matter production of sweet potato. VIII. The internal factors influencing the photosynthetic activity of sweet potato leaf. *Proc. Crop Sci. Soc.* Japan. *33*(3): 230-235.

Udayakumar, M., Devendra, R., Sreenivasa Reddy, V. and Krishna Sastry, K.S. 1981. Nitrate availability under low irradiance and its effect on nitrate reductase activity. *New Phytol.* *88*: 289-297.

Umbreit, W.W., Burris, R.H. and Stauffer, J.S. 1964. *Manometric Techniques*. Burgess Publishing Co., Minneapolis.

Varghese, P.T., Nair, P.K.R., Nelliat, E.V., Rama Varma and Gopala Sundaram, P. 1978. Intercropping with tuber crops in coconut gardens. In: *Proc.* *PLACROSYM I*, Kasaragod, India. pp. 399-415.

Walker, D.A. 1980. Regulation of starch synthesis in leaves - the role of orthophosphate. In: *Physiological Aspects of Crop Productivity*. Int. Potash, Inst. Berne. pp. 195-207.

Wallace, D.H. and Munger, H.M. 1965. Studies of physiological basis for yield differences - growth analysis of six dry bean varieties. *Crop Sci.* *5*: 343-348.

Wardlaw, I.F. 1971. The early stages of grain development in wheat: Response to water stress in a single variety. *Aust.* *J.* *Biol.* *Sci.* *24*: 1047-1055.

Wareing, P.F. 1971. Potential crop production in Britain - Some conclusions. In: Wareing, P.F. and Cooper, J.P. (eds). *Potential Crop Production*, Heinemann, London. pp. 362-378.

Wareing, P.F. and Patrick, J. 1975. Source-sink relations and the partition of assimilates in the plant. In: Cooper, J.P. (Ed). *Photosynthesis and Productivity in Different Environments*. Camb. Uni. Press., Cambridge. pp. 481-499.

Wassink, E.C. 1968. Light energy conversion in photosynthesis and growth of plants. In: Eckardt, F.E. (ed). *Functioning of Terrestrial Ecosystems at the Primary Production Level*. *Proc*. *Copenhagen Symp*. UNESCO. pp. 53-66.

Watson, D.J. 1947. Comparative physiological studies on the growth of field crops. I. Variation of net assimilation rate and leaf area between species and varieties and within and between years. *Ann*. *Bot*. N.S. *11*: 41-76.

Watson, D.J. 1952. The physiological basis of variation in yield. *Adv*. *Agron*. *4*: 101-145.

Watson, D.J. 1958. The dependence of net assimilation rate on leaf area index. *Ann*. *Bot*. N.S. *22*: 37-54.

Watson, D.J. 1968. A prospect of crop physiology. *Ann*. *Appl*. *Biol*. *62*: 1-9.

Watson, D.J. 1971. Size, structure and activity of the productive system of crops. In: Wareing, P.F. and Cooper, J.P. (eds). *Potential Crop Production*. Heinemann, London, pp. 76-88.

Watson, D.J., Thorne, G.N. and French, S.A.W. 1963. Analysis of growth and yield of winter and spring wheats. *Ann*. *Bot*. N.S. *27*: 1-21.

Watson, D.J. and Witts, K.J. 1959. The net assimilation rates of wild and cultivated beets. Ann. Bot. N.S. 23: 431-439.

Wholey, D.W. and Cock, J.H. 1974. Onset and rate of root bulking in cassava. Exp. Agric. 10: 193-198.

Wien, H.C. and Smithson, J.B. 1981. The evaluation of genotypes for intercropping. In: Proc. Int. Workshop on Intercropping, ICRISAT, 10-13 January, 1979, Hyderabad, India. pp. 105-116.

Wierzbicki, B. 1980. Intermittent light as physiological and ecological factor of photosynthesis of pine and spruce. Acta Physiol. Plant. 2: 69-80.

Wilhelm, W.W. and Nelson, C.J. 1978. Growth analysis of tall fescue genotypes differing in yield and leaf photosynthesis. Crop Sci. 18: 951-954.

Willey, R.W. 1979a. Intercropping - its importance and its research needs. Part I. Competition and yield advantages. Field Crop Abstr. 32: 1-10.

Willey, R.W. 1979b. Intercropping - its importance and its research needs. Part II. Agronomic relationships. Field Crop Abstr. 32: 73-85.

Willey, R.W. 1981. A scientific approach to intercropping research. In: Proc. Int. Workshop on Intercropping, 10-13 January, 1979, ICRISAT, Hyderabad, India. pp. 4-14.

Willey, R.W. and Holliday, R. 1971a. Plant population and shading studies in barley. J. Agric. Sci. 77: 445-452.

Willey, R.W. and Holliday, R. 1971b. Plant population, shading and thinning studies in wheat. *J. Agric. Sci.* *77*: 453-461.

Willey, R.W. and Osiru, D.S.O. 1972. Studies on mixtures of maize and beans (*Phaseolus vulgaris*) with particular reference to plant population. *J. Agric. Sci.* Camb. *79*: 517-529.

Williams, C.N. 1972. Growth and productivity of tapioca (*Manihot utillissima*) III. Crop ratio, spacing and yield. *Exp. Agric.* *8*: 15-23.

Williams, W.A., Loomis, R.S., Duncan, W.G., Dovrat, A. and Nunez, A. 1968. Canopy architecture at various population densities and the growth and grain yield of corn. *Crop Sci.* *8*: 303-308.

Williams, W.A., Loomis, R.S. and Lepley, C.R. 1965a. Vegetative growth of corn as affected by population density. I. Productivity in relation to interception of solar radiation. *Crop Sci.* *5*: 211-215.

Williams, W.A., Loomis, R.S. and Lepley, C.R. 1965b. Vegetative growth of corn as affected by population density. II. Components of growth, net assimilation rate and leaf area index. *Crop Sci.* *5*: 216-219.

Wilson, J.W. 1981. Analysis of growth, photosynthesis and light interception for single plants and stands. *Ann. Bot.* *48*: 507-512.

Woods, D.B. and Turner, N.C. 1971. Stomatal responses to changing light by four tree species of varying shade tolerance. *New Phytol*. *70*: 77-84.

Yoshida, S. 1972. Physiological aspects of grain yield. *Ann*. *Rev*. *Pl*. *Physiol*. *23*: 437-464.

Young, D.R. and Smith, W.K. 1980. Influence of sunlight on photosynthesis, water relations and leaf structure in the understorey species *Arnica cordifolia*. *Ecology* *61*: 1380-1390.

Zavitkovski, J. 1982. Characterization of light climate under canopies of intensively cultured hybrid poplar plantations. *Agric*. *Meteorol*. *25*: 245-155.