PHOTOSYNTHETIC EFFICIENCY, GROWTH, YIELD AND QUALITY OF TURMERIC (*Curcuma longa* L.) UNDER DIFFERENT SHADE LEVELS

By

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THESIS

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DECLARATION

I hereby declare that this thesis entitled **"Photosynthetic efficiency, growth, yield and quality of turmeric (*Curcuma longa* L.) under different shade levels"** is a *bonafide* record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

JOSEPH LOUIS

Vellayani,
3-1-2001.

CERTIFICATE

Certified that this thesis entitled **"Photosynthetic efficiency, growth, yield and quality of turmeric (*Curcuma longa* L.) under different shade levels"** is a record of research work done independently by **Mr. JOSEPH LOUIS** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to him.

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LIST OF ABBREVIATIONS

cm	–	centimetre
m	–	metre
g	–	gram
t	–	tonne
s	–	second
kg	–	kilogram
μ	–	micro
mg	–	milligram
mm	–	millimetre
mol	–	mole
CO_2	–	carbon-dioxide
O_2	–	oxygen
ha	–	hectare
°C	–	degree celsius
Fig.	–	figure
KAU	–	Kerala Agricultural University
DAP	–	days after planting
MAP	–	months after planting
DMP	–	dry matter production
LAI	–	leaf area index
LAD	–	leaf area duration
CGR	–	crop growth rate
NAR	–	net assimilatory rate
RGR	–	relative growth rate
HI	–	harvest index
BR	–	bulking rate
SLW	–	specific leaf weight
NADP	–	nicotine adenine - diphosphate
PAR	–	photosynthetically active radiation

INTRODUCTION

1. INTRODUCTION

Turmeric is an export oriented rhizomatous spice crop. India is the largest producer, with a production of 6.59 lakh tonnes from an area of 1.47 lakh hectare. The annual earnings from turmeric comes to Rs. 461 million (George, 1997). The global demand of turmeric by 2000 AD is estimated as 31,000 tonnes (Peter, 1996). It is one of the most important spice crops, extensively used by all classes of people. It is one of most ancient and traditional items of export as well.

The Indian turmeric industry is emerging stronger year after year with its increased production capabilities and range of products. The healing property of turmeric is long acknowledged by practitioners of traditional medicine and scientists working in the US and Britain have discovered evidence to backup claims that turmeric acts as an anti-cancer agent (Anonymous, 1994).

Possibility of area expansion under monocropping in Kerala is limited. Therefore, utilizing the shaded situation under coconut is one feasible approach to achieve the target growth rate of nine per cent (Chadha and Rethinam, 1994). The interspaces of the coconut in Kerala with 9.76 lakh hectare can be utilised for the cultivation of turmeric (FIB, 2000).

Findings of shade studies on coconut based intercropping situations, rated turmeric as a shade tolerant crop and hence suitable for intercropping in coconut gardens (KAU, 1992). The degree of shade tolerance of turmeric is an important factor in determining the production of photosynthates, its partitioning into economically and harvestable yield components. Studies have shown that the yield of turmeric at 25 per cent shade was on par with open condition (Jayachandran *et al.*, 1992). The present study was intended to assess the performance of various morphological, physiological and biochemical parameters, yield and productivity as indicators of shade tolerance in turmeric cultivars when grown under different shade levels.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

Turmeric is an export oriented spice crop which is cultivated along with other perennial plantation crops mostly as intercrop because of its shade tolerant / loving nature. There is only scanty information regarding the growth and productivity of turmeric as influenced by factors like light and microclimate. The growth and development of any crop at any time depends on the amount of light energy intercepted by the crop (Watson, 1958). The three major characters of light namely light intensity, quality of light and duration of light has pronounced effect on photosynthetic production and partitioning of photosynthates for various metabollic activities including partitioning to harvestable yield components (Gifford and Evans, 1981; Bunce, 1986 and Dare, 1988).

The review of literature includes other rhizomatous crops in addition to turmeric. Information about the tuber crops is also included.

2.1 Morphological characters

2.1.1. Growth characters

2.1.1.1. Plant height

Bai and Nair (1982) observed a positive influence of shading on the stem length of ginger. Susan (1989) reported an increase in plant height upto 50 per cent shade beyond which it decreased both in ginger and turmeric. A similar trend in plant height was observed in turmeric (KAU, 1992). In ginger, plant height was found to increase in shade intensity from zero to 75 per cent (Jayachandran *et al.*, 1991). According to Ancy (1992) the plant height in ginger went on increasing with increasing shade levels (25, 50 and 75 per cent). The plant height under open condition was the lowest. Increase in plant height with increase with shade intensities at all stages of growth in ginger (except 60 DAP) was reported by Beena (1992). The highest plant height was observed under 75 per cent shade and lowest under open condition.

Soyabean grown under 70 per cent shade grew much taller than those in the light (Allen, 1975). Tarila *et al.* (1977) reported that high intensity of light reduced plant height in cowpea. Positive influence of shade on plant height was reported in cassava (Ramanujam *et al.*, 1984; Sreekumari *et al.*, 1988), in broad bean (Xia, 1987) and in Colocasia (Prameela, 1990).

Ginger plants grown under full sunlight were found to be shorter compared to shaded plants (Aclan and Quisumbing, 1976). Though no significant difference was observed between shade levels with respect to plant height in turmeric, taller plants were observed at 75 per cent shade in the initial stages and at 50 per cent shade in the later stages (Sheela, 1992). The plant height in ginger was lowest under open condition and it showed an increasing trend with increasing shade intensities at all growth stages (Babu, 1993). A general increasing trend in plant height with increasing shade intensity from 0 to 80 per cent was observed in ginger cv. Rio-De-Janeiro at all growth stages (Sreekala, 1999).

2.1.1.2. Tillering habit

Bai (1981) and Susan (1989) reported increase in the tillering habit at higher light intensity in ginger and turmeric. Some depressing effect of shade on tillering in turmeric was also noticed (KAU, 1992). Decrease in the number of tillers with increasing levels of shade in turmeric was reported by Susan (1989) and Jayachandran *et al.* (1992). However, in colocassia there was no significant reduction in tiller production with respect to increasing levels of shade (Prameela, 1990). According to Aclan and Quisumbing (1976) tillering was not affected by shade in ginger. In ginger cv. Rio-De-Janerio significantly higher tiller production capacity was noticed by Ancy (1992) under 25 per cent shade at 120 and 180 DAP. The lower tiller production capacity was exhibited under heavy shade. Beena (1992) reported that the tiller production in ginger cv. Rio-De-Janerio was maximum at 25 per cent shade. With regard to number of tillers, no significant difference was observed in the tillering habit between the shade levels, cultivars and shade x cultivar interaction (Sheela, 1992). The tillering habit in ginger was maximum at 25 per cent shade level (Babu, 1993). Beena (1992) observed no significant effect of shade on tiller production in ginger cultivars.

Sreekala (1999) reported less tiller production under higher shade intensities in ginger.

2.1.1.3. Number of leaves

Aclan and Quisumbing (1976) reported reduced number of leaves per tiller in ginger grown under full sunlight compared to different levels of shade. Susan (1989) observed a decrease in the number of leaves with shading in ginger and turmeric. Sannamarappa and Shankar (1988) reported no significant variation in leaf number of turmeric due to intercropping in arecanut. There was no significant effect of shading on number of leaves (KAU, 1992). In a shade study at Vellayani, Ancy (1992) observed maximum number of leaves per plant in ginger under 25 per cent shade at all the growth stages and the lowest number of leaves were recorded at 75 per cent shade. Plants in the open recorded more number of leaves and shade levels had significant effect on number of leaves in turmeric only at 120 DAP (Sheela, 1992). The leaf production in ginger was maximum under 25 per cent shade and was found to be significantly superior to other shade levels at 120 DAP and 180 DAP (Babu, 1993).

In cassava, the leaf number decreased when grown under shade in coconut garden (Sreekumari *et al.*, 1988). The clove seedlings kept under shade produced more number of leaves than seedlings exposed to sun (Venkataraman and Govindappa, 1987). Leaf production in ginger under 20 per cent shade was found to be significantly superior compared to other shade levels (Sreekala, 1999).

2.1.1.4. Leaf area

Ginger plants grown under 20 and 40 per cent shade levels produced higher leaf area at all growth stages but minimum leaf area was noticed in plants grown under open condition (Sreekala, 1999). On contrary to this finding, Bai (1981) reported that leaf area was not influenced by different intensities of shade in ginger, turmeric and coleus. Increased leaf area under reduced light intensity was reported in ginger by Ravisankar and Muthuswamy (1988), Ancy (1992) and George (1992). According to Babu (1993) maximum leaf area was produced under 25 per cent shade and minimum under open condition at 120 and 180 DAP.

2.1.2. Root characters

2.1.2.1. Root length

Root and bud growth are usually inhibited by low light intensities and this can lead to a reduction in assimilate flow to the root system (Nelson, 1964). In an experiment to study the effect of defoliation, shading and competition on spotted knap weed (*Centaurea maculosa* Lam.) the foliage, root and crown growth increased significantly when plants received full, rather than half light (Kennett *et al.*, 1992).

Sreekala (1999) observed minimum root length from ginger plants grown under open condition. According to Cannon (1911), Weaver (1920) and Weaver and Crest (1922), the depth of penetration of root system depended on the depth to which the soil was wetted. In open condition, evapotranspiration is more and hence the retention of water in the soil is less. But under shaded conditions, the retention of water at the depth was more and this can result in more root length. According to Jayachandran (1993), the number of roots originating from the first daughter rhizomes was more than from the later produced daughter rhizomes.

2.1.2.2. Root spread

The influence of shade on root activity pattern of cocoa was studied in Ghana (IAEA, 1975). In the absence of shade, the root activity was found to be considerably higher than in its presence. Without shade, root activity appeared to be higher at 90 cm distance from the tree whereas under shade, zones of higher root activity seemed to be more widespread. The root spread was found to be maximum at 20 per cent shade in ginger (Sreekala, 1999).

2.1.2.3. Root weight

The growth index and total leaf, stem and root dry weights were inversely related to light level (Andersen *et al.*, 1991). Ginger plants grown under heavy shade produced more root dry weight compared to medium and low shade (Sreekala, 1999).

2.1.2.4. Root volume

Potted plants of sugarcane when grown under light conditions in a glass house, showed a high quantum of root production. When light was partially cut off through unbleached muslin, the root volume decreased to about 50 per cent. A further reduction in light intensity produced roots which were barely able to support the growth of the plants (Martin and Eckart, 1933). At all shade levels, root volume per plant was found to be more in ginger plants grown under 80 per cent shade up to 120 DAP (Sreekala, 1999).

2.1.3. Rhizome characters

2.1.3.1. Rhizome spread

According to Ancy (1992), rhizome spread of ginger at 50 per cent shade was found to be significantly higher than that under 0 and 25 per cent shade, but was on par with that under heavy shade. Babu (1993) reported higher rhizome spread at 25 per cent shade than 50 and 75 per cent shade levels. According to him, rhizome spread under 75 per cent shade was superior to 50 per cent and open. The rhizome spread was the lowest in ginger plants grown under open condition (Sreekala, 1999).

2.1.3.2. Rhizome thickness

Sreekala (1999) reported that the shade level of 20 per cent was found to be favourable for the accumulation of carbohydrates and this may have resulted in more rhizome thickness.

2.2. Physiological parameters

2.2.1. Dry matter production

The maximum amount of dry matter production by a crop was strongly correlated with the amount of light intercepted by its foliage (Monteith, 1977). Higher dry matter production under shade was noticed in *Xanthosoma sagittifolium* (Caesar, 1980). Venkataraman and Govindappa (1987) reported that coffee seedlings kept under shade produced more total dry matter compared to those exposed to sun. Prameela (1990) reported highest dry matter production in colocasia at 25 per cent shade level and there was a drastic reduction in dry matter production at 50 and 70 per cent shade, the extent of decrease being 22 and 27 per cent respectively of DMP at zero per cent. Soyabean plants grown under 70 per cent shade did not show any reduction in dry matter production (Erikson and Whitney, 1984).

According to Bai and Nair (1982), dry matter production in ginger followed a quadratic pattern with the maximum value lying between 25 and 50 per cent shade levels. Ravisankar and Muthuswamy (1986) recorded an increased level of dry matter production with decreased light intensity in ginger. This was further confirmed by Susan (1989), who recorded the highest dry matter production at 25 per cent shade in ginger. Ancy (1992) observed significant variation among shade levels with respect to dry matter production. Shade levels 25 and 50 per cent were found to be on par with each other but significantly superior to 0 and 75 per cent shade levels, both at 135 and 180 DAP, the extent of decrease being 17.8 and 22.2 per cent respectively of that under open condition. Babu (1993) observed that ginger plants under low shade (25 per cent) produced highest dry matter and plants under heavy shade (75 per cent) produced the lowest DMP. Dry matter production in turmeric increased with increasing shade intensity upto 50 per cent shade and then declined (Sheela, 1992). Sreekala (1999) reported that the maximum dry matter production was from plants grown under 20 per cent shade, followed by plants grown under open condition at 150 and 180 DAP.

2.2.2. Crop growth rate

Crop growth rate of cassava grown under shade was reduced significantly when compared to those plants grown under normal light (Ramanujam and Jose, 1984). The effect of two weeks of 50 per cent shading of potato beginning on days 0, 14 and 28 after the onset of tuberization and six weeks of shade beginning on day zero were studied (Struik, 1986). Shading slowed down leaf development, stolen initiation, tuberization, tuber growth, maturation and reduced CGR. However stem growth and CGR were increased after shading was removed. Early shading of potato cv. Rose increased yield of large tubers and reduced yield of small tubers (Struik, 1986). Ramadasan and Satheesan (1980) reported highest crop growth rate with three turmeric cultivars grown in open condition compared to shaded condition. Ancy (1992) and Babu (1993) observed significantly superior crop growth rate under 25 per cent shade. Maximum CGR was reported from ginger plants grown under 20 per cent shade followed by plants grown under open condition (Sreekala, 1999). The maximum individual CGR recorded in the study conducted by Whiley (1980) in ginger was 39.7 g m^{-2} day^{-1}.

2.2.3. Relative growth rate (RGR)

Jadhav (1987) reported a positive correlation of RGR with shade in rice. Shade levels 60 and 80 per cent recorded low values of RGR in ginger plants during all stages except between 60-90 DAP (Sreekala, 1999).

2.2.4. Net assimilation rate (NAR)

Blackman and Wilson (1951), Newton (1963) and Coombe (1966) reported a positive correlation in crop plants between NAR and irradiance. According to Pandey *et al.* (1980) NAR of chickpea was found to decrease in reduced light intensities. Ramanujam and Jose (1984) also observed reduced NAR of cassava grown under shade compared to those plants grown under normal light. A low rate of NAR under shade was also reported in sweet potato (Laura *et al.*, 1986). In ginger NAR under 25 and 50 per cent shade levels were significantly high but showed a drastic decrease under heavy shade (Ancy, 1997). Beena (1992) found significant difference in NAR between shade levels at both 60 and 120 DAP. The highest value of NAR was observed at 50 per cent shade in ginger.

In ginger, NAR showed a decreasing trend with increasing shade intensities during 60-120 DAP and during 120-180 DAP (Babu, 1993). Twenty five per cent shade registered a significantly higher NAR than other shade levels. In turmeric no significant difference on NAR was observed between shade levels, cultivar and shade x cultivar interactions both at 120 and 180 DAP (Sheela, 1992). NAR increased with increase in shade in ginger (Bai, 1981). Ravisankar and Muthuswamy (1986) reported a significant negative correlation of NAR with light intensity in ginger raised in arecanut garden. NAR was not affected by shading in turmeric (KAU, 1992). Ramadasan and Satheesan (1980) reported highest NAR with three turmeric cultivars grown in open condition compared to those in shaded conditions. Sreekala (1999) reported that shade level beyond 20 per cent showed less NAR in ginger.

2.2.5. Specific leaf weight (SLW)

Duncan grapefruit, pineapple and sweet orange seedlings were grown in full sunlight, 50 and 90 per cent shade and the SLW was highest in full sunlight in fully expanded matured leaves and lowest in 90 per cent shade (Syvertsen and Smith, 1984). Sreekala (1999) reported that ginger grown under open condition recorded more SLW when compared to other shade levels.

2.2.6. Leaf area index (LAI)

Low leaf area index was observed at high light intensities in crops like cotton (Bhat and Ramanujam, 1975) and rice (Janardhan and Murthy, 1980). Sorenson (1984) observed higher leaf area ratio with higher shade intensity in winged bean. In satsuma mandarin orange, reduced light intensity increased specific leaf area and leaf area index (Ono and Iwagaki, 1987). Ramadasan and Satheesan (1980) recorded highest LAI grown in open compared to shade conditions with three turmeric cultivars. According to Bai (1981) leaf area indices of ginger and turmeric were observed to be not influenced by different shade intensities. A higher leaf area index was reported by Ravisankar and Muthuswamy (1986) when ginger was grown as an intercrop in six year old arecanut plantation. Ancy (1992) observed that LAI was significantly lower under open condition compared to other shade levels in all growth stages. The highest leaf area index was recorded for ginger plants grown under 20 per cent shade and lowest under open condition (Sreekala, 1999). LAI was not affected by shading in turmeric (KAU, 1992). As an intercrop, Rio-De-Janeiro recorded the highest LAI of 7.287 and was on par with Nedumangadu (Nizam, 1995).

2.2.7. Leaf area duration (LAD)

According to Babu (1993) highest leaf area duration was observed from ginger plants grown under 25 per cent shade followed by 50 and 75 per cent shade. The leaf area duration was lowest under open conditions. A similar trend was observed in ginger by Sreekala (1999).

2.2.8. Harvest Index (HI)

Prameela (1990) recorded highest harvest index at 25 per cent shade in colocassia and with further increase in shade levels, the harvest index decreased significantly. Susan (1989) observed no significant difference between shade levels with respect to harvest index in ginger and turmeric. The highest harvest index was observed in ginger under open condition.

Ancy (1992) observed a steady decrease in harvest index with increase in shade levels in ginger. However George (1992) recorded highest harvest index in ginger at 25 per cent shade which was comparable with open condition. In ginger, the highest harvest index was noticed from plants grown under open condition and it showed a decreasing trend with increasing shade intensity (Babu, 1993). According to Sheela (1992), shade levels and cultivars of turmeric had no significant effect on the harvest index and the highest value of 0.65 was noticed at 75 per cent shade level. A reduction in harvest index with increasing intensities of shade was reported in ginger (Bai, 1981). In ginger, the harvest index decreased with shade indicating that the partitioning factors are involved in reducing yield beyond the optimum shade (Bai and Nair, 1982). In turmeric, the similar trends of dry matter production and yield response to shade indicate that the photosynthetic factors might play a dominant role in deciding the response of turmeric to shade. Harvest index of ginger plants grown under 20 per cent shade was significantly superior when compared to other shade levels (Sreekala, 1999).

2.2.9. Root shoot ratio

Growth and leaf physiology responses of container grown'Arkin' carambola (*Averrhoea carambola* L.) trees to long term exposure of approximately 25, 50 and 100 per cent sunlight was studied. Trees in full sun had smaller total leaf area, canopy diameter and shoot-root ratio (Marler, *et al.*, 1994).

2.3. Photosynthetic rate and related parameters

2.3.1. Photosynthetic rate

Understanding the photosynthetic carbon contribution to vegetative and reproductive processes is important in defining yield and productivity (Gifford *et al.*, 1984). Light intensity has variable effects on plant morphology, carbohydrate allocation and yield (Mc Marten *et al.*, 1987). Photosynthesis and partitioning of photysynthates into economically important plant parts are primary determinants of plant yield. According to Hardy (1958) shade loving plants had a threshold illumination, beyond which the stomata tends to close. A linear relationship between photosynthesis and light intensities was reported by Gastra (1963).

It has been known for a long time that plants which occupy shaded habitats are incapable of high photosynthetic rate, but they perform efficiently at low light intensities. Since synthesis, translocation, partitioning and accumulation of photosynthetic products within the plant are controlled genetically and influenced by the environment, the yields are likely to be increased by genetic manipulation by identifying plants having both greater sink capacity and growth duration (Monteith, 1977). Adaptation to low light intensity includes greater leaf area per leaf weight ratio (Blackman, 1956), reduced shoot to root ratio (Brouwer, 1966) and reduced rate of transpiration (Kumura, 1968). The photosynthetic rate was greatly reduced in shade in crops like alfalfa (Wolf and Blaser, 1972), bean (Crookston *et al.*, 1975), grapes (Vasundara, 1981), cotton (Singh, 1986) and potato (Singh, 1988).

Ginger appeared to be efficiently utilising low light intensity for its photochemical reaction (Minoru and Hori, 1969). A positive influence of shade on photosynthesis and organic matter accumulation had been reported in the case of ginger and turmeric (Bai and Nair, 1982).

According to Tao and Zhang (1986) the net photosynthetic rate of the plants at 28°C increased with light intensity and the light saturation as well as the light compensation points of shaded plants were lower than that of unshaded plants. Though the photosynthetic efficiency of plant under open condition at higher light intensity was slightly above that of shaded plants, their photorespiration at 80 klx, 34-38°C and 40-60 per cent RH were higher so that the net photosynthetic rate decreased markedly.

Miginiac Maslow *et al.* (1990) reported that high light intensity warms the leaves and may increase the respiration. If warming become too high, the temperature rise may be sufficient to cause thermal inactivation of enzymes like NADP malate dehydrogenase and other chloroplast enzyme. This was reported in many crops like peas, maize and spinach. According to Kochhar (1978), direct strong sunlight may cause photo-oxidation with the use of O_2 and release of CO_2 which reduces the photosynthetic efficiency.

2.3.2. Leaf temperature

Excessive leaf temperature limited the yield of tea under shade condition (Habfield, 1968). Sreekala (1999) reported that leaf temperature did not show much significant variation under different shade levels.

2.3.3. Stomatal conductance

High light intensity during growth increased the stomatal frequency but there was no significant changes either in the length of the stomatal pore or the size of the guard cell. The changes in stomatal frequency and therefore the maximum stomatal pore per unit area of leaf correlated with the maximum stomatal conductance (Holmgren, 1968; Bjorkman *et al.*, 1972). For example, *Atriplex* leaves grown under high light intensity showed a three fold increase in stomatal conductance over leaves grown at the low light intensity (Bjorkman *et al.*, 1972). A four fold increase in stomatal conductance was observed for *Panicum maximum* at high light intensity (Ludlow and Wilson, 1971).

Acuba japonica (Thumb.) cv. *variegata* were exposed under conditions of full sun and shade over two years. Two days after treatment initiation net CO_2 assimilation was proportional to light level, although stomatal conductance to water vapour was not influenced by shading (Andersen *et al.*, 1991). Dewelle *et al.* (1978) measured the difference in stomatal conductance and gross photosynthesis among clones of potato and reported that changes in stomatal conductance and CO_2 assimilation do not show a direct correlation. Sreekala (1999) reported that there is a tendency of ginger plants to decrease the stomatal conductance with increase in shade levels.

2.3.4. Stomatal resistance

The stomatal resistance of a number of plant species with differing light saturated rates of photosynthesis was measured. The minimum stomatal resistance for CO_2 at ambient CO_2 concentration varied widely from an average of 0.72 sec cm^{-1} for *Circaca lutetiana*, a species which grows in shaded wood lands (Holmgreen *et al.*, 1965). Studies on cultivar resistance to transpiration influenced by different intensities of shade (25, 30 and 75 %) in tea clones revealed that there was progressive increase in cultivar resistance with increasing intensities of shade (Harikrishnan and Sharma, 1980).

Handique and Manivel (1987) recorded lower stomatal resistance in tea under full sun compared to leaves under shade. Bjorkman *et al.* (1972) calculated the dependence of CO_2 uptake on the stomatal resistance for *Atriplex* leaves and concluded that resistance of the stomata to CO_2 diffusion in the plants grown at the different light intensities imposed only a minor restriction on their photosynthetic rates in normal air. Sreekala (1999) reported that the least stomatal resistance in ginger was recorded from open condition.

2.4. Biochemical

2.4.1. Chlorophyll (a, b and total)

According to Shirley (1929) shaded leaves generally had an enhanced chlorophyll level per unit weight. Seybold and Egle (1937) observed an increase in chlorophyll 'b' content under low light intensity. The concentration of chlorophyll per unit area or weight in leaves increased with increase in light intensity until the intensity was low for the plant to survive (Gardner *et al.*, 1952). An increase in chlorophyll content with increase in shade levels was reported by Evans and Murran (1953) in cocoa, Bhat and Ramanujam (1975) in cotton. Singh (1988) reported an increased leaf chlorophyll content in potato under 25 per cent of normal sunlight. The total chlorophyll content in the leaves of unshaded plants of black pepper were found to be 44 per cent less than the contents present in the shaded leaves (Vijayakumar and Mammen, 1990).

The chlorophyll contents of tea shoots grown under the shade trees were significantly higher than those from unshaded plots (Mahanta and Baruah, 1992).

Nii and Kurowia (1988) studied the anatomical changes including chloroplast structure in peach leaves under different light conditions and found that chlorophyll content per unit leaf area and per dry weight increase with shading. Shade leaf chloroplasts (10 and 25 per cent of full sun) were larger and rich in thylakoids, while sun leaf chloroplasts (50 and 100 per cent of full sun) showed poorly stacked grana. Liu *et al.* (1984) suggested high chlorophyll a + b and low a/b ratio as a selection parameter for efficient photosynthesis at low light. Lower chlorophyll a/b ratios are typical of shade ecotypes and may enable more efficient absorption of light under shade conditions due to the difference in the absorption spectra of chlorophyll a and b and the variance in light quality in the under storey (Boardman, 1977; Young and Smith, 1980).

Susan (1989) and George (1992) found that chlorophyll and its fractions (Chlorophyll a and b) of ginger increased steadily with increasing levels of shade at Vellanikkara. In a shade study in ginger at Vellayani, Ancy (1992) also observed the same trend with respect to chlorophyll content. An increase in the chlorophyll content in the shaded leaves of ginger and turmeric was reported by Bai (1981). Ravisankar and Muthuswamy (1988) observed higher content of total chlorophyll and its components in ginger grown in two years and six year old arecanut plantations compared to those grown in pure stand in the open. Total chlorophyll and its components increased steadily with increasing levels of shade at 135 DAP (Sheela, 1992). Chlorophyll 'a', chlorophyll 'b' and total chlorophyll were found to show significant increasing trend with increasing shade intensities (Babu, 1993).

Summary Report of ICAR Ad-hoc scheme on shade studies on coconut based intercropping situations conducted from 1988 to 1991 at Vellanikkara, indicated an increase in chlorophyll of turmeric due to shading (KAU, 1992). Sreekala (1990) reported that there is a general increasing trend in chlorophyll content with increasing shade levels. The lower chlorophyll content in sun leaves may be attributed to the decomposition of chlorophyll under intense light intensities (Kochhar, 1978). The increase in chlorophyll content under shade conditions is an adaptive mechanism commonly observed in plants to maintain the photosynthetic efficiency (Attridge, 1990). Satheesan and Ramadasan (1992) observed that all the three turmeric cultures namely Cl.no. 24, CII. 328 and Duggirala had higher chlorophyll b and lower chlorophyll a/b ratio under intercropping system.

2.5. Yield and yield components

2.5.1. Rhizome yield

The environmental factors under which plants grows control the productivity of the plant to a great extent. Of the various environmental factors light is one which has much influence on the growth and productivity of the plant (Bindra and Brar, 1977).

Severe reduction in yield due to shading was reported in many crops like maize (Earely *et al.*, 1966), sorghum (Pepper and Prine, 1972), rice (Rai and Murthy, 1977 and Vijayalakshmi *et al.*, 1987) and soyabean (Wahua and Miller, 1978). In potato, shading at the beginning of tuber initiation reduced the rate of tuber formation and growth while shading during the early stages had no effect on the number of tubers, though it reduced the final yield (Gracy and Holmer, 1970).

Positive influence of shade on yield was reported in many crops. Moon and Pyo (1981) reported highest fresh weight at 35 per cent shade in chinese cabbage, lettuce and spinach beyond which the performance was poor than those in full sunlight. In tannia highest yield was recorded under 25 per cent shade with an almost equal yield at 50 per cent shade (Pushpakumari, 1989).

Aclan and Quisumbing (1976) observed no significant difference in rhizome yield among ginger plants grown under full sunlight, 25 per cent and 50 per cent shade. But heavier shading of 75 per cent reduced the yield. Bai and Nair (1982) observed that the optimum shade appears to be 25 per cent and 50 per cent for ginger and turmeric considering the total dry weight and rhizome yield. Susan (1989) obtained the highest yield in ginger at 25 per cent shade. According to Jayachandran *et al.* (1991) ginger cv. Rio-De-Janerio is a shade loving plant producing higher yield under low shade intensity of 25 per cent and comparable yield with that of open under medium shade.

Ancy (1992) recorded the highest ginger yield under 25 per cent shade followed by 50 per cent, 0 per cent and 75 per cent respectively. The highest ginger yield was from 25 per cent shade followed by 50 per cent, 75 per cent and 0 per cent respectively (Babu, 1993). Plants in the open were significantly inferior to those under shade and the highest yield of ginger was recorded both at 25 per cent and 50 per cent shade on fresh and dry weight basis respectively (Beena, 1992).

Ravisankar and Muthuswamy (1988) observed that fresh rhizome yield increased when ginger was grown as an intercrop in arecanut plantation. Jayachandran *et al.* (1992) revealed that the yield of turmeric at 25 per cent shade was on par with that under open condition. On analysing the performance of different turmeric cultivars at varying shade intensities, all the cultivars were found to be better at 50 per cent shade above which there was a declining trend in yield (Sheela, 1992). A negative correlation of shade with yield was reported in turmeric by Ramadasan and Satheesan (1980). Sreekala (1999) reported that the green ginger yield under open condition and 40 per cent shade was on par.

2.5.2. Top yield

Ancy (1992) reported that the top yield of ginger was lowest in the open and significantly low compared to all other shade levels. With decrease in light intensity, there was a progressive increase in top yield upto 50 per cent shade. Top yield under 25 and 75 per cent shade was found to be on par. According to Babu (1993) the top yield of ginger was significantly higher under 25 per cent shade and the lowest under open condition but the trend was like, 25 per cent recorded highest followed by 75, 50 and 0 per cent shade. The top yield in ginger at 20 per cent shade is on par with open condition (Sreekala, 1999).

2.5.3. Bulking rate

According to Ancy (1992) at both growth phases (90-135 DAP and 135-180 DAP) bulking rate was found to be maximum under 25 per cent shade and was significantly superior to all other shade levels except in the second growth phase (135-180 DAP), where 25 per cent shade was found to be on par with 50 per cent. Bulking rate was significantly low under 75 per cent shade at both growth phases. Babu (1993) observed bulking rate to be maximum under 25 per cent shade at growth phases, 60-120 DAP and 120-180 DAP. Sreekala (1999) reported that the maximum bulking rate of ginger was from 20 per cent shade.

2.6. Quality analysis

2.6.1. Volatile oil

Light regimes received by plant determine the productivity and quality of its produce (Tikhnomirov *et al.*, 1976). The quality of products of tea, coffee and cinchona was found to be improved under shaded conditions (Feng, 1982).

According to Ravisankar and Muthuswamy (1987) ginger cv. Rio-de-Janeiro grown as an intercrop in a six year old arecanut plantation recorded highest volatile oil and non-volatile ether extract contents followed by those grown in two year old arecanut plantation compared to those grown in the open. Contrary to this finding, Susan (1989) reported a steady decrease in the oleoresin content upto 50 per cent levels of shade. According to Beena (1992), an increase in volatile oil content was seen in ginger with increase in shade intensity, but the content of oleoresin was higher under open and 25 per cent shade than under intense shade. While Ancy (1992) recorded highest volatile oil content under 25 per cent shade in ginger, Babu (1993) recorded the lowest content of volatile oil from 25 per cent shade which was on par with open. However, with further increase in shade, the volatile oil was found to increase. Ancy and Jayachandran (1993) reported a positive correlation of non-volatile ether extract with shade intensity of 50 per cent. However, shade intensity beyond 50 per cent decreased the yield.

2.6.2. Curcumin content

Curcurmin content in turmeric rhizome showed a progressive decrease with increase in shade (Susan, 1989). Satheesan and Ramadasan (1987) observed higher curcumin content in turmeric cultivars Duggirala and Cls-24 under intercropping in coconut than under monocropping. The curcumin content was also found to be maximum at 25 per cent shade and showed an increase with increase in potassium level (Jayaraj, 1990). The quality of rhizome in turmeric assessed through percentage of dryage and curcumin content showed improvement under shaded conditions (KAU , 1992). Philip (1983) noticed significant variation in curcumin content among the turmeric varieties tested. The curcumin content was highest at 50 per cent shade while oleoresin content was highest at 75 per cent shade (Sheela, 1992).

MATERIALS AND METHODS

3. MATERIALS AND METHODS

An experiment was laid out at the College of Agriculture, Vellayani, Thiruvananthapuram, Kerala with an objective of studying the biomass production and its partitioning under different shade levels in turmeric cultivars Kanthi, Alleppey and Sobha.

3.1 Experimental site

The experiment was conducted at the Instructional Farm, College of Agriculture, Vellayani situated at 8°5' North latitude and 77°1'E longitude and at an altitude of 29 m above mean sea level.

3.1.1 Season

The field experiment was conducted from July 1998 to March 1999.

3.2 Materials

3.2.1 Planting Material

Turmeric cultivars Kanthi, Alleppey and Sobha were used for the experiment. Healthy disease and pest free rhizome bits weighing 15g was used as planting material.

3.2.2 Manuring

The recommended fertilizer dose of 30 : 30 : 60 kg N, P_2O_5 and K_2O per hectare and cattle manure as basal dose at 40 t/ha as per package of practices (KAU, 1996) was applied.

3.2.3 Mulching

The crop was mulched immediately after planting with green leaves at the rate of 15 t ha^{-1} and it was repeated for a second time after 50 days (KAU, 1996).

3.3 Methods

3.3.1 Layout of the experiment

The experiment was laid out in split - plot design with four shade levels as main plots and three varieties as sub plots. The number of replications was four (Fig. 1).

3.3.2 Seed treatment

Rhizome bits each weighing 15 g were treated with a combination of Indofil M 45 0.3 per cent and 0.5 per cent Malathion for 30 minutes. After the treatment the rhizome bits were dried under shade, by spreading them on a clean floor.

REPLICATION - I

S_1V_1	S_3V_2	S_2V_3	S_0V_2
S_1V_3	S_3V_3	S_2V_2	S_0V_1
S_1V_2	S_3V_1	S_2V_1	S_0V_3
Shade level 25%	Shade level 75%	Shade level 50%	Shade level 0%

REPLICATION - II

S_3V_2	S_2V_3	S_1V_2	S_0V_1
S_3V_1	S_2V_2	S_1V_3	S_0V_3
S_3V_3	S_2V_1	S_1V_1	S_0V_2
Shade level 75%	Shade level 50%	Shade level 25%	Shade level 0%

REPLICATION - III

S_2V_2	S_1V_1	S_3V_1	S_0V_2
S_2V_3	S_1V_2	S_3V_2	S_0V_3
S_2V_1	S_1V_3	S_3V_3	S_0V_1
Shade level 50%	Shade level 25%	Shade level 75%	Shade level 0%

REPLICATION - IV

S_3V_2	S_2V_3	S_0V_3	S_2V_1
S_3V_1	S_2V_2	S_0V_1	S_2V_2
S_3V_3	S_2V_1	S_0V_2	S_2V_3
Shade level 75%	Shade level 50%	Shade level 0%	Shade level 25%

Number of replications : 4
Number of main plot factors : 4
Number of sub plot factors : 3

S_0 - open condition
S_1 - 25% shade
S_2 - 50% shade
S_3 - 75% shade

V_1 - Kanthi
V_2 - Alleppey
V_3 - Sobha

Fig. 1. Layout plan - Split plot design

3.3.3 Planting

Treated rhizome bits were planted at a depth of five cm with buds facing upwards at a spacing of 25 x 30 cm and covered with soil.

3.3.4 Artificial shading

Three shade levels (25, 50 and 75 per cent) were provided by using high density polyethylene nets spread over pandals. Quantum photosensors was used for calibration of the shade.

3.3.5 Aftercare

Hand weeding was done as and when necessary.

3.3.6 Plant protection

No disease was observed but there was the incidence of shoot borer (*Conogethes punctiferalis*) in the early stages which was effectively controlled by spraying 0.05 per cent dimethoate.

3.3.7 Harvest

Destructive sampling was done at bimonthly intervals starting from two months after planting of crop for taking different observations. At 180 DAP, potted turmeric plants were taken to Central Tuber Crops Research Institute for measuring photosynthetic rate and related parameters using leaf chamber analyser, under required shade levels. At final harvest the yield of turmeric was recorded.

3.4 Observations

Random sampling method was adopted. For recording the different biometric observations at bimonthly intervals five plants were selected at random as observation plants, pre-harvest observations started 2 MAP and continued upto 8 MAP.

3.4.1 Morphological parameters

3.4.1 Growth characters

3.4.1.1 Plant height

The height of the plant was measured at bimonthly intervals from 2 MAP from the base of the main pseudostem to the top of the top most leaf and plant height was expressed in cm.

3.4.1.2 Number of tillers

Number of tillers were determined by counting the number of aerial shoots arising around a single plant at bimonthly intervals from 2 MAP.

3.4.1.3 Number of leaves

Number of leaves were determined by counting the number of leaves of all the tillers at bimonthly intervals from 2 MAP.

3.4.1.4 Leaf area

The length and width of leaves were measured at bimonthly intervals from 2 MAP and the leaf area in cm^2 was calculated based on the length and breadth method.

The following relationship was utilised for computing the leaf area (Randhawa, G.S., *et al.*, 1985).

Y = 4.09 + 0.564 (Length x breadth)

where Y = leaf area

length = length of the leaf in cm

breadth = breadth of the leaf in cm

3.4.1.5 Leaf weight

Dry weight of the leaf was taken at bimonthly intervals from 2 MAP after drying the leaves at hot air oven at 70°C. It is expressed in g $plant^{-1}$.

3.4.1.6 Leaf thickness

Leaf thickness at bimonthly intervals from 2 MAP was measured by using micrometer and expressed in mm.

3.4.1.7 Root characters

3.4.1.7.1 Root length

The plants were uprooted at bimonthly intervals from 2 MAP and maximum length of roots was measured and mean length expressed in cm.

3.4.1.7.2 Root spread

Root spread was measured at bimonthly intervals from 2 MAP by placing the root system on a marked paper and measuring the spread of the root system at its broadest part. The root spread is expressed in cm.

3.4.1.7.3 Root weight

Roots separated from individual plants at bimonthly intervals from 2 MAP was taken and dried in shade and its weight was then taken and expressed in g $plant^{-1}$.

3.4.1.7.4 Root volume

Root volume per plant was found at bimonthly intervals from 2 MAP by displacement method and expressed in cm^3 $plant^{-1}$.

3.4.1.8 Rhizome characters

3.4.1.8.1 Rhizome spread

The horizontal spread of rhizome was measured at bimonthly intervals from 2 MAP and expressed in cm.

3.4.1.8.2 Rhizome thickness

Rhizome thickness was measured at monthly intervals from 2 MAP using micrometer and expressed in cm.

3.4.1.8.3 Number of finger rhizomes / plant

Number of finger rhizomes per plant was also counted excluding the mother rhizome at bimonthly intervals from 2 MAP.

3.4.1.9 Physiological

3.4.1.9.1 Dry matter production (DMP)

Leaves, petioles, pseudostem, rhizomes and roots of the uprooted plants were separated and dried to a constant weight at 70°C in a hot air oven at bimonthly intervals from 2 MAP. The sum of these individual components gave the total dry matter production of the plant and expressed as g plant^{-1}.

3.4.1.9.2 Crop growth rate (CGR)

Crop growth rate was worked out using the formula of Watson (1958) at bimonthly intervals form 60 DAP and expressed as g m^{-2} day^{-1}.

CGR = NAR x LAI

3.4.1.9.3 Relative growth rate (RGR)

RGR was calculated as per the method of Blackman (1919) at bimonthly intervals from 2 MAP and is expressed as g day^{-1}

$$RGR = \frac{\log_e W_2 - \log_e W_1}{t_2 - t_1}$$

where w_1 and w_2 are total dry weights per plant at time t_1 and t_2 respectively.

3.4.1.9.4 Net assimilation rate (NAR)

The procedure given by Watson (1958) as modified by Buttery (1970) was followed in calculating the NAR at bimonthly intervals from 60 DAP. The following formula was used to derive NAR and expressed in g m^{-2} day^{-1}.

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

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

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

t_2-t_1 = time interval in days

A_2 = Leaf area index at time t_2

A_1 = Leaf area index at time t_1

3.4.1.9.5 Specific leaf weight (SLW)

Specific leaf weight was assessed at bimonthly intervals from 2 MAP by dividing the individual leaf dry weight by corresponding leaf area. It is expressed as g cm^{-2}.

3.4.1.9.6 Leaf area index (LAI)

Leaf area index was calculated at bimonthly intervals from 2 MAP. Five sample plants were randomly selected for each treatment and the number of leaves on each plant was counted. Maximum length and maximum width of leaves from all the sample plants were recorded separately and leaf area was calculated based on length and breadth method.

$$LAI = \frac{\text{Sum of leaf area of N sample plants } (cm^2)}{\text{Area of land covered by N plants } (cm^2)}$$

3.4.1.9.7 Leaf area duration (LAD)

Leaf area duration was calculated using the formula given by Pomer *et al.* (1967) at bimonthly intervals from 60 DAP.

$$LAD = \frac{Li + (Li + 1) \times (t_2 - t_1)}{2}$$

where

Li = LAI at first stage

Li + 1 = LAI at second stage

$t_2 - t_1$ = Time interval between these stages

3.4.1.9.8 Leaf temperature

Leaf temperature was measured using portable photosynthesis system (LCA-4) and expressed in °C.

3.4.1.9.9 Stomatal conductance

Stomatal conductance was measured using portable photosynthesis system (LCA-4) and expressed in mol m^{-2} s^{-1}.

3.4.1.9.10 Harvest index (HI)

Harvest index was calculated at final harvest as

$$HI = \frac{Y\ econ.}{Y\ biol.}$$

where

Y econ. = total dry weight of rhizome

Y biol. = total dry weight of plant

3.4.1.9.11 Root / shoot ratio

Root / shoot ratio was calculated as the ratio between the average of root dry weight and shoot dry weight of each plant at bimonthly intervals from 2 MAP.

3.4.2 Biochemical

3.4.2.1 Chlorophyll (a, b and total)

Chlorophyll a, chlorophyll b and total chlorophyll content of leaves were estimated 180 DAP. Spectrophotometric method as described by Starves and Hadley (1965) was used to estimate the chlorophyll content and expressed in mg g^{-1}.

3.4.2.2 CO_2 uptake

CO_2 uptake was recorded at 180 DAP. Photosynthetic rate and related parameters were also measured using portable photosynthesis system (LCA-4) and expressed in μ mol mol^{-1}.

3.4.3 Yield and yield components

3.4.3.1 Rhizome yield

The yield of fresh rhizome from each treatment was recorded at 240 DAP and expressed as g plant^{-1}.

3.4.3.2 Top yield

The yield of above ground portion in individual treatment was recorded at 8 MAP and expressed in g plant^{-1} on dry weight basis.

3.4.3.3 Bulking rate

Bulking rate was worked out at bimonthly intervals from 60 DAP on the basis of increase in dry weight of rhizome and expressed in g plant^{-1} day^{-1}.

$$BR = \frac{w_2 - w_1}{t_2 - t_1}$$

where

w_1 = dry weight of rhizome at time t_1

w_2 = dry weight of rhizome at time t_2

3.4.4 Quality analysis

3.4.4.1 Volatile oil

The content of volatile oil was estimated by Clevenger distillation method (A.O.A.C., 1975) and expressed as percentage (v/w) on dry weight basis.

3.4.4.2 Curcumin content

The curcumin content of the rhizomes was estimated by the official analytical method suggested by ASTA (American Spice Trade Association, 1968) using ethanol and expressed as percentage on moisture free basis.

$$\% \text{ of curcumin} = \frac{x \times 0.25 \times 25 \times 100 \times 100}{0.42 \times 1000 \times 0.1 \times 1}$$

x = optical density.

RESULTS

4. RESULTS

The results of the field experimentation and chemical analysis on the biomass production and partitioning of photosynthates in turmeric under different shade levels are presented below.

4.1 Morphological

4.1.1 Growth characters

4.1.1.1 Plant height

The data presented in Table 1 shows the effect of shade levels and varieties on plant height. The effect of shade levels (0, 25, 50 and 75 per cent) on plant height was significant (Table 1). The open condition was found to be inhibitive to the growth of the crop in terms of height. The variety Alleppey at 25 per cent level attained maximum height at 2MAP (19.57 cm) which was on par with Sobha at the same shade level. The height of all the three varieties had no significant difference when the higher shade levels were considered. Different levels of shade significantly resulted in height variations. Plants grown under 25 per cent shade were the tallest (17.96 cm). The height of the plants grown under open condition was minimum (10.74 cm). Varietal effects and interactions were insignificant.

Table 1. Effect of shade levels and varieties on height of turmeric plants (cm)

Shade levels	2 MAP				4 MAP				6 MAP				8 MAP			
	Varieties				Varieties				Varieties				Varieties			
	V_1	V_2	V_3	Mean	V_1	V_2	V_3	Mean	V_1	V_2	V_3	Mean	V_1	V_2	V_3	Mean
S_0	13.30	9.18	9.75	10.74	28.20	25.25	25.23	26.23	60.45	61.70	50.83	57.66	62.45	64.13	56.83	61.13
S_1	15.13	19.58	19.20	17.97	27.25	33.60	30.40	30.42	60.55	61.95	59.33	60.61	63.65	64.48	62.95	63.69
S_2	16.68	16.50	15.75	16.31	25.95	30.00	32.40	29.45	64.65	65.60	65.88	65.38	69.60	71.05	70.08	70.24
S_3	17.48	17.93	17.83	17.74	26.75	25.95	27.25	26.65	60.90	62.50	61.56	61.67	64.30	65.55	66.80	65.55
Mean	15.64	15.79	15.63	—	27.04	28.70	28.82	—	61.65	62.94	59.39	—	64.99	66.30	64.16	—
CD (0.05)																
S	1.438 (S)				1.531 (S)				2.624 (S)				2.865 (S)			
V	1.423 (NS)				1.944 (NS)				2.009 (S)				1.896 (NS)			
SV	2.846 (NS)				3.880 (S)				4.019 (S)				3.793 (NS)			

Months after planting

(S) - Significant (NS) - Not significant

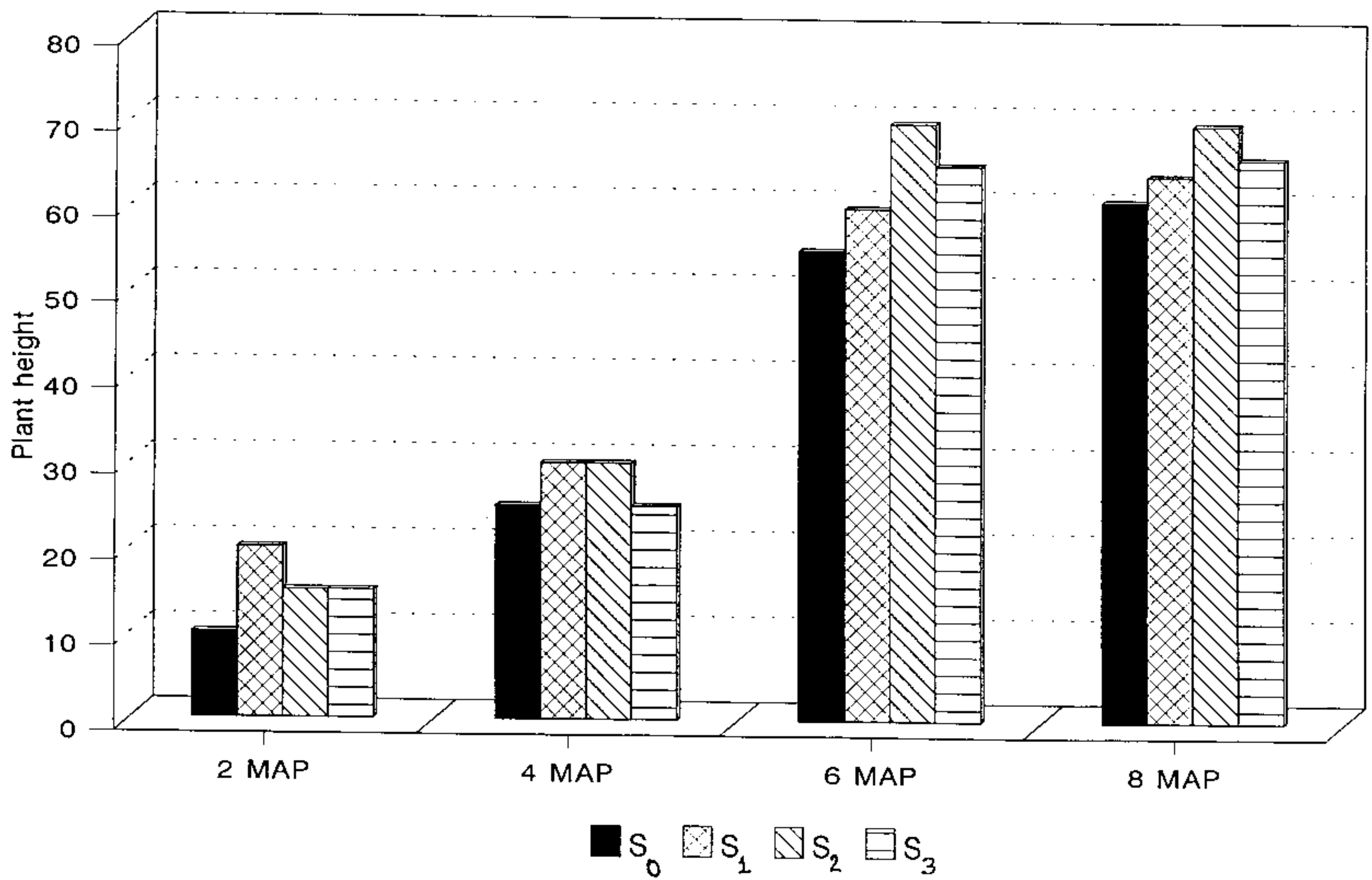


Fig. 2. Effect of shade levels and varieties on plant height (cm)

The performance of the plant at 4 MAP in terms of plant height was maximum at 25 per cent level of shade with a mean height of 30.42 cm and the performance of the plants at 0 per cent and 75 per cent shade levels were on par. Varietal interaction with shade levels was found to be significant. There was significant difference in height among the varieties at 25 per cent and 50 per cent shade levels but it is on par with 0 per cent and 75 per cent shade levels.

There was significant difference in the performance at different shade levels, varieties and shade x variety interaction at 6 MAP. On analysing the data it was found that there was an increase in plant height at 50 per cent shade level while the performance at 25 per cent and 75 per cent shade levels were on par. Height of the plants under open condition was minimum (57.65 cm). Maximum plant height was observed under 50 per cent shade (65.37 cm). Among varieties, Alleppey exhibited the maximum plant height (62.94 cm).

At 8 MAP there was significant effect of shade levels on plant height while varietal effects (shade x varietal) and interactions were not significant. The plant height was found to be maximum at 75 per cent shade (70.24 cm) followed by 50 per cent shade (65.55 cm), 25 per cent shade (63.69 cm) and the lowest (61.13 cm) at open condition.

4.1.1.2. Number of tillers

The data presented in Table 2 show the effect of shade levels and varieties on tiller production.

Table 2. Effect of shade levels and varieties on the number of tillers of turmeric plants

Shade levels	Months after planting															
	2 MAP				4 MAP				6 MAP				8 MAP			
	Varieties				Varieties				Varieties				Varieties			
	V_1	V_2	V_3	Mean	V_1	V_2	V_3	Mean	V_1	V_2	V_3	Mean	V_1	V_2	V_3	Mean
S_0	1.68	1.30	1.20	1.39	3.88	3.90	3.25	3.68	4.50	5.20	3.95	4.50	4.68	5.20	4.10	4.66
S_1	1.78	1.78	1.90	1.82	3.25	3.45	2.95	3.22	6.10	6.25	5.20	5.85	6.20	6.40	5.45	6.02
S_2	1.50	1.50	1.25	1.42	2.40	2.33	2.83	2.52	5.50	5.60	5.58	5.56	5.70	5.68	5.68	5.68
S_3	1.13	1.10	0.85	1.03	2.40	1.88	2.25	2.18	5.48	5.85	6.00	5.78	5.70	6.00	6.17	5.96
Mean	1.52	1.42	1.30	—	2.98	2.89	2.82	—	5.39	5.73	5.18	—	5.57	5.82	5.35	—
CD (0.05)																
S	0.392 (S)				0.847 (S)				0.665 (S)				0.594 (S)			
V	0.271 (NS)				0.384 (NS)				0.465 (NS)				0.383 (NS)			
SV	0.543 (NS)				0.768 (NS)				0.910 (NS)				0.766 (NS)			

(S) - Significant (NS) - Not significant

There was significant effect of shade on the number of tillers, but there was no varietal interaction at 2 MAP. It was found that the effect of shade at 25 per cent had the maximum number of tillers which was 1.81. Both at open condition and at 50 per cent shade, the number of tillers were on par. The lowest number of tillers was recorded at 75 per cent shade. Among the varieties, maximum number of tillers was found to be for the variety Kanthi and the other two varieties namely Sobha and Alleppey were on par. Shade x varietal interaction were insignificant.

The tiller production recorded at 4 MAP under open condition was found to be higher (3.67) followed by 25 per cent shade level (3.21). The effect of shade on the number of tillers was found to be significant at 4 MAP. Variety Alleppey and Kanthi were on par in the number of tiller production in open condition. The lowest number of tiller production was found to be at 75 per cent shade (2.17). Varietal effects and interactions were insignificant.

The tiller production recorded at 6 MAP, at 25 per cent shade was on par with 75 per cent shade level. There was a decline in tiller production at open condition while there was a steady increase in number of tillers at 50 per cent shade level. Varietal effects and interactions were insignificant.

The tiller production at 25 and 75 per cent shade levels measured at 8 MAP was on par. Maximum tillering capacity (6.01) was exhibited by 25 per cent shade level. It was found that the tiller production was at the lowest in open condition Varietal effects and interactions were insignificant.

4.1.1.3. Number of leaves

The data presented in Table 3 show the effect of shade levels and varieties on number of leaves per plant.

Two months after planting, the influence of shade levels (0, 25 and 50 per cent) on leaf production was on par. The plants kept under above shade levels produced 7.23, 7.45 and 7.90 leaves respectively. Maximum number of leaves was recorded at 75 per cent shade level (8.00). The shade and variety interactions are found to be significant. Maximum number of leaves (8.32) was resulted under 75 per cent shade for the variety Alleppey. Effect of shade at 50 per cent and 75 per cent were on par.

The effect of shade on production of leaves measured at 4 MAP was significantly higher at 25 per cent shade compared to other shade levels. Shade levels of 50 and 75 per cent were on par with regard to leaf production. Leaf production was minimum under open condition.

At 6 MAP, shade level of 75 per cent produced maximum number of leaves (19.38) followed by shade level of 50 per cent. The number of leaves produced under open condition was minimum.

The performance of the turmeric plants at 8 MAP was found to show the same trend at 6 MAP where the shade levels of 75 and 50 per cent are found to be on par with a mean values of 19.71 and 19.65. At 25 per cent the number of leaves recorded was 15.50. The least number of leaves produced was under open condition.

Table 3. Effect of shade levels and varieties on the number of leaves of turmeric plants

Shade levels	Months after planting															
	2 MAP				4 MAP				6 MAP				8 MAP			
	Varieties				Varieties				Varieties				Varieties			
	V_1	V_2	V_3	Mean	V_1	V_2	V_3	Mean	V_1	V_2	V_3	Mean	V_1	V_2	V_3	Mean
S_0	6.65	8.00	7.05	7.23	8.93	8.55	7.60	8.36	11.08	12.50	11.20	11.59	15.38	14.38	14.13	14.63
S_1	7.25	7.80	7.30	7.45	10.20	10.75	10.98	10.64	13.70	14.98	15.50	14.73	14.88	15.55	16.08	15.50
S_2	7.48	8.20	8.03	7.90	9.00	9.43	10.83	9.75	19.20	19.25	18.40	18.95	19.40	19.45	20.13	19.66
S_3	8.13	8.33	7.58	8.01	10.10	8.53	8.50	9.04	18.73	20.55	18.88	19.38	19.05	20.90	19.20	19.72
Mean	7.38	8.08	7.49	—	9.56	9.31	9.48	—	15.68	16.82	15.99	—	17.18	17.57	17.38	—
S	0.472 (S)				1.499 (S)				1.911 (S)				1.530 (S)			
V	0.530 (S)				0.694 (NS)				1.020 (NS)				1.192 (NS)			
SV	1.060 (NS)				1.389 (S)				2.041 (NS)				2.385 (NS)			

(S) - Significant (NS) - Not significant

4.1.1.4. Leaf area

The effect of shade levels and varieties on mean leaf area is given in Table 4.

At 2 MAP the effect of shade on leaf area was significant. The maximum leaf area was recorded for S_3 treatment. In the open condition the leaf area recorded was 810.10 cm^2. Treatments S_1 and S_2 gave 685.80 cm^2 and 709.80 cm^2 of leaf areas respectively. Varietal effects of leaf area was significant at 2 MAP. Variety V_2 (Alleppey) recorded the highest leaf area (861.93 cm^2). Interactions were not significant.

At 4 MAP the effect of shade on leaf area was significant. Maximum leaf area was recorded at 25 per cent shade level (2612.65 cm^2) followed by the open condition (2534.30 cm^2). Minimum leaf area was recorded from the S_3 treatment (1822.96 cm^2). Varietal effects was insignificant while interactions (shade x variety) was significant. Treatments S_1V_1 and S_2V_1 were on par. Treatment S_1V_2 (2945.26 cm^2) recorded the highest leaf area. Treatment S_3V_2 (1793.20 cm^2) recorded the lowest leaf area.

At 6 MAP the effect of shade on leaf area was significant. Maximum leaf area (6014.27 cm^2) was recorded from the S_3 treatment. Minimum leaf area (4147.69 cm^2) was recorded from the open condition. At 25 per cent shade level the leaf area was 5087.50 cm^2. Varietal effects and its interactions were insignificant.

At 8 MAP the effect of shade on leaf area was significant. Treatment S_2 (6698.24 cm^2) recorded the maximum leaf area. In the

Table 4. Effect of shade levels and varieties on the leaf area of turmeric plants (cm^2)

Shade levels	Months after planting															
	2 MAP				4 MAP				6 MAP				8 MAP			
	Varieties				Varieties				Varieties				Varieties			
	V_1	V_2	V_3	Mean	V_1	V_2	V_3	Mean	V_1	V_2	V_3	Mean	V_1	V_2	V_3	Mean
S_0	793.20	932.20	704.90	810.10	2833.81	2586.65	2182.50	2534.30	3910.64	4526.16	4006.26	4147.69	5848.07	5623.00	5089.32	5520.13
S_1	696.10	770.90	590.30	685.80	2068.26	2945.26	2824.40	2612.65	4365.42	5375.70	5521.46	5087.50	5069.40	5807.67	5654.40	5510.44
S_2	605.78	788.20	735.70	709.80	2065.23	2150.87	2890.20	2368.79	5337.43	5851.90	5898.01	5695.78	6191.50	6825.25	7077.97	6698.24
S_3	883.50	956.30	736.40	858.70	2102.82	1572.81	1793.20	1822.96	5429.02	6250.15	6363.63	6014.27	5315.65	6577.25	6725.69	6206.19
Mean	744.63	861.93	691.80	—	2267.50	2313.90	2422.60	—	4760.63	5500.98	5447.34	—	5606.12	6208.20	6136.85	—
CD (0.05)																
S	112.810 (S)				448.410 (S)				529.389 (NS)				947.059 (S)			
V	88.160 (S)				406.650 (NS)				780.850 (NS)				782.235 (NS)			
SV	176.300 (S)				813.300 (NS)				1561.701 (NS)				1564.470 (NS)			

(S) - Significant (NS) - Not significant

open condition the leaf area recorded was 5520.13 cm^2. Lowest leaf area of 5510.43 cm^2 was recorded at 25 per cent shade level. Varietal effects and the interactions were insignificant.

4.1.1.5. Leaf weight

The data in Table 5 depict the effect of shade levels and varieties on leaf dry weight.

At 2 MAP, the effect of shade levels on leaf weight was significant. Maximum leaf weight was recorded at 75 per cent shade level (2.61 g $plant^{-1}$) followed by 50 and 25 per cent. However, the leaf weight of plants grown under 50 and 25 per cent shade levels was on par. The lowest leaf weight of 1.47 g/plant was recorded at open condition. The effect of variety and its interaction (shade x variety) was not significant.

At 4 MAP, the leaf weight of the crop under different shade levels was found to follow a trend similar to that at 2 MAP where the shade level of 75 per cent recorded the maximum leaf weight of 5.08 g/plant followed by 50 per cent shade level (4.92 g/plant). The lowest leaf weight (3.38 g/plant) was recorded for open condition. Varietal effect was not significant. Shade x variety interaction was also not significant.

Both at 6 MAP and 8 MAP, the trend in leaf weight was found to be similar to that of the earlier periods (2 MAP and 4 MAP). At 6 MAP, the maximum leaf weight (11.11 g $plant^{-1}$) was at 75 per cent shade level and lowest at open condition (9.85 g $plant^{-1}$) and at 8 MAP, the maximum

Table 5. Effect of shade levels and varieties on the leaf weight (g plant^{-1}) of turmeric plants

Shade levels	2 MAP				4 MAP				6 MAP				8 MAP			
	Varieties				Varieties				Varieties				Varieties			
	V_1	V_2	V_3	Mean	V_1	V_2	V_3	Mean	V_1	V_2	V_3	Mean	V_1	V_2	V_3	Mean
S_0	1.39	1.45	1.59	1.48	3.23	3.50	3.42	3.38	9.85	9.87	9.35	9.69	10.13	9.98	9.55	9.88
S_1	1.75	1.85	1.80	1.80	4.55	4.05	4.40	4.33	10.44	10.20	9.45	10.03	10.53	10.95	10.38	10.62
S_2	2.70	2.18	2.13	2.33	4.53	5.30	4.95	4.93	11.58	11.30	10.60	11.16	11.88	11.65	11.03	11.52
S_3	2.69	2.68	2.45	2.61	4.95	5.38	4.93	5.08	13.21	13.08	10.45	10.25	13.28	13.93	11.55	12.92
Mean	2.13	2.04	1.99	—	4.31	4.56	4.42	—	11.27	11.11	9.96	—	11.45	11.63	10.63	—
CD (0.05)																
S	0.209 (S)				0.645 (S)				0.482 (S)				0.636 (S)			
V	0.259 (NS)				0.544 (NS)				0.645 (S)				0.629 (S)			
SV	0.518 (NS)				1.088 (NS)				1.290 (NS)				1.259 (NS)			

Months after planting

(S) - Significant (NS) - Not significant

leaf weight was recorded at 75 per cent shade level (12.91 g/plant) followed by 50 and 25 per cent shade levels. The lowest leaf dry weight was recorded at open condition. At 6 MAP, the varieties V_1 and V_2 were on par (11.11 and 11.27) while the variety V_3 recorded a leaf weight of 9.96 g/plant. At 8 MAP, the varieties V_1 and V_2 were on par while the variety V_3 recorded a leaf weight of 10.62 g/plant. Interaction at both 6 and 8 MAP was not significant.

4.1.1.6. Leaf thickness

The data presented in Table 6 indicate the effect of shade levels and varieties on the leaf thickness.

Effect of shade on leaf thickness at 2 MAP was found to be significant. Effect of shade levels on the leaf thickness of turmeric plants grown under open condition (5.31) and 25 per cent (5.41) were on par. There was no significant effect of varieties on leaf thickness and all the varieties were found to be on par at 2 MAP. Lowest leaf thickness was recorded at 50 per cent shade level (5.0 mm). Interactions (shade x variety) were not significant.

At 4 MAP the effect of shade on leaf thickness was not significant. Leaf thickness was found to be maximum at 25 per cent shade level (6.61 mm) while leaf thickness was found to be on par at 0 per cent and 50 per cent shade. The lowest leaf thickness was recorded at 75 per cent shade. There was no varietal influence on leaf thickness where all the varieties were found to be on par. Shade x variety interaction was not significant.

Table 6. Effect of shade levels and varieties on the leaf thickness (mm) of turmeric plants

Shade levels	Months after planting															
	2 MAP				4 MAP				6 MAP				8 MAP			
	Varieties				Varieties				Varieties				Varieties			
	V_1	V_2	V_3	Mean	V_1	V_2	V_3	Mean	V_1	V_2	V_3	Mean	V_1	V_2	V_3	Mean
S_0	5.38	5.13	5.43	5.31	6.20	6.08	6.00	6.09	7.00	7.08	7.10	7.06	9.18	9.28	9.45	9.30
S_1	5.48	5.35	5.40	5.41	6.63	6.65	6.58	6.62	7.68	7.35	7.83	7.62	10.55	9.75	11.23	10.50
S_2	4.98	4.93	5.10	5.00	5.95	6.10	6.03	6.03	6.90	7.13	7.03	7.02	8.93	9.48	9.15	9.18
S_3	5.33	5.08	5.00	5.13	6.03	6.13	5.80	5.98	7.05	7.48	7.25	7.26	8.78	9.00	8.90	8.89
Mean	5.29	5.12	5.23	—	6.20	6.24	6.10	—	7.16	7.26	7.30	—	9.36	9.38	9.68	—
CD (0.05)																
S	0.410 (NS)				0.543 (NS)				0.610 (NS)				1.048 (S)			
V	0.254 (NS)				0.229 (NS)				0.216 (NS)				0.578 (NS)			
SV	0.509 (NS)				0.459 (NS)				0.433 (NS)				1.157 (NS)			

(S) - Significant (NS) - Not significant

At 6 MAP, the effect of shade on leaf thickness was not significant. Leaf thickness was found to be maximum at 25 per cent shade. There is not much significant variation in leaf thickness for the other three shade levels and also there is no significant variation in the leaf thickness among the three varieties at 6 MAP. Shade x variety interaction was not significant.

At 8 MAP, there was significant effect of shade on leaf thickness at 25 per cent (10.5 mm). Shade levels at open condition (9.30 mm) and 50 per cent (9.12 mm) were found to be on par. The lowest value of 8.8 mm leaf thickness was found to be at 75 per cent shade level. Varietal effect of leaf thickness on shade levels was not significant. The interactions (shade x variety) were also not significant.

4.1.2. Root characters

4.1.2.1. Root weight

The data for dry weight of the root as affected by shade levels and varieties is depicted in Table 7.

At 2 MAP, the effect of different levels of shade on root weight was significant. The dry weight of the root for the treatment S_0 and S_1 were on par and for the treatments S_2 and S_3 were also on par. The maximum dry weight of the root was for the treatment S_1 (4.97 g) and the lowest value (2.50 g) was recorded for the treatment S_3. There was no varietal difference on the weight of the root. The interaction of shade x variety on root weight was not significant.

Table 7. Effect of shade levels and varieties on the root weight (g $plant^{-1}$) of turmeric plants

Shade levels	Months after planting															
	2 MAP				4 MAP				6 MAP				8 MAP			
	Varieties				Varieties				Varieties				Varieties			
	V_1	V_2	V_3	Mean	V_1	V_2	V_3	Mean	V_1	V_2	V_3	Mean	V_1	V_2	V_3	Mean
S_0	4.90	4.78	5.24	4.97	7.18	6.50	6.68	6.78	10.78	11.90	12.58	11.75	2.80	3.20	3.58	3.19
S_1	4.87	5.08	4.98	4.98	6.65	5.90	6.85	6.47	12.50	14.10	13.63	13.41	3.75	4.15	3.65	5.85
S_2	2.55	2.65	2.88	2.69	5.20	4.88	3.00	4.36	7.28	6.83	7.10	7.07	5.25	5.38	5.48	5.37
S_3	2.30	2.76	2.45	2.50	3.05	2.98	4.28	3.43	5.85	5.52	5.83	5.75	3.78	3.40	2.95	3.38
Mean	3.66	3.81	3.88	—	5.52	5.06	5.20	—	9.10	9.60	9.78	—	3.89	4.03	3.91	—
CD (0.05)																
S	0.858 (S)				0.657 (S)				2.707 (S)				1.925 (NS)			
V	0.366 (NS)				0.549 (NS)				0.816 (NS)				0.320 (NS)			
SV	0.733 (NS)				1.099 (S)				1.632 (NS)				0.640 (S)			

(S) - Significant (NS) - Not significant

The data recorded for the weight of the root at 4 MAP, revealed that the effect of shade was significant. The plants grown under treatment S_0 produced maximum roots (6.78 g) followed by the plants grown under 25 per cent shade (6.46 g). The lowest value of 3.4 g was recorded for the treatment S_3. The varietal effect was not significant. Interaction was significant. S_0V_1 recorded the maximum value of 7.17 g and the treatment S_3V_2 recorded the lowest value of 2.17 g.

At 6 MAP, there was significant variation in the root weight of plants grown under different levels of shade. The effect of the various shade levels can be depicted as $S_1>S_0>S_2>S_3$. The highest value of 13.40 g was recorded for the treatment S_1. In the open condition, the dry weight of the root was 11.75 g. The varietal effect and its interaction (shade x variety) was not significant.

At 8 MAP, the influence of shade levels (0, 25, 50 and 75 per cent) on root was not significant. Varietal effect of shade was also not significant. The interaction (shade x variety) was significant.

4.1.2.2. Root spread

The effect of shade levels and varieties on root spread is given in Table 8.

At 2 MAP, the effect of shade on the root spread was significant. Maximum root spread was recorded at open condition folllowed by 25 per cent shade level. The lowest root spread (6.66 cm) was recorded from plants grown under 75 per cent shade level. Treatments S_0V_1 and S_1V_3 were on par. S_3V_2 recorded the lowest (6.32 cm) of root spread.

Table 8. Effect of shade levels and varieties on the root spread (cm) of turmeric plants

Shade levels	Months after planting															
	2 MAP				4 MAP				6 MAP				8 MAP			
	Varieties				Varieties				Varieties				Varieties			
	V_1	V_2	V_3	Mean	V_1	V_2	V_3	Mean	V_1	V_2	V_3	Mean	V_1	V_2	V_3	Mean
S_0	12.54	11.33	11.98	11.95	21.40	21.00	20.30	20.90	33.10	34.43	31.83	33.17	17.23	17.32	17.15	17.25
S_1	10.18	10.10	12.13	10.80	20.13	20.08	22.53	20.91	32.73	31.83	37.45	34.00	11.65	16.83	17.88	17.45
S_2	8.25	8.28	8.38	8.30	14.23	14.75	14.65	14.54	19.03	21.00	21.25	20.43	13.55	13.13	13.95	13.54
S_3	6.83	6.33	6.85	6.67	10.65	10.33	10.85	10.61	14.63	12.40	15.53	14.18	11.96	12.20	10.58	11.58
Mean	9.45	9.01	9.83	—	16.60	16.54	17.08	—	24.81	24.91	26.51	—	15.10	14.88	14.89	—
CD (0.05)																
S	1.372 (S)				1.675 (S)				4.074 (S)				2.690 (S)			
V	0.788 (NS)				1.179 (NS)				1.480 (S)				1.422 (NS)			
SV	1.577 (NS)				2.359 (NS)				2.960 (S)				2.844 (NS)			

(S) - Significant (NS) - Not significant

The varietal effect of root spread was not significant. The interaction (shade x variety) was not significant.

At 4 MAP, the influence of shade levels (0 and 25 per cent) on root spread was on par. Shade levels of 50 and 75 per cent recorded 14.54 cm and 10.60 cm of root spread. Varietal effects was not significant. The interaction was also not significant.

The effect of shade levels at 6 MAP, was significant. Treatment S_1 gave the highest value (34.00 cm) followed by S_0 (33.10 cm). The lowest value (14.18 cm) was recorded from the S_3 treatment. Varietal effects on root spread was significant. Variety V_3, recorded the maximum root spread of 26.51 cm and varieteis V_1 and V_2 were on par. Treatment S_0V_2 gave the highest value (34.40 cm) and the lowest value (12.40 cm) was recorded for the treatment S_3V_2. The interactions on root spread were significant.

Treatment S_0 and S_1 were on par while S_2 and S_3 recorded different values of 13.54 cm and 11.58 cm of root spread during the growth period of 8 MAP. The lowest value of 11.58 cm of root spread is recorded for the treatment S_3. Varietal effects was not significant and the interaction (shade x variety) was also not significant.

4.1.2.3. Root length

Table 9 depicts the effect of shade levels and varieties on root length.

At 2 MAP, the influence of shade levels (0, 25, 50 and 75 per cent) on root length was significant. At 2 MAP, the root length was

Table 9. Effect of shade levels and varieties on the root length (cm) of turmeric

Shade levels	Months after planting															
	2 MAP				4 MAP				6 MAP				8 MAP			
	Varieties				Varieties				Varieties				Varieties			
	V_1	V_2	V_3	Mean	V_1	V_2	V_3	Mean	V_1	V_2	V_3	Mean	V_1	V_2	V_3	Mean
S_0	25.15	23.10	25.23	24.49	35.63	33.03	36.63	35.09	42.40	41.88	42.28	42.18	21.75	21.88	22.55	22.06
S_1	24.48	24.13	26.53	25.04	34.00	39.38	38.13	37.17	40.13	44.50	44.43	43.02	21.78	23.00	21.13	21.97
S_2	14.33	11.58	9.60	11.83	16.78	13.95	12.88	14.53	27.00	30.14	26.13	27.75	15.68	15.98	15.65	15.77
S_3	9.65	10.63	11.68	10.65	11.75	13.50	13.15	12.80	22.38	21.78	20.68	21.61	12.45	12.58	11.45	12.16
Mean	18.40	17.36	18.26	—	24.54	24.97	25.19	—	32.98	34.56	33.38	—	17.91	18.36	17.69	—
CD (0.05)																
S	4.118 (S)				3.356 (S)				3.491 (S)				4.470 (S)			
V	2.017 (NS)				2.264 (NS)				1.864 (NS)				1.559 (NS)			
SV	4.035 (NS)				4.529 (NS)				3.729 (NS)				3.118 (NS)			

(S) - Significant (NS) - Not significant

found to have maximum values of 25.0 cm for the treatment S_1 and in the open condition it was 24.49 cm. The lowest value recorded was 10.65 cm for the S_3 treatment. S_2 treatment recorded 11.83 cm for the root length. Treatment S_1V_3 gave the highest root length (26.52 cm). Treatments S_2V_3 and S_3V_1 was on par. Varietal effects on rootlength was not significant. Interactions were also not significant.

The influence of shade levels on root length at 4 MAP, was significant. The root length was found to be maximum at 25 per cent shade level (37.16 cm) followed by the open condition at 4 MAP. In the open condition the root length was 35.09 cm. The lowest root length was recorded for the treatment S_3 (12.80 cm). The effect of shade levels on the influence of the root length in the order $S_1 > S_0 > S_2 > S_3$. Treatment S_1V_2 (39.37 cm) gave the highest root length. The lowest root length was recorded from the treatment S_3V_1 (11.75 cm). Varietal effects on root length and the interactions were insignificant.

At 6 MAP, the effect of shade levels on the root length was found to follow a similar pattern when compared during the earlier growth periods. Shade level S_1 recorded the highest root length (43.02 cm), followed by S_0 treatment (42.18 cm). Treatment S_3 recorded the lowest (21.61 cm) root length. Treatments S_0V_1 and S_0V_3 were on par.

At 8 MAP, the influence of shade levels of (0, 25, 50 and 75 per cent) on the root length was significant. Shade level S_1 (25 %) gave the maximum root length (22.90 cm) followed by the shade level 0 per cent (open condition). S_3 recorded the lowest value (12.15 cm). Treatment S_3V_3 gave the lowest root length (11.45 cm). Varietal effects on the root length and interactions were insignificant.

4.1.3. Rhizome characters

4.1.3.1. Rhizome spread

The effect of shade levels and varieties on the rhizome spread is shown in the Table 10.

There was a positive influence of shade in the rhizome spread at 2 MAP with the maximum response of rhizome spread from the treatment S_1 followed by S_0 and S_2 which were on par and the lowest rhizome spread of 4.42 cm was recorded from the treatment S_3. The highest value of rhizome spread (7.50 cm) was recorded at 25 per cent shade level. The treatments S_1V_1, S_1V_2 and S_1V_3 were on par. The influence of shade level S_3 on the three turmeric cultivars were on par. Varietal effects on rhizome spread and the interactions were insignificant.

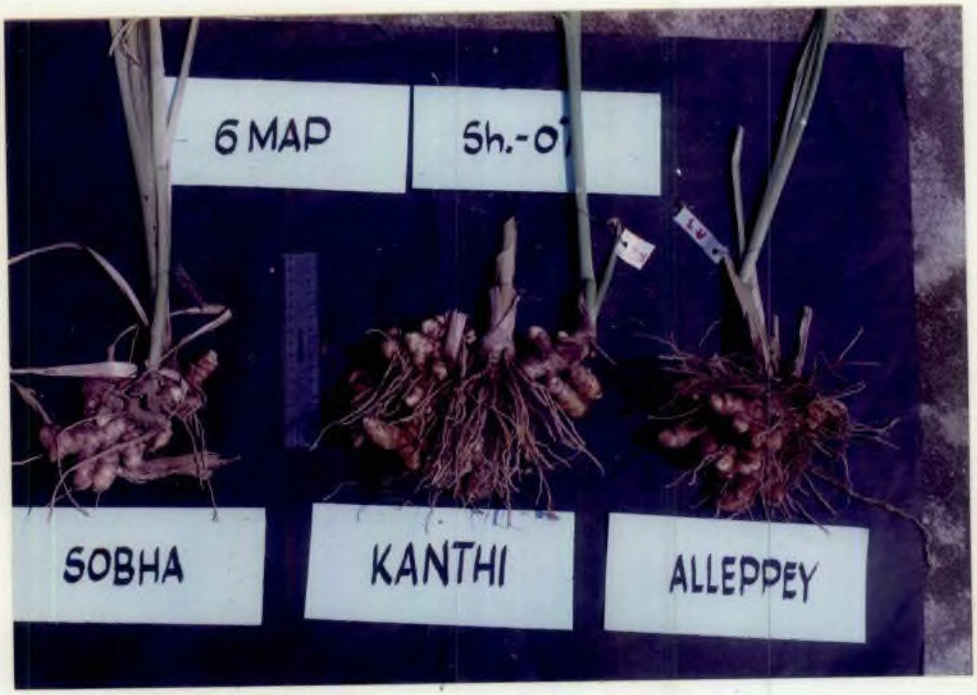
During the growth period of 4 MAP, the rhizome spread was found to be significant when grown under shade levels (0, 25, 50 and 75 per cent). Treatment S_1, gave the highest rhizome spread (11.41 cm) followed by S_0 (8.67 cm). The lowest rhizome spread was recorded from S_3. Treatment S_1V_2 and S_1V_1 were on par. The lowest rhizome spread (5.70 cm) was recorded from the treatment S_3V_2. Varietal effects on rhizome spread and the interactions were insignificant.

Plate 1. Rhizome study of the crop at 6 MAP under different levels of shade

a. open condition

Plate 1. Rhizome study of the crop at 6 MAP under different levels of shade

b. 25 per cent


6 MAP
Sh.-0
SOBHA
KANTHI
ALLEPPEY


6 MAP
Sh.-25%
SOBHA
KANTHI
ALLEPPEY

Table 10. Effect of shade levels and varieties on the rhizome spread (cm) of turmeric plants

Shade levels	Months after planting															
	2 MAP				4 MAP				6 MAP				8 MAP			
	Varieties				Varieties				Varieties				Varieties			
	V_1	V_2	V_3	Mean	V_1	V_2	V_3	Mean	V_1	V_2	V_3	Mean	V_1	V_2	V_3	Mean
S_0	6.15	5.65	5.73	5.84	8.03	8.85	9.15	8.68	11.80	11.33	11.70	11.61	17.15	17.85	16.93	17.31
S_1	7.80	7.93	7.05	7.59	11.75	11.95	10.53	11.41	17.03	17.80	14.28	16.37	22.95	21.78	22.38	22.37
S_2	5.28	5.03	4.93	5.08	7.20	6.95	7.03	7.06	9.13	8.80	9.05	8.99	13.38	13.48	12.08	12.98
S_3	4.08	4.33	4.88	4.43	5.78	5.70	5.93	5.80	7.00	6.83	6.90	6.91	12.05	13.85	12.00	12.63
Mean	5.83	5.73	5.64	-	8.19	8.36	8.16	-	11.24	11.19	10.48	-	16.38	16.74	15.84	-
CD (0.05)																
S	0.632 (S)				0.5481 (S)				1.936 (S)				2.288 (S)			
V	0.484 (NS)				0.6246 (NS)				1.258 (NS)				1.002 (NS)			
SV	0.969 (NS)				1.2493 (NS)				2.517 (NS)				2.005 (NS)			

(S) - Significant (NS) - Not significant

The effect of shade levels (0, 25, 50 and 75 per cent) on rhizome spread at 6 MAP was significant. Maximum rhizome spread was recorded from the 25 per cent shade level (16.36 cm). In the open condition the rhizome spread was (11.61 cm). The lowest rhizome spread (6.91 cm) was recorded from the shade treatment S_3. Treatments S_1V_1 and S_1V_2 were on par. The lowest rhizome spread was recorded from the treatment S_3V_2. Varietal effects were not significant. Interactions were also not significant.

During all the growth stages inclusive of 8 MAP, the trend in the influence of rhizome spread by the different shade levels was found to exhibit a similar pattern with the shade level of 25 per cent (treatment S_1) recording the highest rhizome spread. The maximum rhizome spread at 8 MAP recorded from the S_1 treatment was 22.36 cm and in the open condition the rhizome spread was 17.31 cm. The other two shade levels S_2 and S_3 were on par in the influence of rhizome spread (12.97 cm and 12.63 cm respectively). Maximum rhizome spread was recorded from the treatment S_1V_1 and the lowest rhizome spread was recorded from the treatment S_3V_3. Varietal effects on rhizome spread and shade x variety interaction were not significant.

4.1.3.2. Number of finger rhizomes / plant

The data presented in Table 11 represent the effect of shade levels and varieties on number of finger rhizomes / plant.

Number of finger rhizomes / plant was found to vary at all shade levels. The maximum number of finger rhizome/plant was recorded at

Table 11. Effect of shade levels and varieties on the number of finger rhizomes of turmeric plants

Shade levels	Months after planting															
	2 MAP				4 MAP				6 MAP				8 MAP			
	Varieties				Varieties				Varieties				Varieties			
	V_1	V_2	V_3	Mean	V_1	V_2	V_3	Mean	V_1	V_2	V_3	Mean	V_1	V_2	V_3	Mean
S_0	8.75	9.75	8.09	8.83	15.00	16.00	11.75	14.25	19.00	18.75	15.75	17.83	22.50	22.25	19.25	21.33
S_1	11.75	14.25	11.75	12.58	17.25	20.00	17.25	18.17	21.75	24.00	22.50	22.75	23.75	25.25	25.50	24.83
S_2	7.00	6.25	5.50	6.25	9.50	10.75	9.75	10.00	15.00	13.75	14.75	14.50	15.75	18.00	17.50	17.08
S_3	5.25	5.50	5.00	5.25	7.75	8.50	8.25	8.11	12.25	11.00	12.50	11.92	16.50	13.00	13.75	14.42
Mean	8.19	8.94	7.56	—	12.38	13.81	11.75	—	17.00	16.88	16.38	—	19.63	19.63	19.00	—
CD (0.05)																
S	1.791 (S)				1.336 (S)				2.289 (S)				3.844 (S)			
V	1.142 (NS)				1.709 (NS)				1.749 (NS)				1.405 (NS)			
SV	2.285 (NS)				3.418 (NS)				3.496 (NS)				2.810 (NS)			

(S) - Significant (NS) - Not significant

Plate 1. Rhizome study of the crop 6 MAP under different levels of shade

c. 50 per cent

Plate 1. Rhizome study of the crop 6 MAP under different levels of shade

d. 75 per cent


6 MAP
Sh.-50%
SOBHA
KANTHI
ALLEPPEY


6 MAP
Sh.-75%
SOBHA
KANTHI
ALLEPPEY

25 per cent shade level (12.5). There was significant variation in number of finger rhizomes/plant for the other 3 shade levels namely S_0 (8.83), S_2, (6.25) and S_3 (5.25). Treatment S_1V_2 (14.25) gave the highest rhizome spread. Treatments S_1V_1 (11.75) and S_1V_3 (11.75) were on par at 2 MPA. Varietal effects on the number of finger rhizomes per plant was insignificant Interactions were insignificant.

Influence of different shade levels (0, 25, 50 and 75 per cent) was significant on the number of finger rhizomes/plant at 4 MAP. Shade levels S_0, S_1, S_2 and S_3 recorded the number of finger rhizomes/plant as 14.25, 18.16, 10.00 and 8.11 respectively. Treatment S_1 recorded the highest number of finger rhizomes / plant (18.16) followed by S_0 (14.25). Treatments S_2 and S_3 were not on par. Treatment S_1V_2 (14.2) recorded the highest number of finger rhizomes/plant while treatments S_1V_1 and S_1V_3 (17.25) were on par. Effect of shade level S_3 on the number of finger rhizomes / plant for the three turmeric cultivars were on par. Varietal effects and interactions were insignificant.

The influence of shade at 6 MAP on the number of finger rhizome/ plant exhibited a similar trend as in the earlier growth periods of 2 MAP and 4 MAP. Treatment S_1 gave the highest number of finger rhizomes/ plant (22.75) followed by S_0 (17.83). Treatment S_1V_2 recorded the maximum number of finger rhizomes/plant (24.00). Treatments S_1V_1 and S_1V_3 were not on par. Varietal effects and interactions were insignificant.

At 8 MAP, the influence of shade levels (0, 25, 50 and 75 per cent) on the number of finger rhizomes / plant was significant. The number of finger rhizomes / plant recorded from the treatments S_1 and S_0 were 24.83 and 21.33. The performance of the shade levels can be observed in the descending order as $S_1>S_0>S_2>S_3$. Treatment S_1V_3 and S_1V_2 were on par. Varietal effects on number of finger rhizomes per plant was not significant. Interactions was insignificant. Treatment S_3V_2 (13.00) recorded the lowest number of finger rhizomes per plant.

4.1.3.3. Rhizome thickness

The effect of shade levels and varieties on rhizome thickness is depicted in Table 12.

There was significant variation in the influence of shade levels on the rhizome thickness at 2 MAP. The Rhizome thickness was maximum for shade level of 25 per cent (4.11 cm). In the open condition, the thickness of the rhizome was 3.0 cm. For the shade levels 50 per cent and 75 per cent, the rhizome thickness were on par. Varietal effects on rhizome thickness was significant. Variety, Alleppey recorded the maximum (3.01 cm) rhizome thickness while the other two varieties namely Kanthi (2.93 cm) and Sobha (2.73 cm) were on par. Interactions (shade x variety) was significant. Treatment S_1V_2 (4.25 cm) gave the highest rhizome thickness. Lowest rhizome thickness was recorded from the treatment S_2V_3 (1.77 cm). Effect of shade level S_1 on the three turmeric cultivars were on par.

Table 12. Effect of shade and variety on th rhizome thickness (cm) on turmeric plants

Shade levels	Months after planting															
	2 MAP				4 MAP				6 MAP				8 MAP			
	Varieties				Varieties				Varieties				Varieties			
	V_1	V_2	V_3	Mean	V_1	V_2	V_3	Mean	V_1	V_2	V_3	Mean	V_1	V_2	V_3	Mean
S_0	2.95	3.30	2.90	3.06	4.35	5.15	5.03	4.84	5.48	5.98	6.10	5.85	6.03	6.15	6.20	6.13
S_1	4.03	4.25	4.08	4.12	5.30	5.35	5.38	5.34	6.40	6.40	6.80	6.53	6.93	6.95	7.00	6.96
S_2	2.95	2.53	1.78	2.42	4.28	3.93	4.08	4.09	5.65	5.23	5.03	5.30	5.75	5.60	5.98	5.78
S_3	1.83	2.10	2.15	2.03	4.03	4.13	4.03	4.06	5.28	5.30	5.30	5.29	5.88	5.85	5.58	5.77
Mean	2.94	3.04	2.73	—	4.49	4.64	4.63	—	5.70	5.73	5.81	—	6.14	6.14	6.19	—
CD (0.05)																
S	0.236 (S)				0.257 (S)				0.329 (S)				0.254 (S)			
V	0.182 (S)				0.183 (NS)				0.159 (NS)				0.241 (NS)			
SV	0.364 (S)				0.366 (S)				0.318 (S)				0.483 (NS)			

(S) - Significant (NS) - Not significant

Rhizome thickness was found to be maximum for shade level of 25 per cent (5.34 cm) at 4 MAP. In open condition (S_0) the rhizome thickness was 4.84 cm. Treatments S_3 and S_4 were on par in terms of rhizome thickness. At 25 per cent shade level the rhizome thickness of all the three turmeric cultivars were on par. Varietal effects was not significant. Interactions were significant. Treatment S_1V_3 gave a rhizome thickness of 5.37 cm.

At 6 MAP, the influence of shade levels (0, 25, 50 and 75 pe cent) was significant. At 6 MAP, the rhizome thickness was found to be maximum at 25 per cent shade level (6.53 cm). In the open condition, the rhizome thickness was 5.85 cm. The other two shade levels of 50 per cent (S_2) and 75 per cent (S_3) were found to be on par with rhizome thickness of 5.30 and 5.29 cm. Varietal effects was not significant. Interactions was significant treatment S_1V_3 gave a rhizome thickness of 6.80 cm.

Rhizome thickness of turmeric plants grown under the influence of shade levels (0, 25, 50 and 75 per cent) was found to show a similar trend during all the growth stages especially at 8 MAP. Here the maximum rhizome thickness was recorded from 25 per cent shade level with a rhizome thickness of 7.00 cm. In the open condition, the rhizome thickness was 6.12 cm. The other two shade levels of 50 and 75 per cent recorded rhizome thickness of 5.77 and 5.78 cm respectively. Treatment S_1V_3 gave the highest (7.01 cm) rhizome thickness. Treatments S_1V_1 (6.92) and S_1V_2 (6.95) were on par. Varietal effects and interactions were insignificant.

4.2. Physiological

4.2.1. Dry matter production

The data presented in Table 13 show the effect of shade levels and varieties on dry matter production.

At 2 MAP, the dry matter production was found to be maximum for S_1 treatment (44.92 g) followed by S_0 treatment (36.13 g). There was significant variation in the dry matter production due to the effect of different levels of shade and the trend in the order as $S_1 > S_0 > S_2 > S_3$. Varietal effects on dry matter production was insignificant. Shade x varietal interaction on DMP was significant. The treatment S_1V_2 gave the highest DMP of 50.70 g at 2 MAP and the lowest DMP of 33.54 g was recorded from the treatment S_3V_1.

At 4 MAP, the dry matter production was found to be maximum at 25 per cent shade level followed by the open condition. The highest value of DMP was recorded from S_1 treatment (102.72 g) and the lowest value of DMP recorded at S_3 treatment was 74.35 g. In the open condition the DMP was 81.74 g. Treatment S_1V_2 recorded the highest DMP of 108.27 g while treatment S_3V_1 recorded the lowest DMP of 71.84 g. Varietal effects and interactions on DMP were insignificant

At 6 MAP, the DMP was found to be significantly influenced by the different levels of shade and the pattern of influence was found to be similar to that during the earlier growth periods of 2 and 4 MAP. The highest value of 202.67 g of DMP was recorded from the treatment S_1

Table 13. Effect of shade levels and varieties o the dry matter production (g $plant^{-1}$) of turmeric plants

Shade levels	Months after planting															
	2 MAP				4 MAP				6 MAP				8 MAP			
	Varieties				Varieties				Varieties				Varieties			
	V_1	V_2	V_3	Mean	V_1	V_2	V_3	Mean	V_1	V_2	V_3	Mean	V_1	V_2	V_3	Mean
S_0	33.08	37.39	37.36	36.13	77.60	82.70	84.92	81.74	180.12	183.79	187.87	183.93	209.37	220.8	210.87	213.60
S_1	44.57	50.70	39.50	44.927	103.82	108.27	95.17	102.72	197.87	204.09	206.05	202.67	260.50	264.84	264.62	263.32
S_2	34.32	34.11	35.45	34.63	76.47	76.57	73.27	75.441	179.30	179.84	166.42	175.18	184.32	171.49	183.12	179.64
S_3	33.54	33.75	34.63	33.97	71.84	76.69	74.50	74.35	159.32	154.84	156.60	156.92	146.30	140.74	151.57	146.20
Mean	36.53	38.99	36.73	—	82.43	86.06	81.96	—	179.15	180.64	178.23	—	200.12	199.47	202.54	—
CD (0.05)																
S	5.420 (S)				10.973 (S)				10.825 (S)				22.548 (S)			
V	2.570 (NS)				4.051 (NS)				7.939 (NS)				17.760 (NS)			
SV	5.149 (S)				8.115 (NS)				15.878 (NS)				35.521 (NS)			

(S) - Significant (NS) - Not significant

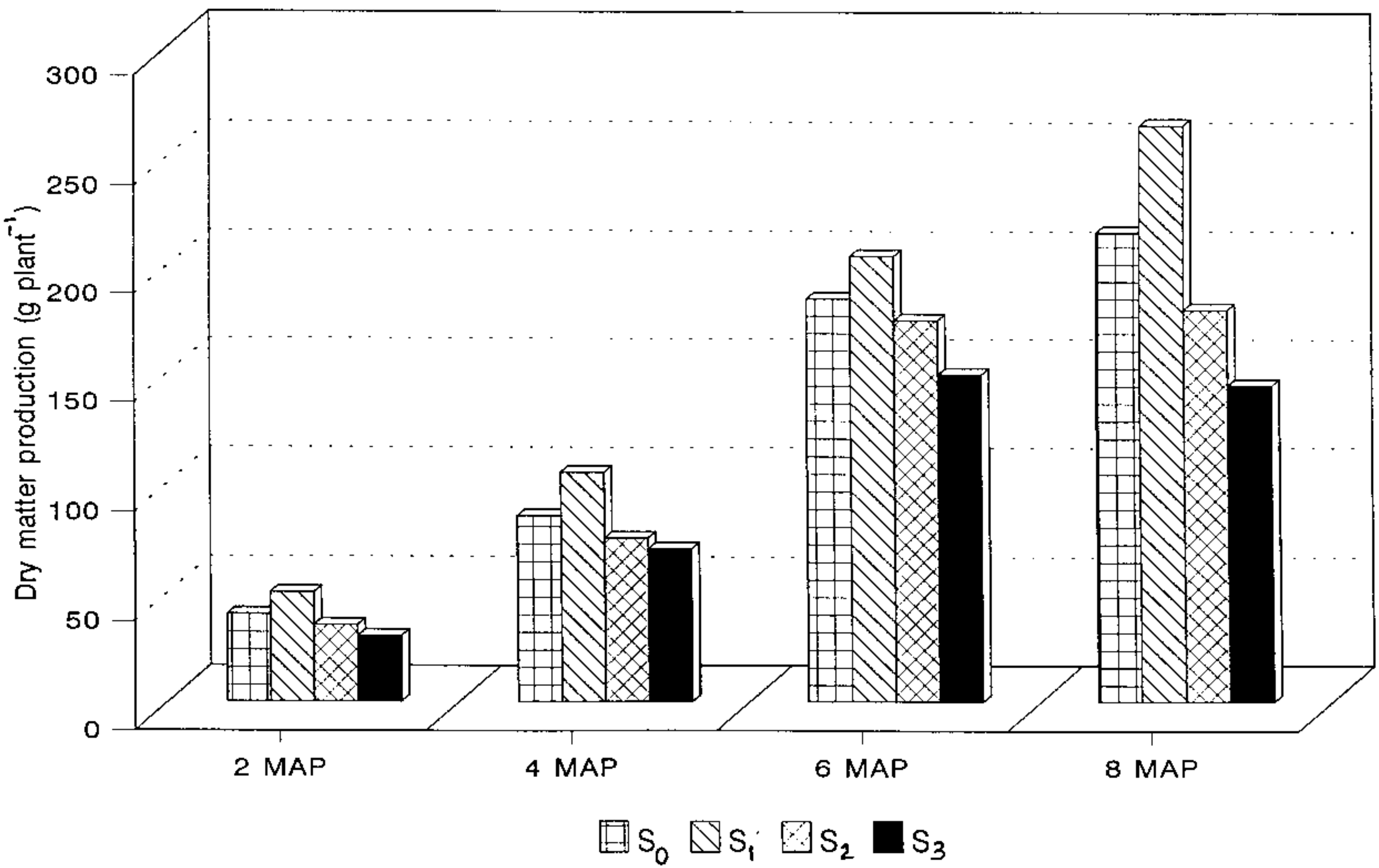


Fig. 3. Effect of shade levels and varieties on dry matter production

and in the open condition the DMP was 183.93 g. For treatment S_2 and S_3 the DMP values were 175.18 g and 156.92 g. The lowest value was recorded for the treatment S_3. Treatment S_1V_3 gave the highest DMP of 206.00 g. Varietal effects and its interactions were insignificant at 6 MAP.

At 8 MAP, the effect of shade on DMP exhibited a pattern similar to all the other earlier growth stages. Influence of different levels of shade (0, 25, 50 and 75 per cent) was significant and it can be arranged *in the descending order as* $S_1>S_0>S_2>S_3$. *Treatment* S_1 *gave the highest* DMP (263.32 g). The lowest DMP of 146.20 g was recorded from S_3. In the open condition DMP, recorded was 213.60 g. The treatment with the highest DMP was from S_1V_2 and that with the lowest DMP was from S_3V_2 treatment. Varietal effects and interactions were insignificant.

4.2.2. Crop growth rate

Table 14 shows the effect of shade levels and varieties on the crop growth rate.

At 60-120 DAP, the effect of shade on the CGR was insignificant. Varietal effects was significant. Variety V_2 (0.421 gm^{-2} day^{-1}) recorded the maximum CGR. Variety V_3 recorded a minimum CGR of 0.333 gm^{-2} day^{-1}. Interactions were significant. Treatments S_0V_2 and S_3V_3 were on par. Treatment S_3V_2 (0.52 gm^{-2} day^{-1}) gave the highest CGR.

At 120-180 DAP, the effect of shade on CGR was significant. Maximum CGR (1.26 gm^{-2} day^{-1}) was recorded from the open condition.

Table 14. Effect of shade levels and varieties on crop growth rate (g m^{-2} day^{-1}) of turmeric plants

	Days after planting											
	60 - 120 MAP				120 - 180 MAP				180 - 240 MAP			
Shade levels	Varieties				Varieties				Varieties			
	V_1	V_2	V_3	Mean	V_1	V_2	V_3	Mean	V_1	V_2	V_3	Mean
S_0	0.31	0.41	0.38	0.37	1.40	1.20	1.18	1.26	0.39	0.44	0.41	0.41
S_1	0.50	0.39	0.28	0.39	0.98	1.18	1.26	1.14	0.94	0.97	1.00	0.97
S_2	0.32	0.37	0.26	0.31	0.92	0.94	0.92	0.93	0.28	0.45	0.49	0.41
S_3	0.35	0.52	0.41	0.43	0.85	0.54	0.60	0.66	0.38	0.28	0.24	0.30
Mean	0.37	0.42	0.33	—	1.04	0.97	0.99	—	0.50	0.53	0.53	—
CD (0.05)												
S	0.157 (NS)				5.516 (S)				0.305 (S)			
V	5.303 (S)				4.175 (NS)				0.218 (NS)			
SV	0.106 (S)				8.351 (S)				0.437 (NS)			

(S) - Significant (NS) - Not significant

At 25 per cent shade level, the CGR was 12.138 gm^{-2} day^{-1}. Minimum CGR of 0.66 gm^{-2} day^{-1} was recorded from S_3. Varietal effects was insignificant. Interactions was significant. Maximum CGR was recorded from the S_0V_1 (1.4 gm^{-2} day^{-1}) treatment and minimum CGR was recorded from the S_3V_2 (0.538 gm^{-2} day^{-1}) treatment. Treatments S_1V_1 and S_2V_1 were on par.

At 180-240 DAP, the effect of shade on CGR was significant. Maximum CGR was recorded at 25 per cent shade level (0.97 gm^{-2} day^{-1}). Minimum CGR was recorded at 75 per cent shade level (0.297 gm^{-2} day^{-1}). In the open condition, CGR recorded was 0.41 gm^{-2} day^{-1}. Varietal effects and interactions were insignificant.

4.2.3. Relative growth rate

On analysing the data for the relative growth rate during the growth periods of 2 to 4 MAP, 4 to 6 MAP and 6 to 8 MAP, it was found that there were not much significant effect on the relative growth rate of turmeric plants under different shade levels. Varietal effects and interactions were not significant.

4.2.4. Net assimilation rate

Table 16 shows the effect of shade levels and varieties on the net assimilation rate.

During the growth period of 60 to 120 DAP, the effect of shade on the NAR was insignificant. Varietal effects was insignificant.

Table 15. Effect of shade levels and varieties on relative growth rate of (g day^{-1}) of turmeric plants

Shade levels	Months after planting											
	2 - 4 MAP				4 - 6 MAP				6 - 8 MAP			
	Varieties				Varieties				Varieties			
	V_1	V_2	V_3	Mean	V_1	V_2	V_3	Mean	V_1	V_2	V_3	Mean
S_0	0.013	0.013	0.014	0.013	0.014	0.013	0.014	0.014	0.003	0.003	0.002	0.003
S_1	0.014	0.013	0.014	0.014	0.009	0.011	0.013	0.011	0.004	0.005	0.004	0.004
S_2	0.013	0.013	0.012	0.013	0.014	0.014	0.014	0.014	0.002	0.003	0.003	0.003
S_3	0.002	0.012	0.012	0.011	0.014	0.013	0.013	0.013	0.003	0.002	0.002	0.002
Mean	0.013	0.013	0.013	—	0.013	0.013	0.013	—	0.003	0.003	0.003	—
CD (0.05)												
S	0.00059 (NS)				0.000230 (NS)				0.00018 (NS)			
V	0.00013 (NS)				0.000186 (NS)				0.00012 (NS)			
SV	0.00027 (NS)				0.000372 (NS)				0.00024 (NS)			

(S) - Significant (NS) - Not significant

Table 16. Effects of shade levels and varieties on net assimilation rate (g m^{-2} day^{-1}) of turmeric plants

Shade levels	Days after planting											
	60 - 120 MAP				120 - 180 MAP				180 - 240 MAP			
	Varieties				Varieties				Varieties			
	V_1	V_2	V_3	Mean	V_1	V_2	V_3	Mean	V_1	V_2	V_3	Mean
S_0	0.298	0.335	0.410	0.347	0.399	0.389	0.415	0.401	0.082	0.392	0.081	0.185
S_1	0.548	0.385	0.375	0.436	0.397	0.317	0.352	0.355	0.168	0.134	0.117	0.140
S_2	0.406	0.360	0.270	0.345	0.372	0.338	0.249	0.319	0.048	0.057	0.060	0.055
S_3	0.290	0.422	0.417	0.376	0.316	0.262	0.251	0.276	0.052	0.032	0.031	0.038
Mean	0.385	0.375	0.368	—	0.371	0.326	0.317	—	0.087	0.153	0.072	—
CD (0.05)												
S	0.1477 (NS)				0.0628 (S)				0.1607 (NS)			
V	0.0638 (NS)				0.0603 (NS)				0.1360 (NS)			
SV	0.1277 (S)				0.1206 (NS)				0.2720 (NS)			

(S) - Significant (NS) - Not significant

Interactions was significant. Treatments S_0V_1 and S_3V_1 were on par. *Treatment* S_1V_1 *(0.55 gm^{-2} day^{-1}) recorded the highest* NAR. Treatments S_3V_2 and S_3V_3 were on par.

The data *recorded during* the growth periods of 120 to 180 DAP on NAR shows the effect of shade levels as significant. Maximum NAR was recorded from S_0 treatment. At 25 per cent shade level, the NAR was 0.355 gm^{-2} day^{-1}. Minimum NAR was recorded from S_3 treatment (0.276gm^{-2} day^{-1}). Varietal effects and interactions were insignificant.

The effect of shade levels, varietal effects and interactions on the NAR during the growth periods of 180 to 240 DAP were insignificant.

4.2.5. Specific leaf weight

Table 17 shows the effect of shade levels and varieties on specific *leaf weight.*

Data on specific leaf weight for turmeric plants grown under the influence of shade levels (0,25,50 and 75 per cent) at 2 MAP was significant. Treatments S_1, S_2 and S_3 were on par. In the open condition the specific leaf weight recorded was 0.002 g cm^{-2}. Varietal effects was significant. Varieties V_1 and V_3 were on par. Interactions were significant. Treatment S_2V_1 *(0.0045 gm cm^{-2}) recorded the highest SLW. Treatments* S_1V_1 and S_1V_2 were on par. Treatment S_0V_1 (0.0017 g cm^{-2}) gave the lowest SLW. Treatments S_2V_2 and S_3V_2 were on par.

Table 17. Effect of shade levels and varieties on specific leaf weight (g cm^{-2}) of turmeric plants

Shade levels	2 MAP				4 MAP				6 MAP				8 MAP			
	Varieties				Varieties				Varieties				Varieties			
	V_1	V_2	V_3	Mean	V_1	V_2	V_3	Mean	V_1	V_2	V_3	Mean	V_1	V_2	V_3	Mean
S_0	0.002	0.002	0.002	0.002	0.001	0.002	0.002	0.001	0.003	0.002	0.002	0.003	0.002	0.002	0.002	0.002
S_1	0.003	0.003	0.003	0.003	0.002	0.002	0.002	0.002	0.003	0.002	0.002	0.002	0.002	0.002	0.002	0.002
S_2	0.005	0.003	0.003	0.003	0.003	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
S_3	0.003	0.003	0.004	0.003	0.002	0.003	0.003	0.003	0.003	0.002	0.002	0.002	0.003	0.002	0.002	0.002
Mean	0.003	0.002	0.003	—	0.002	0.002	0.002	—	0.003	0.002	0.002	—	0.002	0.002	0.002	—
CD (0.05)																
S	4.9868 E-04 (S)				4.5029 E-04 (S)				2.9584 E-04 (S)				3.336 E-04 (NS)			
V	4.59 E-04 (S)				3.7636 E-04 (NS)				3.6536 E-04 (S)				2.96 E-04 (S)			
SV	9.18 E-04 (S)				7.5272 E-04 (NS)				7.3072 E-04 (NS)				5.921E-04 (NS)			

(S) - Significant (NS) - Not significant

Data on SLW for turmeric plants grown under the influence of different levels of shade at 4 MAP was significant. Treatments S_1 and S_2 were on par. S_3 recorded the highest SLW (0.003 g cm^{-2}). In the open condition the SLW was 0.001 g cm^{-2}. Varietal effects was not significant. Interactions were significant. Treatments S_0V_3, S_1V_2 were on par. Treatment S_0V_1 gave the lowest SLW of 0.0013g cm^{-2}. Treatment S_3V_2 (0.0034 g cm^{-2}) recorded the maximum SLW.

The effect of shade levels (0,25,50 and 75 per cent) on SLW at 6 MAP was significant. In the open condition, a maximum SLW of 0.003 g cm^{-2} was recorded. Treatments S_1, S_2 and S_3 were on par. Varietal effects was significant. Varieties V_2 and V_3 were on par. Variety V_1 (kanthi) recorded a SLW of 0.003 g cm^{-2}. Interactions was insignificant.

The effect of shade levels on SLW at 8 MAP was insignificant. Varietal effects was significant. Interactions were insignificant.

4.2.6. Leaf area index

Table 18 shows the effect of shade levels and varieties on leaf are index.

The effect of shade on leaf area index at 2 MAP was significant. Leaf area index at 2 MAP were found to have a maximum value of 1.15 for the treatment S_3 while treatment S_1 and S_2 were on par. Treatment S_0 recorded a leaf area index of 1.07. Varietal effects was significant. Variety V_2 (Alleppey) recorded a leaf area index of 1.15. The other two varieties namely V_1 (Kanthi) and V_3 (Sobha) were on par. Interactions were not significant.

Table 18. Effect of shade levels and varieties on leaf area index of turmeric plants

Shade levels	2 MAP				4 MAP				6 MAP				8 MAP			
	Varieties				Varieties				Varieties				Varieties			
	V_1	V_2	V_3	Mean	V_1	V_2	V_3	Mean	V_1	V_2	V_3	Mean	V_1	V_2	V_3	Mean
S_0	1.054	1.232	0.939	1.075	3.770	3.425	2.895	3.363	5.175	6.025	5.340	5.513	7.795	7.492	6.782	7.357
S_1	0.927	1.027	0.787	0.914	2.733	3.925	3.737	3.465	5.818	7.157	7.342	6.773	6.767	7.700	7.560	7.343
S_2	0.806	1.049	0.981	0.946	2.750	2.875	3.847	3.158	7.100	7.787	7.855	7.581	8.252	9.097	9.425	8.925
S_3	1.177	1.275	1.981	1.145	2.794	2.082	2.407	2.428	7.225	8.327	8.475	8.009	7.090	8.765	8.955	8.270
Mean	0.992	1.146	0.922	—	3.012	3.077	3.222	—	6.33	7.324	7.253	—	7.476	8.264	8.181	—
CD (0.05)																
S	0.1514 (S)				0.6092 (S)				0.6938 (S)				1.2635 (S)			
V	0.1171 (NS)				0.5408 (NS)				1.0381 (NS)				1.0376 (NS)			
SV	0.2343 (NS)				1.0817 (S)				2.0763 (NS)				2.075 (NS)			

Months after planting (MAP)

(S) - Significant (NS) - Not significant

The leaf area index at 4 MAP was significant under the influence of shade levels of 0,25,50 and 75 per cent. Treatments S_0, S_1 and S_2 were on par. Treatment S_3 gave a leaf area index of 2.4. Varietal effects was insignificant. Interactions was significant. Treatments S_1V_1, S_2V_1 and S_3V_1 were on par. Treatment S_1V_1 and S_1V_3 were also on par. Treatment S_1V_2 (3.93) recorded the highest leaf area index. Treatment S_2V_2 and S_0V_3 were on par. Treatment S_3V_2 (2.08) recorded the lowest leaf area index.

The effect of shade on leaf area index at 6 MAP was significant. Maximum leaf area index of 8.01 was recorded by S_3 treatment. In the open condition the leaf area index recorded was 5.51. At 25 per cent shade level the leaf area index was 6.7. Varietal effects was insignificant. Varieties V_2 and V_3 were on par. Interactions (shade x variety) were insignificant.

Leaf area index at 8 MAP was significant under the influence of different levels of shade (0, 25, 50 and 75 per cent). Treatment S_2 recorded the highest leaf area index (8.73) followed by treatment S_3 (8.27). Treatments S_0 and S_1 were on par.

4.2.7. Leaf area duration

Table 19 shows the effect of shade levels and varieties on leaf area duration.

During the growth period of 60 to 120 DAP the effect of shade on leaf area duration was significant. Maximum leaf area duration was recorded from the treatment S_1 (132.35) followed by the open condition (131.70). Lowest leaf area duration of 100.8 was recorded from S_3 treatment. At 50

Table 19. Effect of shade and variety on leaf area duration of turmeric plants

Shade levels	Days after planting											
	60-120 DAP				120-180 DAP				180-240 DAP			
	Varieties				Varieties				Varieties			
	V_1	V_2	V_3	Mean	V_1	V_2	V_3	Mean	V_1	V_2	V_3	Mean
S_0	143.82	133.85	[illegible]	131.78	187.59	749.92	190.90	376.14	264.89	256.41	240.48	253.92
S_1	113.15	148.18	135.69	132.35	205.00	245.78	251.91	234.23	235.65	257.00	258.30	250.32
S_2	112.96	116.39	138.47	122.61	244.12	265.04	266.93	258.70	281.19	229.10	309.15	296.48
S_3	114.41	93.58	94.67	100.89	248.15	280.44	284.93	271.18	244.98	288.76	2953.37	276.37
Mean	121.09	123.01	121.63	—	221.22	385.30	248.67	—	256.67	275.32	275.82	—
CD (0.05)												
S	15.645 (S)				296.724 (NS)				406.078 (NS)			
V	15.968 (NS)				229.393 (NS)				302.386 (NS)			
SV	31.936 (NS)				458.786 (NS)				60.477 (NS)			

(S) - Significant (NS) - Not significant

per cent shade level, the leaf area duration recorded was 122.6. Varietal effects and interactions were insignificant.

The effect of shade levels on the leaf area duration during the growth periods of 120 to 180 DAP and 180 to 240 DAP was insignificant. Varietal effects and interactions were insignificant during the growth phases of 120 to 180 DAP and 180 to 240 DAP.

4.2.8. Harvest index

Table 20 shows the effect of shade on the harvest index at 240 DAP.

Table 20. Effect of shade levels and varieties on harvest index at 240 DAP

Shade levels	Varieties			
	V_1	V_2	V_3	Mean
S_0	0.9188	0.9193	0.9090	0.9160
S_1	0.9258	0.9200	0.9160	0.9210
S_2	0.8545	0.8553	0.8663	0.8590
S_3	0.8535	0.8347	0.8580	0.8490
Mean	0.8880	0.8820	0.8870	
CD (0.05)				
S	0.00181 (S)			
V	0.00114 (NS)			
SV	0.00228 (NS)			

(S) - Significant (NS) - Not significant

The harvest index measured for the turmeric plants grown under the influence of different shade levels (0, 25, 50 and 75 per cent) at 8 MAP was significant. Maximum harvest index was observed from 25 per cent shade level (0.921) followed by the open condition (0.916). The lowest harvest index was recorded from the shade level of 75 per cent (0.849). The varietal effect on the harvest index and interactions were not significant.

4.2.9. Root-shoot ratio

Table 21 shows the effect of shade levels and varieties on root-shoot ratio.

The effect of shade on root-shoot ratio at 2 MAP was significant. The root-shoot ratio at 2 MAP was found to be maximum for S_0 treatment (0.524) followed by S_1 treatment (0.475). The lowest value (0.146) for root-shoot ratio was from S_3 treatment. Varietal effects and interactions were insignificant.

At 4 MAP, the root-shoot ratio was significant for turmeric plants grown under the influence of different shade levels. Shade level S_0 gave the maximum root-shoot ratio of 0.387 followed by S_1 (0.273) and the least value of 0.117 was observed from the treatment S_3. Treatment S_0V_1 (0.42) gave the highest root-shoot ratio. Treatment S_3V_2 (0.1) gave the lowest root-shoot ratio. Varietal effects and interactions were insignificant.

Table 21. Effect of shade levels and varieties on root / shoot ratio

Shade levels	2 MAP				4 MAP				6 MAP				8 MAP			
	Varieties				Varieties				Varieties				Varieties			
	V_1	V_2	V_3	Mean	V_1	V_2	V_3	Mean	V_1	V_2	V_3	Mean	V_1	V_2	V_3	Mean
S_0	0.494	0.471	0.608	0.524	0.422	0.373	0.367	0.387	0.188	0.201	0.237	0.208	0.199	0.231	0.198	0.209
S_1	0.495	0.442	0.487	0.475	0.297	0.271	0.311	0.293	0.210	0.223	0.211	0.214	0.247	0.243	0.199	0.230
S_2	0.193	0.202	0.215	0.203	0.228	0.198	0.123	0.183	0.113	0.106	0.118	0.112	0.262	0.288	0.297	0.282
S_3	0.154	0.175	0.111	0.146	0.119	0.103	0.128	0.117	0.097	0.091	0.096	0.095	0.216	0.176	0.160	0.184
Mean	0.334	0.322	0.355	—	0.266	0.236	0.232	—	0.152	0.155	0.165	—	0.231	0.234	0.214	—
CD (0.05)																
S	9.785 (S)				5.458 (S)				4.322 (S)				0.115 (NS)			
V	6.727 (NS)				3.513 (NS)				1.956 (NS)				2.905 (NS)			
SV	0.134 (NS)				7.027 (NS)				3.912 (NS)				5.811 (NS)			

Months after planting

(S) - Significant (NS) - Not significant

At 6 MAP the root-shoot ratio was maximum for the shade level S_1 (0.214). In the open condition it was 0.208. The lowest value of 0.095 was recorded from S_3 treatment. Treatment S_0V_3 gave the highest root-shoot ratio. Varietal effects was not significant. Interactions were insignificant.

At 8 MAP, the effect of shade levels on root-shoot ratio was insignificant. At 8 MAP, the root-shoot ratio was maximum for the shade level of 50 per cent (0.282) and the lowest value of 0.184 was recorded from S_3 treatment. In the open condition, the root-shoot ratio value was 0.209. Varietal effects and interactions were insignificant.

4.3 Photosynthetic rate and related parameters

4.3.1 Leaf internal CO_2 concentration

Table 22 depicts the effect of shade levels and varieties on the leaf internal CO_2 concentration at 180 DAP.

Leaf internal CO_2 concentration for turmeric plants which were grown under different shade levels was significant at 180 DAP.

Leaf internal CO_2 recorded for the turmeric plants at 6 MAP is found to be maximum for the S_0 treatment followed by S_1 treatment. The lowest value recorded was for the S_3 treamtent. Varietal effect on leaf internal CO_2 concentration was not significant. Vareity V_1 gave a value of 236.3 μ mol mol^{-1}. The interaction (shade x variety) was not significant.

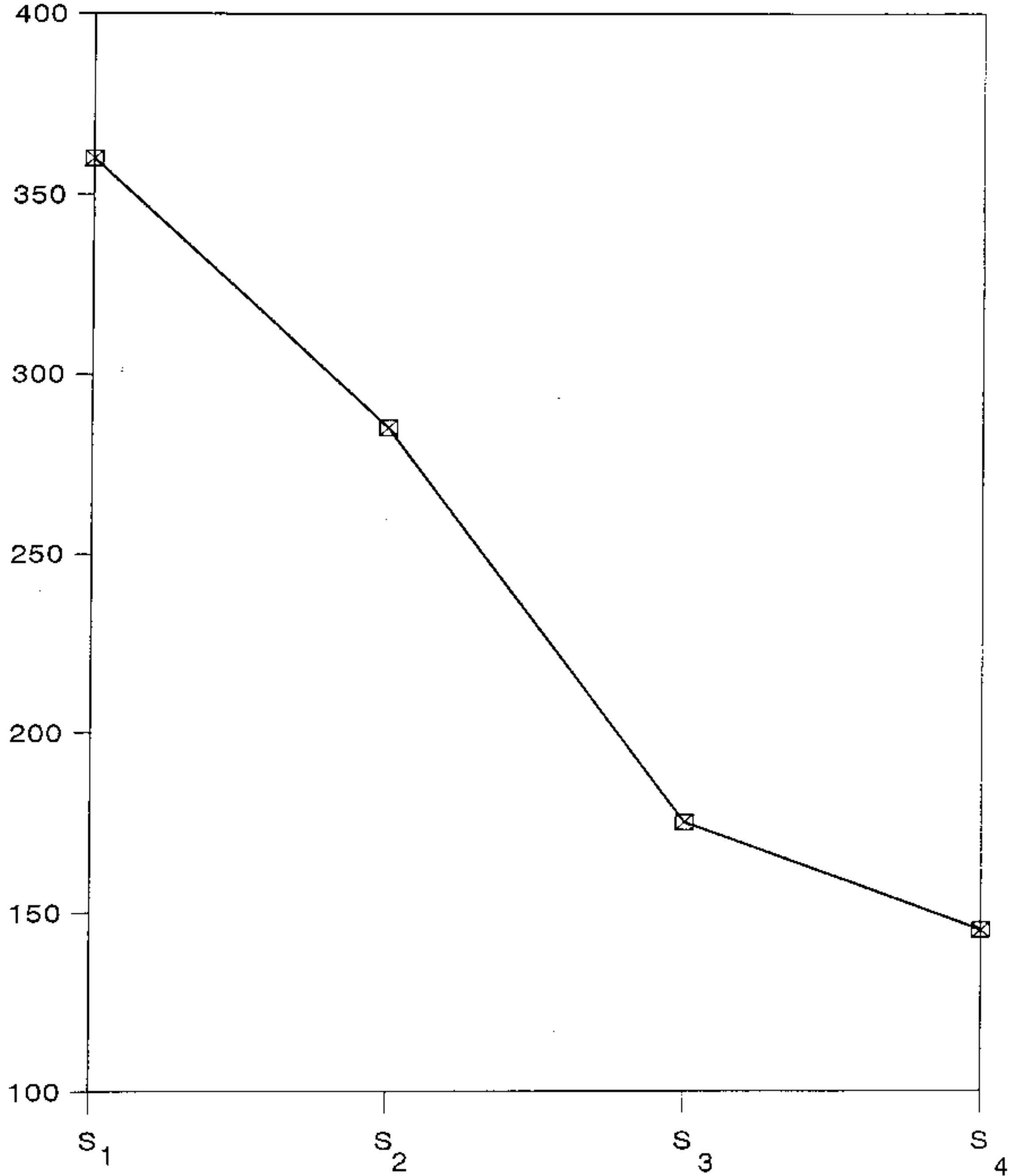


Fig. 4. Effect of shade levels and varieties on leaf internal carbon dioxide concentration at 180 DAP (µmol mol^{-1})

Table 22. Effect of shade levels and varieties on leaf internal CO_2 concentration at 180 DAP (μ mol mol^{-1})

Shade levels	Varieties			
	V_1	V_2	V_3	Mean
S_0	351.375	363.175	360.725	358.425
S_1	283.325	287.425	285.400	285.383
S_2	170.350	173.625	172.750	172.242
S_3	140.250	139.850	145.850	142.983
Mean	236.325	241.019	241.931	
CD (0.05)				
S	16.6549 (S)			
V	14.3935 (NS)			
SV	28.7871 (NS)			

4.3.2 Leaf temperature

Table 23 shows the effect of different shade levels and varieties on the leaf temperature at 180 DAP. Leaf temperature recorded for turmeric plants grown under the influence of shade levels (0, 25, 50 and 75 per cent) at 6 MAP was significant. The maximum leaf temperature of 39.2°C was recorded for the S_0 treatment. The lowest leaf temperature was recorded for the S_1 treatment. At 75 per cent shade level, the leaf temperature recorded was 32°C and for 50 per cent shade level, the leaf temperature was 31.9°C which was on par with the S_3 treatment. The varietal effect on leaf temperature was not significant. The interaction (shade x variety) was significant. S_0V_2 treatment recorded the highest leaf temperature (40.2). S_2V_3 treatment recorded the lowest leaf temperature.

Table 23. Effect of shade levels and varieties on leaf temperature at 180 DAP (°C)

Shade levels	Varieties			
	V_1	V_2	V_3	Mean
S_0	38.67	40.29	38.70	39.22
S_1	30.67	30.98	31.01	30.88
S_2	33.22	32.65	29.94	31.93
S_3	30.61	31.52	33.89	32.01
Mean	33.29	33.89	33.38	
CD (0.05)				
S	1.318 (S)			
V	0.962 (NS)			
SV	1.925 (S)			

4.3.3 Stomatal conductance

The stomatal conductance of turmeric plants at 6 MAP under the influence of different levels of shade (0, 25, 50 and 75 per cent) was significant (Table 24 and Fig. 5). The maximum stomatal conductance of 0.737 mol $m^{-2}s^{-1}$ was recorded for the S_0 treatment followed by S_1 treatment (0.4 mol $m^{-2}s^{-1}$). The varietal effect was not significant. The interaction effect was also not significant.

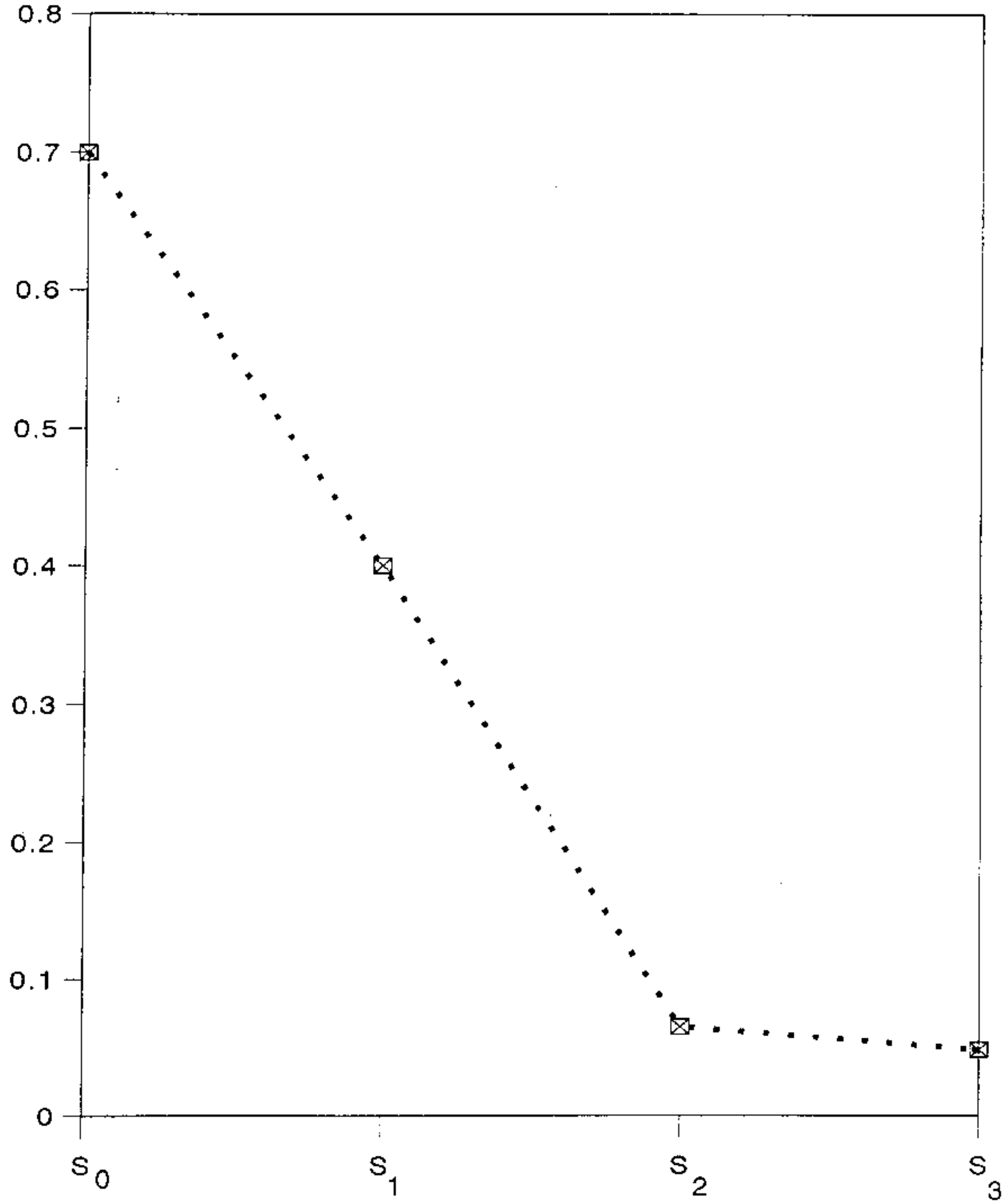


Fig. 5. Effect of shade levels and varieties on stomatal conductance (mol $m^{-2}s^{-1}$)

Table 24. Effect of shade levels and varieties on stomatal conductance at 180 DAP (mol $m^{-2}s^{-1}$)

Shade levels	Varieties			
	V_1	V_2	V_3	Mean
S_0	0.772	0.695	0.742	0.737
S_1	0.575	0.330	0.322	0.409
S_2	0.062	0.065	0.067	0.065
S_3	0.044	0.050	0.048	0.048
Mean	0.364	0.285	0.295	
CD (0.05)				
S	0.1155 (S)			
V	0.0070 (NS)			
SV	0.1514 (NS)			

4.3.4 Photosynthetic rate

The photosynthetic rate at 6 MAP for turmeric plants grown under different shade levels (0, 25, 50 and 75 per cent) was significant (Table 25 and Fig. 6). It can be arranged in the descending order as $S_0>S_1>S_2>S_3$. The highest photosynthetic rate of 7.5 μ mol $m^{-2}s^{-1}$ was recorded for the treatment S_0 followed by S_1 treatment (5.3 μ mol $m^{-2}s^{-1}$). The lowest value of 1.3 μ mol $m^{-2}s^{-1}$ was recorded for the S_3 treatment. Varietal effect of turmeric plants on the photosynthetic rate was not significant. The shade x variety interaction was not significant.

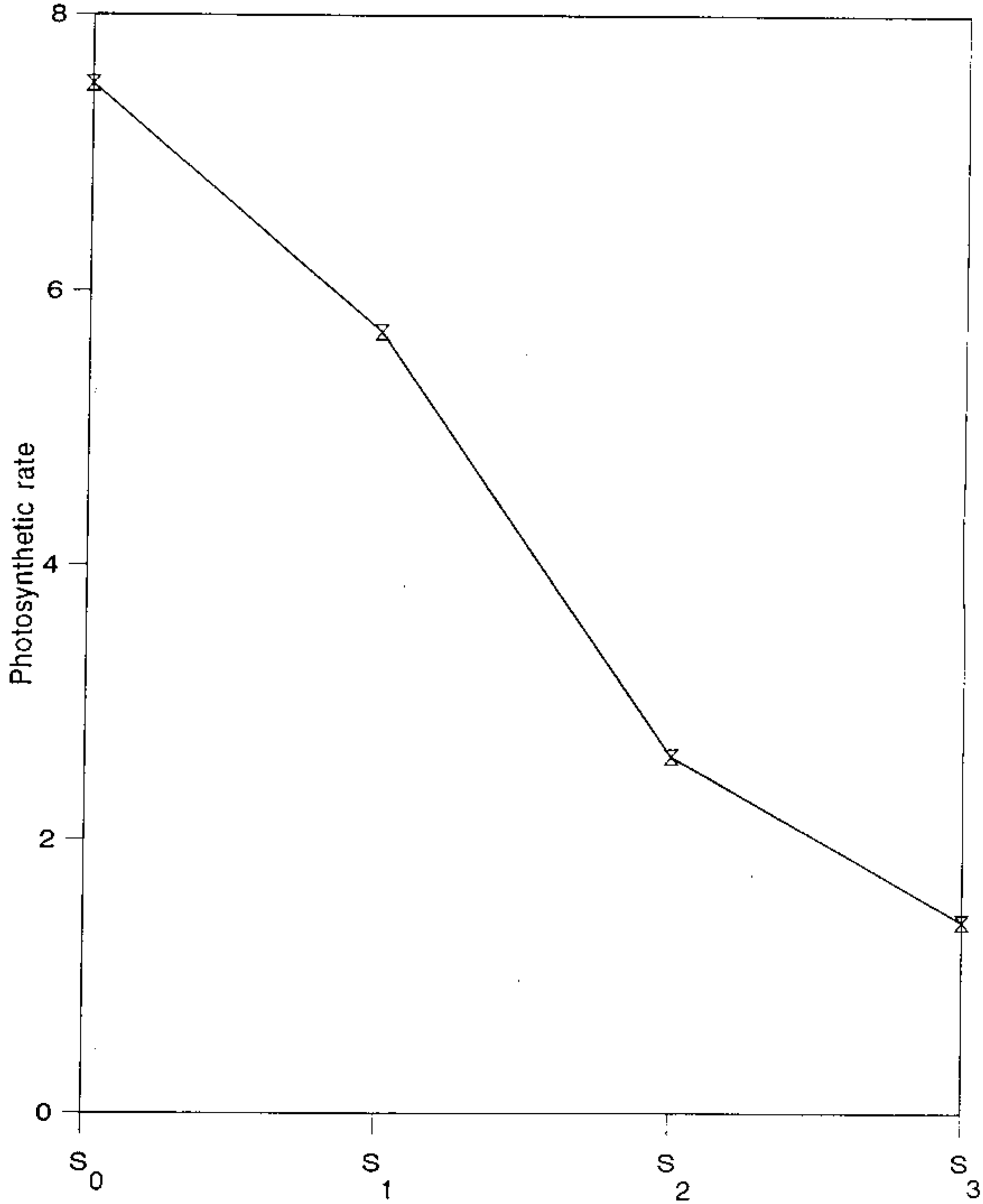


Fig. 6. Effect of shade levels and varieties on photosynthetic rate ($\mu mol\ m^{-2}s^{-1}$)

Table 25. Effect of shade on photosynthetic rate at 180 DAP (μ mol $m^{-2}s^{-1}$)

Shade levels	Varieties			
	V_1	V_2	V_3	Mean
S_0	7.72	7.60	7.31	7.54
S_1	5.13	5.50	5.32	5.72
S_2	2.34	2.77	2.31	2.64
S_3	1.42	1.35	1.26	1.35
Mean	4.15	4.30	4.17	
CD (0.05)				
S	0.809 (S)			
V	0.416 (NS)			
SV	0.832 (NS)			

4.5 Biochemical

4.5.1 Chlorophyll

The effect of shade levels and varieties on chlorophyll 'a' content is presented in Table 26 A and Fig. 7. There was significant effect of shade on the chlorophyll 'a' content in the leaves of turmeric plants at 6 MAP. The chlorophyll 'a' content was maximum at higher shade levels of 75 per cent and 50 per cent while in the open condition, the chlorophyll 'a' was lowest. The mean chlorophyll 'a' at open condition was 0.2 mg g^{-1} while that at 25 per cent shade level was 0.7 mg g^{-1} on fresh weight basis. The maximum value of 1.1 mg g^{-1} was recorded for the treatment S_3 on fresh weight basis. Varietal effect of shade was significant. Variety V_1 and V_3 was on par and variety V_2 recorded the highest value of 0.8 mg g^{-1} of chlorophyll 'a' on fresh weight basis. Shade x variety interaction on chlorophyll 'a' was not significant.

Table 26A. Effect of shade levels and varieties on chlorophyll 'a' content in the leaves (mg g^{-1} on fresh weight basis) at 180 DAP

Shade levels	Varieties			
	V_1	V_2	V_3	Mean
S_0	0.162	0.375	0.297	0.278
S_1	0.707	0.727	0.702	0.712
S_2	0.992	1.072	0.940	1.002
S_3	1.850	1.202	1.127	1.138
Mean	0.737	0.844	0.767	
CD (0.05)				
S	0.1172 (S)			
V	0.0050 (S)			
SV	0.1180 (NS)			

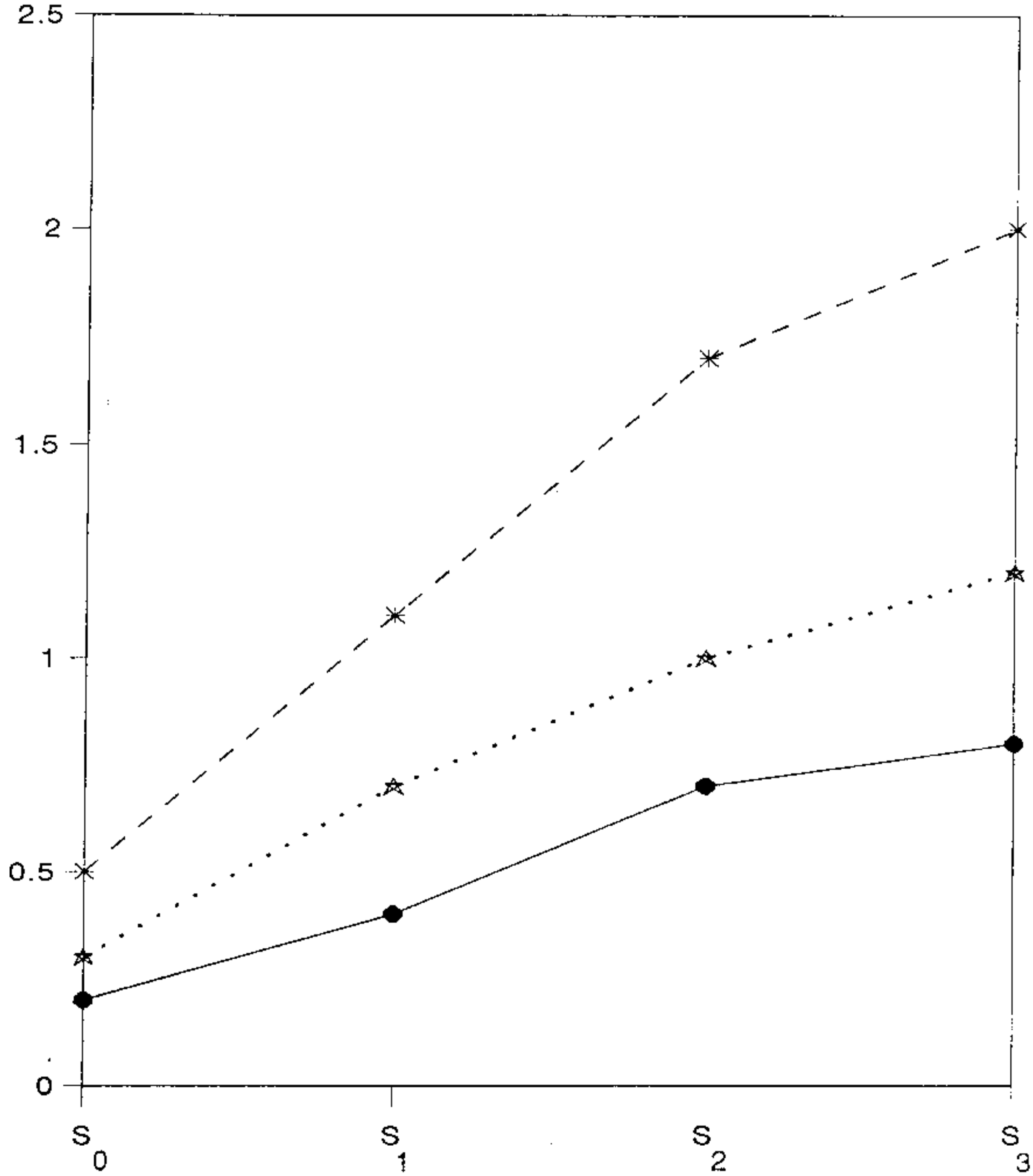


Fig. 7. Effect of shade levels and varieties on chlorophyll content (mg g^{-1}) fresh weight basis at 180 DAP

Table 26 B. Effect of shade levels and varieties on chlorophyll 'b' content in leaves (mg g^{-1} on fresh weight basis) at 180 DAP

Shade levels	Varieties			
	V_1	V_2	V_3	Mean
S_0	0.2500	0.2925	0.2325	0.258
S_1	0.4525	0.4950	0.4625	0.470
S_2	0.7400	0.7575	0.7300	0.743
S_3	0.7575	0.9380	0.7800	0.825
Mean	0.5500	0.6210	0.5510	
CD (0.05)				
S	0.0250 (S)			
V	0.04188 (S)			
SV	2.828 E-2 (NS)			

Chlorophyll 'b' content of the turmeric leaves at 6 MAP under different levels of shade was significant. Maximum chlorophyll 'b' on fresh weight basis was recorded at 75 per cent shade level. In the open condition the chlorophyll 'b' content recorded was 0.2 mg g^{-1} which was the lowest when compared to other shade levels. At 25 per cent shade level, it was recorded as 0.47 mg g^{-1} on fresh weight basis. Varietal effect on chlorophyll 'b' content of turmeric leaves was significant.

Varieties V_1 and V_3 were on par. The maximum chlorophyll 'b' content was recorded for the variety V_2. The interactions (shade x variety) were not significant.

4.6 Yield and yield components

4.6.1 Top yield

There was significant variation in the influence of shade levels on the production of the top part of the plant at 2 MAP (Table 27). The influence of shade level on top yield can be arranged descendingly as $S_3>S_2>S_1>S_0$. The lowest value (8.86 g) for dry weight of the top part of the plant was for the treatment S_0 (open condition) and the maximum value of 15.26 g was recorded for the S_3 treatment (75 % shade level). Varietal effects was found to be significant. Variety V_1 and V_3 was on par. Variety V_2 gave the maximum top yield of 12.72 g. The interactions (shade x variety) was significant. The interaction of shade level S_2 on the three cultivars was on par. Treatment S_3V_2 recorded the maximum top yield and treatment S_0V_1 gave the lowest top yield.

At 4 MAP, the effect of shade levels on the top yield of the plant was significant. Shade level of 75 per cent gave the highest top yield, while shade level of 0 per cent (open condition) recorded the lowest top yield. At 25 per cent shade level, the top yield was 22.72 g. Varietal effects was found to be significant for the top yield at 4 MAP. All the three cultivars namely varieties V_1, V_2 and V_3 recorded a top yield of 23.10 g, 24.50 g and 26.19 g respectively. The interactions (shade x variety) were not significant.

Table 27. Effect of shade levels and varieties on top yield (g $plant^{-1}$)

Shade levels	Months after planting															
	2 MAP				4 MAP				6 MAP				8 MAP			
	Varieties				Varieties				Varieties				Varieties			
	V_1	V_2	V_3	Mean	V_1	V_2	V_3	Mean	V_1	V_2	V_3	Mean	V_1	V_2	V_3	Mean
S_0	7.62	10.23	8.75	8.86	16.98	17.50	18.40	17.62	57.80	59.42	54.85	57.39	14.17	14.60	15.30	14.69
S_1	9.98	11.45	10.28	10.57	23.15	21.97	23.05	22.72	59.42	62.67	64.17	62.09	15.50	16.92	16.97	16.46
S_2	13.28	13.27	13.60	13.75	23.72	25.20	27.33	25.41	65.52	64.92	61.12	63.85	20.85	18.65	18.25	19.25
S_3	14.91	15.92	14.95	15.26	28.57	33.65	36.00	32.74	61.40	61.37	61.80	61.69	17.52	14.72	18.45	18.56
Mean	1.45	12.72	11.89	-	23.10	24.50	26.19	-	61.03	62.22	60.51	-	17.01	17.47	17.24	-
CD (0.05)																
S	1.054 (S)				7.865 (S)				2.843 (S)				2.360 (S)			
V	0.433 (S)				2.189 (S)				4.130 (NS)				1.367 (NS)			
SV	0.866 (S)				4.378 (NS)				8.260 (NS)				2.734 (NS)			

(S) - Significant (NS) - Not significant

The influence of shade levels at 6 MAP was found to be significant. The treatment S_2 (50% shade) produced the maximum dry weight (63.85 g) followed by S_1 (62.00 g). Treatment S_0 (open condition) recorded the lowest dry weight of the top part of the plant (57.39 g). Varietal effects was not significant and variety V_2 gave the highest (62.22 g) top yield. Shade x variety interactions were not significant.

At 8 MAP, the effect of shade level on the dry weight of the top part of the plant was significant. The highest value of 19.25 g was recorded for the treatment S_2 and the lowest mean value of 14.69 g was recorded for the treatment S_0. The effect of varieties on the top yield of turmeric plants was not significant. Shade x variety interactions were not significant.

4.6.2 Yield

Shade levels of 0, 25, 50 and 75 per cent had a significant effect on the yield of fresh rhizome of turmeric (Table 28 and Fig. 8). The maximum yield was recorded at 25 per cent shade level. In the open condition the yield recorded was 24.08 t ha^{-1}. The lowest yield of 17.78 t ha^{-1} was recorded under 75 per cent shade level. Varieties, Kanthi and Alleppey were on par with yields of 31.18 and 31.46 t ha^{-1} at 25 per cent shade level and also in the open condition these two varieties were on par. Varietal effect of shade on yield was significant. Varieties V_2 and V_3 were on par. Variety V_1 gave the highest yield of 24.54 t ha^{-1}. The interactions (shade x variety) were not significant.

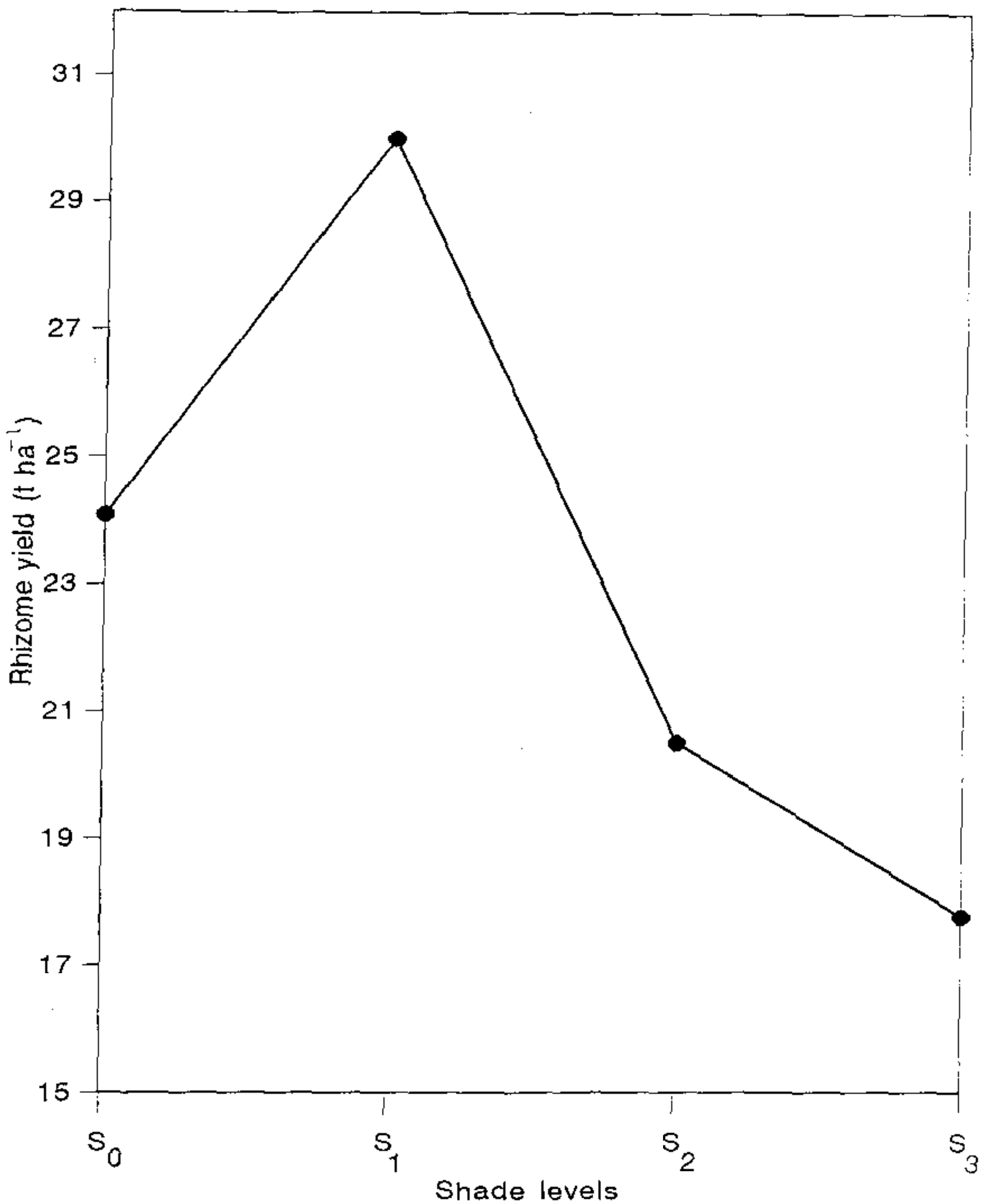


Fig. 8. Effect of shade levels and varieties on fresh rhizome yield (t ha^{-1})

Table 28. Effect of shade levels and varieties on the turmeric yield at 240 DAP (t ha^{-1})

Shade levels	Varieties			
	V_1	V_2	V_3	Mean
S_0	26.22	25.64	20.39	24.083
S_1	31.46	31.18	27.38	30.006
S_2	21.84	18.95	20.75	20.513
S_3	18.66	16.62	18.06	17.785
Mean	24.545	23.097	21.645	-
CD (0.05)				
S	2136.8510 (S)			
V	1697.2477 (S)			
SV	3394.6353 (NS)			

4.6.3 Bulking rate

The data presented in Table 29 show the effect of shade levels and varieties on bulking rate.

During the growth period of 2 to 4 MAP the effect of different levels of shade (0, 25, 50 and 75 per cent) on the bulking rate was significant. Maximum bulking rate was observed at 25 per cent shade level (0.629). A bulking rate of 0.515 was observed at open condition. With increase in shade levels the bulking rate was found to decrease. Varietal effects and interactions (shade x variety) were insignificant.

Table 29. Effect of shade levels and varieties on the bulking rate of turmeric rhizomes

Shade levels	Months after planting											
	2 - 4 MAP				4 - 6 MAP				6 - 8 MAP			
	Varieties				Varieties				Varieties			
	V_1	V_2	V_3	Mean	V_1	V_2	V_3	Mean	V_1	V_2	V_3	Mean
S_0	0.3407	0.5988	0.6045	0.515	0.9650	0.8920	1.0070	0.955	1.344	1.503	1.180	1.343
S_1	0.5725	0.7670	0.5465	0.629	0.8580	0.7575	1.0108	0.875	1.921	1.939	2.076	1.979
S_2	0.4800	0.3583	0.4013	0.413	0.9763	1.0200	0.9100	0.969	0.851	0.683	0.571	0.704
S_3	0.3290	0.2407	0.2865	0.285	0.9130	0.7875	0.8841	0.8620	0.544	0.495	0.680	0.574
Mean	0.4310	0.4910	0.4600	—	0.9280	0.8640	0.9530	—	1.167	1.155	1.127	—
CD (0.05)												
S			0.2162 (S)				0.3339 (NS)				0.4672 (S)	
V			0.1347 (NS)				0.1073 (NS)				0.2501 (NS)	
SV			0.2695 (S)				0.2147 (NS)				0.5003 (NS)	

(S) - Significant (NS) - Not significant

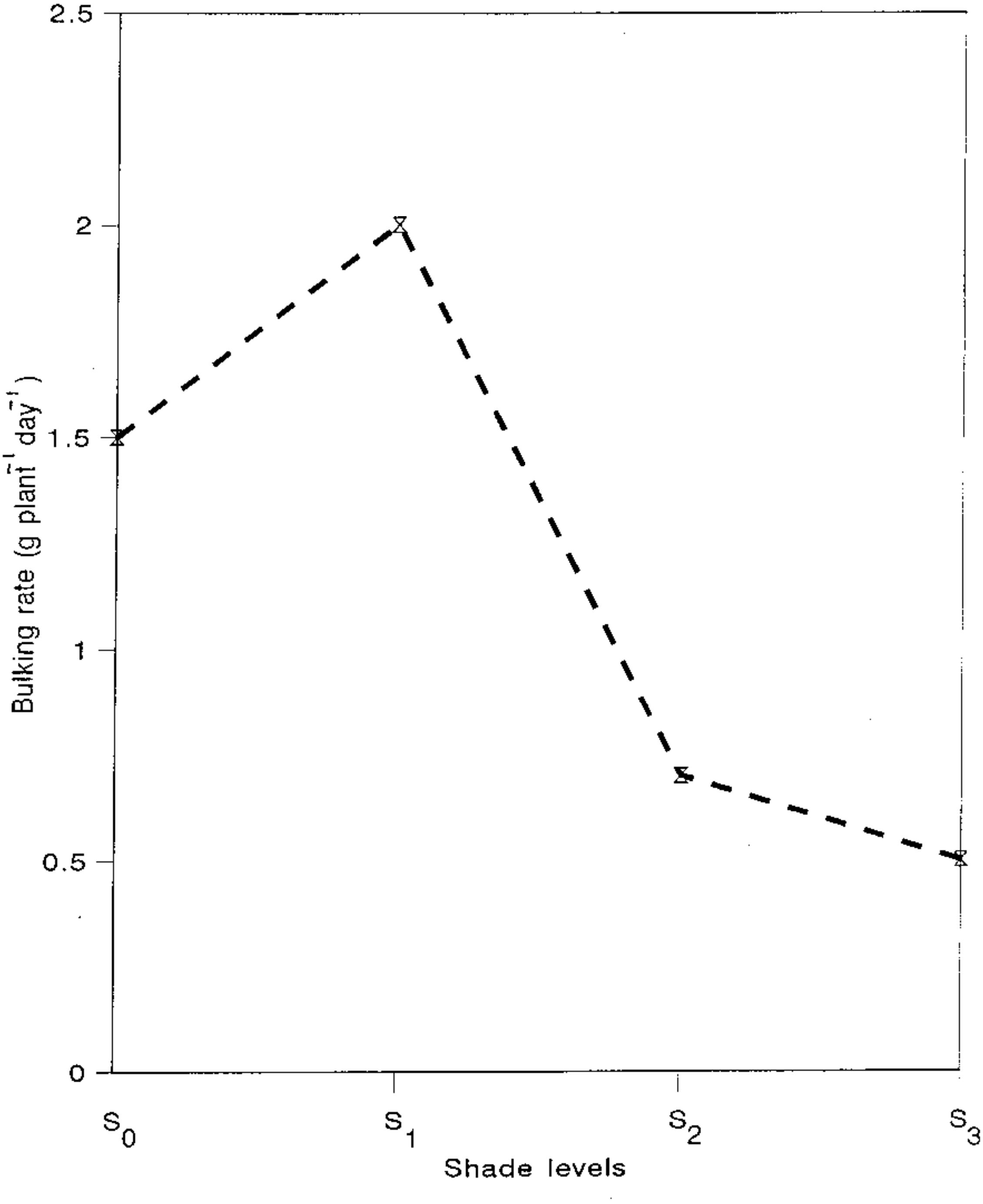


Fig. 9. Effect of shade levels and varieties on bulking rate at 6-8 MAP

The effect of different levels of shade (0, 25, 50 and 75 per cent) on the bulking rate was found to be insignificant for the growth periods of 4-6 MAP. Varietal effects and interactions were insignificant during this growth period.

The bulking rate of turmeric at 6-8 MAP was found to be significant. S_1 treatment gave the highest bulking rate (1.979) followed by the open condition (1.3). The lowest bulking rate was recorded from the S_3 treatment. At 50 per cent shade level it was 0.704. The highest bulking rate was recorded for the variety Sobha (2.0). Varietal effect of shade and its interaction (shade x variety) were insignificant.

4.7 Quality analysis

4.7.1 Volatile oil

At 8 MAP, the influence of different shade levels and varieties (0, 25, 50 and 75 per cent) on volatile oil content of turmeric rhizomes was significant (Table 30). There was an increasing trend in the volatile oil content with increased shade level. The maximum volatile oil was recorded at shade level of 75 per cent and the least in the open condition. Varietal effect on the volatile oil content was not significant. The interaction (shade x variety) was significant. The highest voltaile (6.2%) oil content was recorded by the S_3V_2 treatment and the lowest (2.2%) by S_0V_1 treatment.

Table 30. Effect of shade levels and varieties on the volatile oil content (v/w %) of turmeric rhizomes

Shade levels	Varieties			
	V_1	V_2	V_3	Mean
S_0	2.25	2.45	2.62	2.50
S_1	3.32	3.65	4.05	3.67
S_2	4.40	4.30	4.35	4.35
S_3	6.10	6.25	6.12	6.15
Mean	4.22	4.21	4.28	-
CD (0.05)				
S	0.497 (S)			
V	0.154 (NS)			
SV	0.308 (S)			

4.7.2 Curcumin content

The influence of shade levels and varieties on the curcumin content of turmeric rhizomes was significant (Table 31). The curcumin content was found to be maximum at 50 per cent shade level and the lowest was recorded at open condition. The curcumin content recorded for all the three turmeric cultivars were on par. Varietal effects and the interaction effects (shade x variety) was not significant. Variety, Kanthi recorded the maximum curcumin content (7.0) at 50 per cent shade level and the lowest was recorded by the variety Alleppey (4.5) at open condition.

Table 31. Effect of shade levels and varieties on the curcumin content of turmeric rhizomes (%)

Shade levels	Varieties			
	V_1	V_2	V_3	Mean
S_0	4.87	4.69	4.51	4.69
S_1	5.06	5.03	5.12	5.07
S_2	7.04	6.82	6.75	6.87
S_3	5.89	5.81	6.20	5.97
Mean	5.71	5.59	5.64	
CD (0.05)				
S	0.356 (S)			
V	0.364 (NS)			
SV	0.728 (NS)			

DISCUSSION

5. DISCUSSION

Sunlight is the primary source of energy for photosynthesis. The yield of a plant is mainly determined by the factors associated with solar radiation namely its intensity, quality and duration. Light is a significant factor which has a direct bearing on photosynthesis, photorespiration and translocation of assimilates to economic parts. When light becomes a limiting factor as encountered under shaded situations, the processes of photosynthesis and partitioning of photosynthates into economically important plant parts are partially modified and needs to be therefore investigated in detail.

The differential response of turmeric to shade, based on the studies conducted at various locations in India and elsewhere established the shade loving/ tolerant nature of turmeric. Turmeric is recommended to be grown as an intercrop in India either in coconut based cropping system or arecanut based cropping system, the amount of solar radiation reaching the plantation floor is limited or restricted. So the degree of shade tolerance of the intercrop, turmeric, is an important factor in determining the productivity. Hence there is a need to assess performance of turmeric under shaded condition in terms of the various morphological, physiological and biochemical characters which ultimately can lead to a conclusion on the adaptability of turmeric to low light levels.

5.1. Morphological

5.1.1. Growth characters

5.1.1.1. Plant height

A general increasing trend in plant height with increasing shade intensity from 0 to 75 per cent was observed. Open condition has recorded the lowest plant height during all the growth periods. Maximum plant height was recorded for the variety Alleppey (Table 1). The results shows that the mean plant height was (61.1 cm) in the open condition and the maximum plant height was (70.2 cm) at 50 per cent shade level. This finding is in agreement with the results of Bai and Nair (1982) in turmeric. Observation of Susan (1989) in turmeric that 50 per cent shade level accorded the highest plant height and open condition gave the shortest plant which also supports the result.

According to Meyer and Anderson (1952) high irradiance may result in high rates of transpiration which are likely to result in internal deficiencies of water and a consequent retardation of cell division or cell enlargement which ultimately results in low height in plant under open condition.

5.1.1.2. *Number of tillers*

There was significant difference between shade levels, with respect to tiller production. According to Bai and Nair (1982) tiller production was not affected by shade. However in the present study the number of tillers per plant was found to be low in open condition, except at 4 MAP, and the highest number of tillers / plant was observed at 25 per cent shade level. In the present study tiller production for shade levels of 50 and 75 per cent during the period of 6 MAP and 8 MAP was on par (Table 2).

The possible reason that can be attributed to this phenomena is that the available low light intensity may be inadequate to stimulate the production of new tillers. Maximum tiller production was observed to be at 25 per cent shade level which can be considered to contribute the optimum light intensity for tiller production.

5.1.1.3. Number of leaves

At all growth stages there was significant variation in the number of leaves per plant with different shade levels especially the leaf production was maximum at 75 per cent shade level. The lowest leaf production was recorded under open condition (Table 3). In the present investigation the result obtained contradicts the findings of Sheela (1992), Susan (1989) and KAU (1992). Their finding is that the maximum number of leaves was recorded in the open condition. The maximum number of leaves recorded under 50 and 75 per cent shade levels may be due to the less evapo-transpiration and improved microclimate which favours the morphological growth of the crop in terms of plant height and number of leaves.

5.1.1.4. Leaf area

Leaf area was found to increase at different shade levels during all the growth stages of the crop. The effect of shade levels of 0, 25, 50 and 75 per cent on the leaf area recorded much variation during all the growth stages. Maximum leaf areas recorded at 2 MAP, 4 MAP, 6 MAP and 8 MAP were S_3, S_1, S_3 and S_2 treatments respectively (Table 4). Bai (1981) reported that leaf area was not influenced by different intensities of shade in ginger, turmeric and coleus. The tendency of increase in leaf area under heavy shade levels was reported by Ravisankar and Muthuswamy (1988), Ancy (1992) and George (1992). The increasing leaf area under heavy shade may be due to the reduced irradiation which can prevent scorching or wilting of leaves and also the reduced leaf temperature, thereby favouring the retention of more number of leaves. The increased leaf area under shade may be the phenomenon of the plants adaptation to expose larger photosynthetic surface under limited illumination (Attridge, 1990).

5.1.1.5. Leaf weight

The highest dry weight of leaf was recorded at 75 per cent shade level and the lowest under open condition (Table 5). The maximum number of leaves, plant height and more number of tiller production during all the growth stages may be the reason for maximum leaf dry weight.

5.1.1.6. Leaf thickess

Leaf thickness was found to be maximum at 25 per cent shade level during all the growth stages of the crop and the next higher leaf thickness was recorded in the open condition (Table 6). Plants grown in the open condition and shade showed much difference in leaf morphology, like thicker leaf, stronger development of the palisade and spongy mesophyll cells. It is found that shade plants in their native habitats usually have thin leaves with a lower fresh weight per leaf area (Rabinowitch, 1945; Bjorkman, 1968; Good Child *et al.*, 1972).

5.1.2. Root characters

5.1.2.1. Root weight

The dry weight of the root was found to show an increasing trend for the shade levels of 0 per cent and 25 per cent during 2, 4 and 6 MAP. At 8 MAP, there was a general decreasing trend in root weight. This decreasing trend in the root weight after 6 MAP may be due to the death of roots formed initially. Plants grown under heavy shade are found to have low root weight at 8 MAP. The probable reason may be that there is less loss of moisture from the cells and the microclimate is highly favourable for retention of moisture both at the cellular region and also in the soil. This aspect might have indirectly resulted in low root weight.

5.1.2.2. Root spread

Root spread was found to be maximum and on par with shade levels of 0 per cent and 25 per cent during 4 MAP and 8 MAP (Table 8). While the maximum root spread was recorded at 25 per cent shade level followed by the next level at open condition for the periods of 2 MAP and 6 MAP.

The congenial shade at 25 per cent might have resulted in maximum spread of roots under 25 per cent shade. At heavier shade root spread was less.

5.1.2.3. Root length

At 2, 4 and 6 MAP maximum root length was recorded at 25 per cent shade level followed by open condition (Table 9). At 8 MAP maximum root length was found in open. The increase in root length may be due to the increased evapotranspiration and so the retention of moisture within the cells and also the soil is less. So there is a need to balance the water uptake and loss of moisture from the cells and the root development is maximum thereby the depth and penetration of root system increases. At 180 DAP and 240 DAP, root length was found to decrease which may be due to the death of roots formed initially. According to

Jayachandran (1998) the number of roots originating from the first daughter rhizome was more than that from the later produced daughter rhizomes. The possible reason for the rate of reduction in root length can be due to the fact that the fresh rhizomes (daughter rhizomes) are also producing roots which may not get sufficient growing period to produce longer roots as in the case of initial roots.

5.1.3. Rhizome characters

5.1.3.1. Rhizome spread

Rhizome spread was found to be maximum for the shade level of 25 per cent during all the growth periods and the lowest rhizome spread was recorded at 75 per cent shade level (Table 10). Babu (1993) recorded more rhizome spread at 25 per cent shade in ginger, while Sreekala (1999) recorded the lowest rhizome spread in the open condition.

In the present investigation the rhizome spread was maximum at 25 per cent shade level indicating that light shade is optimum for the accumulation of photosynthates in turmeric.

5.1.3.2 Number of finger rhizomes

The number of finger rhizomes/plant was found to be maximum at 25 per cent shade level (S_1) followed by S_0 (open condition). The lowest value recorded was for treatment S_3 (75 per cent shade level) (Table 11). Favourable low light intensity might have helped in more accumulation of carbohydrates and it can result in increased rhizome spread and number of finger rhizomes.

5.1.3.3. Rhizome thickness

Rhizome thickness was found to be maximum at 25 per cent shade level and the next best shade level was the open condition (0 per cent). Rhizome thickness was the lowest under heavy shade levels (Table 12). It is clear from the present investigation that the rhizome characters namely rhizome spread, number of finger rhizomes/plant and rhizome thickness are found to be positively correlated with the shade factor at 25 per cent shade level followed by the S_0 treatment. This can be explained by the fact that the optimum light intensity is necessary for the process of photosynthesis and the translocation and partitioning of photosynthates to economic plant part namely the rhizome.

5.2. Physiological

5.2.1. Dry matter production

Maximum dry matter production was reported from 25 per cent shade followed by plants grown under open condition during all the growth stages of the crop. Caesar (1980) reported an increase in dry matter accumulation at higher shade levels in *Xanthosoma sagittifolium*. A similar increase in DMP in ginger was observed by Susan (1989), Ancy (1992), George (1992) in ginger. Babu (1993) observed an increase in

DMP under 25 per cent shade, Prameela (1990) reported highest DMP at 25 per cent shade level and there was a drastic reduction in DMP at 50 and 70 per cent shade, the extent of decrease being 22 and 27 per cent respectively of DMP at 0 per cent per cent. According to Bai and Nair (1982), DMP in ginger followed a quadratic pattern with the maximum value between 25 and 50 per cent. The lowest DMP was seen in 75 per cent shade and the DMP at 25, 50 and 75 per cent shade were 75, 63 and 46 of the dry weight in the open, respectively (KAU, 1992). The above results on DMP in ginger and turmeric confirm that the highest DMP is at 25 per cent shade level (Table 13). The results reveal that the low level of shade (25%) and the resultant microclimate induced good vegetative growth and higher rhizome production. In the present investigation the result obtained is in confirmity with the results established by the earlier investigators.

5.2.2. Crop growth rate

The variation observed in crop growth rate under different shade levels reveal significant variation at growth periods of 120 to 180 DAP and 180 to 240 DAP. Maximum CGR was reported from turmeric plants grown under 25 per cent shade followed by plants grown under open condition (Table 14) at 180-240 DAP. Minimum CGR was observed in plants grown under heavy shade (75 per cent) at all growth periods. According to Ancy (1992) and Babu (1993) maximum CGR was reported from ginger plants grown under 25 per cent shade.

Low shaded conditions (25 per cent shade) seems to be favourable for enhanced CGR. The higher leaf area index and other favourable conditions might have reflected in higher CGR. The CGR value at 25 per cent was slightly higher by 0.56 than the CGR value at open condition which reveals that shade level of 25 per cent is favourable for the growth of turmeric plants. Apart from this observation it is found that very high shade level of 75 per cent is detrimental to the growth of the plants.

5.2.3. Relative growth rate

The effect of shade on relative growth rate was found to be insignificant (Table 15) at all growth phases. The mean relative growth rate was less than 0.1 during all the growth periods.

5.2.4. Net assimilation rate

NAR was found to be significant only during the growth period of 120-180 DAP. Maximum NAR between 120-180 DAP was reported from open condition (Table 16). This finding is in agreement with the results of Ancy (1992) and Sreekala (1999) for ginger plants. Blackman and Wilson (1951), Newton (1963) and Coombe (1966) reported a positive correlation between NAR and irradiance. The high rate of NAR is due to high rate of photosynthesis. With increase in shade level, the photosynthetically active radiation falling on the leaf surface will be less which finally reflected in a low NAR for 75 per cent shade level.

5.2.5. Specific leaf weight

Significant variation in specific leaf weight under different shade levels was reported during all the growth phases except at 8 MAP. The lowest SLW was recorded for turmeric plants grown under open condition during the growth periods of 2 MAP and 4 MAP. At 6 MAP, S_0 treatment recorded a SLW of 0.003 g cm^{-2} (Table 17). This finding is in agreement with the findings of Syvertsen and Smith (1984) who reported highest SLW under full sun. SLW is dependent on the leaf weight and leaf area.

5.2.6. Leaf area index

The effect of shade on leaf area index was significant at all growth stages. At 2 MAP and 6 MAP maximum leaf area index was recorded from S_3 treatment while at 4 MAP and 8 MAP, the maximum leaf area index were recorded from treatments S_1 and S_3 respectively (Table 18). Bai (1981) reported no influence of LAI under different shade intensities in ginger, turmeric and coleus. Ravisankar and Muthuswamy (1988) and Ancy (1992) observed maximum LAI under low shade levels.

5.2.7. Leaf area duration

The effect of shade on leaf area duration was significant for the growth period of 60 to 120 DAP, while the rest of the growth periods (120 to 180 DAP and 180 to 240 DAP) were insignificant. Varietal effects and interactions were insignificant during all the growth periods (Table 19).

5.2.8. Harvest Index

Harvest index was found to be significantly influenced by shade levels and the maximum HI value of 0.921 was recorded for 25 per cent shade level and in the open condition it was 0.916. The lowest value of HI was recorded for 75 per cent shade level (Table 20). This trend shows that the photosynthates produced was assimilated efficiently into the rhizome. The rhizome yield was high and hence higher HI. Under heavier shade less photosynthates was produced and the DMP was low. The finding of Susan (1989) and Prameela (1990) is that light shading increased the harvest index of ginger and colocasia which substantiate the above result in this investigation. Bai and Nair (1981) found that the HI decreased with increasing shade indicating that the partitioning factor are involved in reducing yield beyond the optimum shade.

5.2.9. Root / Shoot ratio

Root shoot ratio was found to be significant at all the growth stages. Open condition recorded the maximum root / shoot ratio being the growth periods of 2 MAP and 4 MAP and during 6 MAP, it was 25 per cent shade level (Table 21). Cripps (1971) in apple, reported high root / shoot ratio at open condition. It is possible that the moisture stress in the soil under open condition may have reduced the shoot growth and resulted in high root shoot ratio.

5.3. Photosynthetic rate and related parameters

5.3.1. Leaf internal carbon-dioxide concentration

Leaf internal CO_2 concentration showed significant variation with respect to different shade levels. Sreekala (1999) reported that more leaf internal CO_2 for ginger plants grown under heavier shade levels of 60 and 80 per cent. In the present investigation on the leaf internal CO_2 concentration, it was observed that the maximum leaf internal CO_2 concentration of 358.425 u mil mol^{-1} was recorded in the open condition (Table 22).

5.3.2. Leaf temperature

Leaf temperature was found to vary for turmeric plants grown under different shade levels. The maximum leaf temperature was under open condition and under heavier shade levels of 50 and 75 per cent, the temperatures were on par (Table 23). Plants grown at 25 per cent shade level showed an internal leaf temperature of 30°C. Internal leaf temperature variation can be due to the influence of the atmospheric conditions (especially light intensity) and also the influence of microclimate under shaded situations.

5.3.3. Stomatal conductance

Under different shade levels, the stomatal conductance showed significant variation. The plants grown under open condition exhibited significant superiority over the S_1 treatment (Table 24). The tendency of the plants to decrease the stomatal conductance with increase in shade levels was observed. The changes in stomatal frequency and therefore the maximum stomata per unit area of leaf correlated with the maximum stomatal conductance (Holmgren, 1968; Bjockman *et al.* 1972; Edwards and Ludwig, 1975; Crookston *et al.*, 1975). In the present investigation it was found that the stomatal conductance of 0.737 mol m^{-2} s^{-1} was recorded at 0 per cent shade level and in 25 per cent it was 0.409 mol $m^{-2}s^{-1}$. This finding is in agreement with the findings of Ludlow and Wilson (1971) who reported a four fold increase in stomatal conductance in *Panicum maximum* at high light intensity.

5.3.4. Photosynthetic rate

Photosynthetic rate showed significant variation under different shade levels (Table 25). Photosynthetic rate under open condition was more followed by 25 per cent shade level. The yield also was high under 25 per cent shade level. Better performance of ginger and turmeric under light shade than in open is reported by Aclan and Quisumbing (1976), Bai (1981), Susan (1989), Ancy (1992) and Babu (1993). Photosynthetic rate was found to increase with increasing levels of PAR. PAR was high under 0 per cent shade and hence high photosynthetic rate. Ginger appeared to be efficiently utilising low light intensity for its photochemical reaction (Minoru and Hari, 1969). According to Kochhar (1978), direct strong sunlight can cause photooxidation with the use of oxygen and release of CO_2 which reduces the photosynthetic efficiency. This may be the reason for less yield under direct sun when compared to 25 per cent shade level. Under 25 per cent shade level, it is found that the yield was high, which clearly points to the fact that there may be a threshold illumination intensity for optimum performance of photosynthesis which can be safely concluded to be at 25 per cent shade level. It can also be inferred that the high photosynthetc rate in the open condition can also result in the accumulation of relatively high carbohydrate level and also increased degradation of carbohydrates caused by increased respiration at high light intensity. At intense shade, photosynthetic rate was very low.

5.4. Biochemical

5.4.1. Chlorophyll content

There was a very consistent and conspicuous trend of increase in chlorophyll 'a', 'b' and total chlorophyll with increasing shade levels. (Table 26). This result is in agreement with the finding of Bai (1981), Ramanujam and Jose (1984), Susan (1989), Ancy (1992), Babu (1993), Sreekala (1998), Sheela (1992) and KAU (1992).

The lower chlorophyll content in some leaves may be attributed to the decomposition of chlorophyll under intense light (Kochhar, 1978). The increase in chlorophyll content under shaded conditions is an adaptive mechanism commonly observed in plants to maintain the photosynthetic efficiency (Attridge, 1990). Heavier shade limited the efficient utilisation of increased chlorophyll content. The higher leaf content of chlorophyll was also apparent in the visual appearance of the crop and it looked distinctly green under shade than in the open.

5.5. Yield and yield components

5.5.1. Top yield per plant

Top yield of turmeric plants were significant under different shade levels during all the growth periods. It was found that during the growth period of 2 MAP and 4 MAP, maximum top yield was recorded for the S_3 treatment (75 per cent shade level) while at 6 MAP and 8 MAP, the top yield was maximum for the S_2 treatment (50 per cent shade level) (Table 27). The lowest value for the top yield was recorded in the open condition during all the growth phases. This result is not in agreement with the findings of Susan (1989) and Sheela (1992).

5.5.2. Yield

The effect of shade on the yield of turmeric 8 MAP was found to be significant at 25 per cent level which recorded the maximum yield followed by the open condition (Table 28). Susan (1989), Jayachandran *et al.* (1990), Ancy (1992), George (1992) and Babu (1993) reported maximum ginger yield at 25 per cent shade. Bai and Nair (1982) reported a maximum yield of 53.26 t/ha of turmeric on fresh weight basis at 50 per cent shade level. Sheela (1992) also reported maximum yield at 50 per cent shade. In a similar study, it was found that turmeric can come up well under shade at least up to the intermediate level of about 50 per cent and give reasonable yields (KAU, 1992). Yield is a function of DMP and BR. The photosynthetic rate was found to be more under 25 per cent shade level and also the translocation and utilisation of photosynthates to economic parts is more at 25 per cent shade level. Kochhar (1978) reported the inhibitory effect of strong light on photosynthesis wherein photooxidation of certain cell constituents takes place with the use of O_2 and the release of CO_2. This can ultimately reduce the photosynthetic efficiency. This may be the reason for the poor performance of turmeric under open condition when compared to low shade of 25 per cent. Apart from this, Hardy (1958) explained the better performance of some crops under low shade due to the presence of a threshold illumination intensity beyond which the functionality of cells breaks down due to increased photorespiration, denaturation of enzymes and photo-oxidation.

5.5.3. Bulking rate

In the present investigation the bulking rate at 6-8 MAP was found to be maximum at 25 per cent shade level followed by the open condition (Table 29). Intense shade reduce bulking rate and this may be attributed to reduced photosynthetic efficiency as evident from dry matter production. Zara *et al.* (1982) and Robert Nkrumah *et al.* (1986) in cassava and Ancy (1992), George (1992) and Babu (1993) in ginger, also reported the same results.

5.6. Quality analysis

5.6.1. Volatile oil

A significant change in volatile oil content under various shade levels was shown in Table 30. Heavier shade levels showed more volatile oil content. S_0 recorded the least volatile oil content. Light regimes received by plant determine the productivity and quality of its produce (Tikhromiro *et al.*, 1976). Shade grown plants show higher volatile content which may be due to the accumulation of secondary metabolites such as resins, resin acids, unoxidised sugars and undergoes oxidation, degradation, isomerisation and polymerisation (Zachariah and Gopalan, 1987).

5.6.2. Curcumin content

The curcumin content was maximum at 50 per cent shade level and the lowest was for the open condition (Table 31). This finding in the present investigation is in conformity with the finding of Sheela (1992) plants grown under 50 per cent shade save higher curcumin content. Jayaraj (1990) reported the maximum curcumin content at 25 per cent shade level with an increase in potassium level. The results of the present study indicates the beneficial effect of shade levels in enhancing curcumin content and thereby the quality of the produce.

The results of the present investigation indicate that turmeric is a shade tolerant / loving crop. Parameters like number of tillers, rhizome spread and thickness, crop growth rate, dry matter production, bulking rate and harvest index observed for plants grown under 25 per cent shade was the highest. These factors contributed positively to the yield and the plants grown under 25 per cent shade level produced significantly higher rhizome yield.

Though photosynthetic rate was maximum under open condition, the yield was high under 25 per cent shade level. The probable high level of photo oxidation and photo respiration under open condition may be one possible reason for low yield under open condition. In 50 and 75 per cent shade levels, though the chances of photo oxidation and photo respiration were less, the low level of photosynthetic rate and increased vegetative growth, probably at the expense of translocation of photosynthates to rhizome, might have contributed to lower yield compared to the yield under 25 per cent shade level. The higher yield in plants grown under 25 per cent shade level compared to open, 50 and 75 per cent shade level indicate that low shade level is more favourable for growth and yield of turmeric.

The results of quality parameters like volatile oil and curcumin content also reveal the beneficial effect of shade in enhancing the quality of turmeric rhizomes.

SUMMARY

6. SUMMARY

An experiment was conducted at the College of Agriculture, Vellayani, for studying the effects of different levels of shade (0, 25, 50 and 75 per cent) on the photosynthetic efficiency, growth, yield and quality of turmeric (*Curcuma longa* L.) under varying levels of shade adopting split plot design with four shade levels as main plots and three varieties (Kanthi, Sobha and Alleppey) as subplots. The number of replications was four. Shade levels of 25, 50 and 75 per cent were provided with high density polyethylene nets spread over pandals. Quantum photosensors was used for calibration of the shade. The salient findings are summarised below.

The plant height recorded from open condition was significantly low. Under shade, the plant height showed an increasing trend with increasing shade intensity.

The highest number of tiller production was noted under 25 per cent shade at all growth stages except at 120 DAP. The lowest number of tiller production was noted under 75 per cent shade during the growth periods of 60 DAP and 120 DAP, while at 180 DAP and 240 DAP, open condition recorded the lowest tiller production.

The number of leaves per plant was found to be minimum under open condition during all the growth periods. Under heavy shade the leaf number was more and the size of the leaf was high which resulted in more leaf area than open condition. Leaf weight was high under heavy shade.

Rhizome spread was found to be maximum at 25 per cent shade level and was significantly superior when compared to all the other shade levels. The number of finger rhizomes per plant was found to be significantly superior at 25 per cent shade level when compared to other shade levels. Rhizome thickness was found to be maximum at 25 per cent shade level and with increasing shade levels the rhizome thickness was found to decrease.

Dry matter production was observed to be higher under 25 per cent shade followed by open condition. Under open condition DMP was found to be higher than that under heavy shade.

Crop growth rate showed significant variation during all the growth periods. Maximum CGR was recorded from S_3 treatment at 60-120 DAP. Open condition recorded the maximum CGR at 120-180 DAP and during the growth period of 180-240 DAP, maximum CGR was recorded at 25 per cent shade.

NAR was significant only during the growth period of 120-180 DAP. Maximum NAR during this period was recorded at open condition followed by 25 per cent shade level.

The bulking rate of turmeric at 6-8 MAP was found to be significant. 25 per cent shade levels gave the highest bulking rate (1.979) followed by the open condition (1.3). The harvest index measured under different levels of shade at 8 MAP was significant. At 25 per cent shade the harvest index recorded was maximum (0.921). Increasing levels of shade recorded a decrease in harvest index.

Photosynthetic rate and related parameters like leaf internal CO_2 concentration, leaf temperature, stomatal conductance were measured for turmeric plants growth under the influence of shade levels of 0, 25, 50 and 75 per cent. Photosynthetic rate was maximum under open condition. Yield was observed to be maximum at 25 per cent shade levels. Parameters like leaf internal CO_2 and leaf temperature were maximum at open condition. Maximum stomatal conductance of 0.737 mol $m^{-2}s^{-1}$ was observed at open condition.

The chlorophyll 'a', chlorophyll 'b' and total chlorophyll were found to be increasing progressively with increasing levels of shade.

The highest fresh turmeric yield was recorded under 25 per cent (30.0 t ha^{-1}) shade followed by open condition. A similar trend in the dry turmeric yield per plant was also observed.

The volatile oil content was found to be the lowest under open condition and it showed an increasing trend with increasing shade levels. Maximum volatile oil was observed under 75 per cent shade level (6.15 %) and maximum curcumin content was observed from plant grown at 50 per cent shade level (6.87 %).

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* Originals not seen

PHOTOSYNTHETIC EFFICIENCY, GROWTH, YIELD AND QUALITY OF TURMERIC (*Curcuma longa* L.) UNDER DIFFERENT SHADE LEVELS

By

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ABSTRACT OF THE THESIS
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ABSTRACT

A field experiment was conducted at the College of Agriculture, Vellayani during the period from 1998-'99 to study the effect of shade on photosynthetic efficiency, partitioning of photosynthates and quality of turmeric (*Curcuma longa* L.) under different shade levels. The experiment was laid out as split plot design with shade levels of 0, 25, 50 and 75 per cent as main plot treatments and 3 varieties, Kanthi, Alleppey and Sobha as sub plot treatments. The number of replications was four. Artificial shade was provided using high density polyethylene shade nets and calibrated using quantum photosensors. Bimonthly observations of various growth parameters were taken from two months after planting. At six months after planting photosynthetic related parameters were recorded. The various growth parameters like number of tillers, dry matter production, crop growth rate, bulking rate and harvest index which contributed to yield was highest under 25 per cent shade. The yield recorded at 25 per cent shade was significantly superior when compared to open, indicating the shade tolerance of the crop.

Different shade levels influenced the quality of turmeric rhizomes as determined by the volatile oil content which was maximum under 75

per cent shade level and curcumin content was maximum under 50 per cent shade level.

The photosynthetic rate and related parameters like leaf temperature, leaf internal CO_2 concentration and stomatal conductance of turmeric were measured at 6 MAP using leaf chamber analyser. Photosynthetically Active Radiation (PAR) on leaf surface, stomatal conductance, leaf internal CO_2 concentration and leaf temperature was high under open condition. Photosynthetic rate was maximum in plants grown at open condition. Though at 25 per cent shade, the photosynthetic rate was less, the yield was high at this shade level when compared to the open condition. Under open condition there is a possibility of an increase in photo-oxidation / photo-respiration resulting in the inefficient translocation of photosynthates from the source to the sink.

The results indicate that low levels of shade is favourable for growing turmeric to get high rhizome yield and this specific nature of turmeric can be fully exploited for growing this as an intercrop or as a crop component in homesteads.