BIOMASS PRODUCTION AND PARTITIONING OF PHOTOSYNTHATES IN GINGER (*Zingiber officinale* R.) UNDER DIFFERENT SHADE LEVELS

BY

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DECLARATION

I hereby declare that this thesis entitled " **Biomass production and partitioning of photosynthates in ginger** (*Zingiber officinale* R.) **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.

Vellayani

04-11-1999

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CERTIFICATE

Certified that this thesis entitled "**Biomass production and partitioning of photosynthates in ginger** (*Zingiber officinale* R.) **under different shade levels** " is a record of research work done independently by Ms. Sreekala G. S under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship ar associateship to her.

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SREEKALA G. S.

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LIST OF ABBREVIATIONS

BR	bulking rate
^{14}C	carbon- 14
CD	critical difference
CGR	crop growth rate
Cl	chlorine
cm	centimetre
CO_2	carbon dioxide
cpm	counts per minute
CRD	completely randomised design
°C	degree celsius
DAP	days after planting
DMP	dry matter production
Fig	figure
g	gram
H	hydrogen
ha	hectare
HI	harvest index
IBA	indole butyric acid
IST	Indian standard time
K	potassium
KAU	Kerala Agricultural University
kg	kilogram
LAD	leaf area duration
LAI	leaf area index

m	metre
μ	micro
mg	milligram
mm	millimetre
mol	mole
N	nitrogen
Na	sodium
NAR	net assimilation rate
NVEE	non-volatile ether extract
O	oxygen
P	phosphorous
PAR	photosynthetically active radiation
RGR	relative growth rate
RWC	relative water content
S	second
SLW	specific leaf weight

INTRODUCTION

1. INTRODUCTION

Ginger is one of the principal spice crops not only in India but in the entire world. India is the largest producer and exporter of ginger to more than fifty countries. Thus ginger is one of the important cash crops earning foreign exchange to our country. In the world market, the demand for ginger is expected to rise from 18,000 to 25,000 tonnes by 2005 AD. Since Kerala shares the major part of export from India, its role becomes manifold further. Practically it is difficult to increase the area under ginger cultivation. But there is ample scope for utilising the area under coconut plantations. Since many studies have established the shade / tolerant nature of ginger, the area under coconut can be utilised for growing ginger. Thus to make use of this a clear cut information about shade tolerance becomes necessary.

Recent studies at College of Agriculture, Vellayani, revealed that ginger under open condition showed higher CO_2 uptake but the yield was less compared to plants kept under 20 and 40 per cent shade. This indicates that the carbohydrates prepared at the initial stage is not translocated to the rhizomes as expected.

According to Watson (1958) the amount of light energy intercepted by a crop is a major discriminant in crop production. Thus the light intensity and quality have pronounced effects on photosynthetic production and allocation. Ginger appeared to be efficiently utilising low light intensity for its photochemical reaction (Minoru and Hori, 1969). The plant yield is primarily determined by photosynthesis and its partitioning into economically important plant parts

(Pettigrew, *et al.*, 1993). The major determinants that govern the efficient utilisation of photosynthate for crop growth include net assimilation, respiratory losses and assimilate partitioning to harvestable yield components. (Gifford and Evans, 1981; Bunce, 1986 and Daie, 1988). Thus the present study was done with the objective of studying the biomass production and partitioning of photosynthates in ginger as influenced by different shade levels.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

Ginger is an important export oriented spice crop. India's major share of export is met from the state of Kerala. Further expansion of area under monocropping is limited. But there is ample scope for utilising the wast shaded regions under coconut plantations. Though many studies have established the shade loving nature of ginger, the mechanism involved is not clearly understood. The present study is intended to know about the biomass production and partitioning of photosynthates in ginger grown under different shade levels.

The review of literature is classified into two sections. The first section deals with the response of ginger and other crops to the varying intensities of shade. The second section deals with the translocation of labelled assimilates.

Response of crops to varying intensities of shade

The growth and development of any crop at anytime is determined by the solar energy. Shade has response on various growth parameters like vegetative characters, photosynthesis, dry matter accumulation, yield and quality.

2.1. Morphological characters

2.1.1. Growth characters

2.1.1.1 Plant height

Allen (1975) noticed that soybean grown under 70 per cent shade grew much taller (120 cm) than those in the light (90 cm). Tarila *et al.* (1977)

reported that high intensity of light reduced plant height in cowpea. Positive influence of shade on plant height was reported on groundnut (George, 1982), tomato (Kamaruddin, 1983), winged bean (Sorenson, 1984), cassava (Ramanujam *et al.*, 1984 ; Sreekumari *et al.*, 1988), sweet red pepper (Rylski and Spingelman, 1986), broad bean (Xia, 1987), rice (Jadhav, 1987 ; Singh *et al.*, 1988). passion fruit (Menzel and Simpson, 1988) and in colocosia (Prameela, 1990).

. Negative influence of shade on plant height was noticed in bird's foot, terfoil and alfalfa (Cooper, 1966) and redgram (George, 1982). On the otherhand in plants like cowpea, blackgram and colocasia plant height was unaffected by shading (George, 1982).

Lalitha Bai and Nair (1982) while experimenting with tuber and rhizomatous crops observed positive influence of shading on plant height in ginger, turmeric, coleus and sweet potato.

Ginger plants grown under full sunlight were found to be shorter compared to shaded plants (Aclan and Quisumbing, 1976). Plant height was found to increase in ginger when the shade intensity was increased from zero to 75 per cent (Susan Varughese, 1989 ; Jayachandran *et al.*, 1991 ; Ancy, 1992 ; Babu, 1993).

2.1.1.2 Number of tillers

In rice it is reported that shading at the vigorous tillering stage reduced tiller formation (Oshima and Murayama, 1960). A reduction in the number of tillers by shading was also reported by Moursi *et al.* (1976). Decrease in the number of tillers with increasing levels of shade in turmeric was reported by Susan Varughese (1989) and Jayachandran *et al.* (1992). In colocasia, however there was no significant difference in tiller production with respect to increasing levels of shade (Prameela, 1990).

Aclan and Quisumbing (1976) observed in ginger that tillering was not affected by shade. On the contrary Susan Varughese (1989) observed a decrease in the number of tillers with an increase in shade at all growth stages in ginger. According to Ancy (1992) under 25 per cent shade higher tiller number was found at 120 and 180 days after planting. Tiller production under 50 per cent shade was found to be comparable with that under open, but significantly lower than that under 25 per cent shade. George (1992) also reported a higher tiller production in ginger cv. Rio-de-Janeiro at 25 per cent shade. Babu (1993) also reported a higher tiller production at 120 and 180 DAP under 25 per cent shade in ginger cv. Rio-de-janeiro. He also observed more tiller number in open compared to 75 per cent shade at 180 DAP.

2.1.1.3 Number of leaves

In sweet potato leaf number declined in response to higher shade levels (Laura *et al.*, 1986). Xia (1987) found that *Vicia faba* plants subjected to 50 and 20 per cent shade exhibited 30 per cent reduction in the number of leaves per plant. In cassava also the leaf number decreased when grown under shade in coconut garden (Sreekumari *et al.*, 1988).

Simbolon and Sutarno (1986) observed that *Amaranthus* spp. kept at medium shade produced more leaves than at higher levels of shade. The clove seedlings kept under shade produced more number of leaves than seedlings exposed to sun (Venkataramanan and Govindappa, 1987).

Aclan and Quisumbing (1976) reported reduced number of leaves per tiller in ginger grown under full sunlight compared to different levels of shade. On the contrary, Susan Varughese (1989) observed a decrease in the number of leaves at all stages by increasing the intensity of shading from 0 to 75 per cent in both ginger and turmeric. According to Ancy (1992) maximum number of leaves per plant was seen under 25 per cent shade at all the growth stages and lowest number of leaves were recorded at 75 per cent shade. Babu (1993) observed maximum leaf production under 25 per cent shade and found to be significantly superior to other shade levels at 120 and 180 DAP.

2.1.1.4 Leaf area

In bird's foot trefoil there was a decrease in leaf area under conditions of moderate shading (Mckee, 1962). In rice also leaf area development was reduced due to low light intensity (Venkateswaralu and Srinivasan, 1978).

Vinson (1923) studied the effects of shading on geranium and reported larger leaf area under shaded conditions. Leaf area per plant of red clover was also found to increase under conditions of moderate shading (Mckee, 1962). Panikar *et al.* (1969) observed an increase of 15.1 and 17.6 per cent in the length and breadth of leaves in tobacco under shade as compared to unshaded plants. Gratani *et al.* (1987) found that leaf area of sun leaves (upper layer) was lower than that of shade ones within beech crown.

According to Babu (1993) maximum leaf area was produced under 25 per cent shade and minimum under open condition at 120 and 180 DAP.

2.1.1.5 Leaf weight

Hiroi and Minoru (1970) explained the effect of different intensities of light on *Aphelandra squarrosa* and reported that the weight of leaf was highest at 30 and 16 per cent light. In a fertilizer cum shade trial on container grown plants of *Ficus macrophylla,* Thomas and Teobe (1983) observed higher foliar dry weight at 20 per cent shading.

2.1.1.6 Leaf thickness

Leaf morphology is strongly influenced by light levels during development. A comparative study on light and shade on leaflets of common flowering plant *Vicia americana* revealed striking differences in leaflet form, size and thickness (Cormack, 1955).

Fails *et al.*, (1982) observed that in *Ficus benajamina* plants, shade grown leaves were larger, thinner, flatter and darker green than the sun grown leaves.

In a study on the light acclimation in citrus leaves, citrus plants were grown in different light situations like full sunlight, 50 and 90 per cent shade. Those grown in full sunlight had the highest leaf thickness and the lowest thickness was reported on the 90 per cent shade (Syvertsen and Smith, 1984).

In a pot trial on beans (*Phaseolus vulgaris*) grown at different light intensity has shown that leaf thickness increased with increasing light intensity (Silva *et al.*, 1985). Different cultivars of cranberry grown at four light levels, simulating levels naturally occurring in the plant canopy in the field, showed that leaf thickness was reduced substantially with increased shading (Stang *et al.*, 1985). In dicots shade leaves are typically larger in area but thinner than sun leaves (Salisberry and Ross, 1991).

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 on studying 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).

In study of stock plant etiolation and stem banding, stem cuttings of upright European horn bean (*Carpinus betulus* L. Fastigiata) were taken at two week intervals over four months following bud break and rooted under intermittent mist for 30 days. In two shading studies, stock plants were grown in a glass greenhouse index 0, 50, 75 or 95 per cent shade or initially etiolated (100 per cent shade) for 15 days. Auxin concentration interacted with shaded to yield at 95 per cent shade and 3.7 mm IBA, the highest rooting per centage and the greatest root counts and lengths (Maynard and Bassuk, 1992).

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 activity seemed to be more wide spread.

2.1.2.3 Root weight

A study was conducted to find the influence of light intensity on growth and leaf physiology of *Acuba japonica* (Thunb.) cv. Variegata. It was assessed under conditions of full sun and under shade cloth (light transmittance of 69, 47 and 29 per cent full sun) over two years. The growth index and total leaf, stem and root dry weights were inversely related to light level (Andersen, *et al.*, 1991).

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).

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 on any other shade levels.

According to him rhizome spread under 75 per cent shade was superior to 50 per cent and open. Plants under open condition revealed the lowest rhizome spread.

2.2. Histological

2.2.1.Stomatal frequency

Growth and leaf physiology responses of container grown 'Arkin' carambola (*Averrhoa carambola* L.) trees to long term exposure of approximately 25, 50 and 100 per cent sunlight were studied. Trees grown in 100 per cent sunlight had a more vertical branch orientation and greater stomatal density than shaded trees (Marler *et al.*, 1994).

2.3. Physiological

2.3.1. Dry matter production

Monteith (1969) observed that the maximum amount of drymatter production by a crop was strongly correlated with the amount of light intercepted by its foliage. Higher drymatter production under shade was noticed in *Xanthosoma sagittifolium* (Caeser, 1980) cotton (Singh, 1986). Venkataramanan and Govindappa (1987) reported that coffee seedlings kept under shade produced more total drymatter compared to those exposed to sun. Prameela (1990) reported highest drymatter production at 25 per cent shade level and there was a drastic reduction in drymatter 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.

A reduction in drymatter accumulation under shade is noted on several crops such as *Colocasia esculenta* (Caesar, 1980), peanut plants (Farnham *et al.*, 1986) rice (Vijayalakshmi *et al.*, 1987) and turmeric (Susan Varughese, 1989).

However soybean plants grown under 70 per cent shade did not show any reduction in dry matter (Erikson and whitney, 1984).

Increased drymatter production at reduced light is reported in ginger (Ravisankar and Muthuswamy, 1986). Susan Varughese (1989) reported higher drymatter production at 25 per cent shade. Ancy (1992) observed that the dry matter production at 25 and 50 per cent was on par with each other but significantly superior to zero and 75 per cent shade. Babu (1993) reported highest drymatter production at 25 per cent shade thus confirming the study of Susan Varughese.

2.3.2. Crop growth rate

Crop growth rate of cassava grown under shade were 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 zero, 14 and 28 after the onset of tuberization and 6 weeks of shading beginning on day zero were studied. Shading slowed down leaf development, stolon initiation, tuberization, tuber growth, maturation and tuber resorption and reduced CGR. However stem growth and CGR were increased after shading was removed. Early shading of potatoes 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.

2.3.3. Relative growth rate

Jadhav (1987) reported a positive correlation of relative growth rate with shade in rice.

2.3.4. Net assimilation rate

According to Pandey *et al.*, (1980) net assimilation rate of chickpea was found to decrease with decrease in light intensities. Ramanunajam and Jose (1984) also observed reduced NAR of cassava growth 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).

Ramadasan and Satheesan (1980) reported highest net assimilation rate with three turmeric cultivars grown in open condition compared to those in shaded condition.

2.3.5. Specific leaf weight

Duncan grape fruit, pineapple and sweet orange seedlings were grown in full sunlight, 50 and 90 per cent shade. Specific leaf weight were highest in full sun in fully expanded matured leaves and lowest in 90 per cent shade (Syvertsen and Smith, 1984).

2.3.6. Leaf area index

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 wenged 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. On the other hand, Lalitha Bai (1981) reported that the leaf area indices of ginger, turmeric and coleus were not influenced by different shade intensities.

A high leaf area index was reported by Ravisankar and Muthuswamy (1988) when ginger was grown as an interscrop in six year old arecanut plantation. Ancy (1992) also observed a higher leaf area index under shaded condition compared to open at all growth stages.

2.3.7. Leaf area duration

According to Babu (1993) highest leaf area duration was observed from 25 per cent shade followed by 50 and 75 per cent shade. However leaf area duration was lowest under open conditions in ginger

2.3.8. Harvest index

Prameela (1990) recorded highest harvest index at 25 per cent shade in colocasia and with further increase in shade levels the harvest index decreased significantly.

Susan Varughese (1989) observed no significant difference between shade levels with respect to harvest index in ginger. Ancy (1992) recorded highest harvest index in open and a steady decrease in harvest index with increase in shade levels in ginger. However, George (1992) recorded highest harvest index at 25 per cent shade which was comparable with open condition. Babu (1993) reported highest harvest index in open and a decreasing trend with respect to increasing shade.

2.3.9 Relative water content

The relative water content is considered as an important connotation of internal water status and a higher value during stress situation indicates drought tolerance. RWC decreased under moisture stress situation to 66 and 40 per cent in unhardened ground nut and in cow pea while in hardened plants the drop was only to 76 per cent in both the crops (Chari et al., 1986).

2.3.10. Root shoot ratio

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

2.4 Photosynthetic rate and related parameters

2.4.1 Leaf temperature

Excessive leaf temperature limited the yield of tea under unshaded condition. This was reported by Habfield (1968).

2.4.2. 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 area per unit area of leaf correlated with the maximum stomatal conductance (Holmgren, 1968 ; Bjorkman *et al.*, 1972 ; Edwards and Ludwig, 1975 ; Crookston *et al.*, 1975). 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 (Thunb) cv variegata were exposed under conditions of full sun and shade over two years. Two days after treatment initiation net carbondioxide assimilation was proportional to light level, although stomatal conductance to water vapour was not influenced by shading (Andersen *et al.*, 1991).

2.4.3. 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 *Helianthus annus* a well known sun species to 21.0 sec cm^{-1} for *Circaea lutetiana*, a species which grows in shaded wood lands (Holmgren *et al.*, 1965).

Studies on cultivar resistance to transpiration influenced by different densities of shade (25, 50 and 75 per cent) in tea clones revealed that there was a progressive increase in cultivar resistance with increasing densities of shade (Harikrishnan and Sharma, 1980).

Handique and Manivel (1987) recorded lower stomatal resistance in tea under full sun compared to leaves under shade.

2.4.4. Photosynthetic rate

Understanding the photosynthetic carbon contribution to vegetative and reproductive processes is important in defining yield productivity (Gifford *et al.*,1984). Light intensity has variable effects on plant morphology, carbohydrate allocation and yield Photosynthesis and partitioning of photosynthates into economically important plant parts are primary determinants of plant yield(Mc Master *et al.*,1987).

Gastra (1963) reported a linear relationship between photosynthesis and light intensities. The photosynthetic rate was greately reduced in shade in crops like alfalfa (Wolf and Blaser, 1972), bean (Crockson *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), Lalitha Bai and Nair (1982) reported a positive influence of shade on photosynthesis and organic matter accumulation in ginger and turmeric.

Hardy (1958) reported that shade loving plants had a threshold illumination, beyond which the stomata tends to close. According to Tao and Zhang (1986) the net photosynthetic rate of tea plants at 28 degree celsius 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 efficency of plants under open condition at higher light intensity was slightly above that of shaded plants, their photorespiration at 80 KLx, 34-38 degree celsius and 40-60 per cent relative humidity 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. This was seen in many plants. When the chloroplast of peas, maize and spinach were illuminated with high light intensity, the NADP malate dehydogenase, the chloroplast enzyme was totally inactivated.

Photosynthetic characteristics of ginger was studied by Zhao *et al.*, (1991) and found that the rate was highest in the middle leaves of the plant and lower in the apical leaves than the basal leaves. The rate decreased as the temperature increased from 20 to 40 degree celsius and was low at a light intensity of 500 Lx increasing up to 30000 Lx and then decreasing slightly with further increase to 60000 Lx.

2.5. Biochemical

2.5.1. 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 of 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 contents 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 in the shade of 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 increased with shading. Shade leaf chloroplast (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.

Contradictory to the above findings Pandey *et al.* (1980) in chickpea and Grant and Ryug (1984) in leaves of kiwi fruit observed that chlorophyll content was unaffected by shading whereas Rao and Mittra (1988) in peanut and Bhutani *et al.* (1989) in maize found that shading reduced chlorophyll content.

An increase in chlorophyll content with increasing shade levels in ginger and turmeric was reported by Lalitha Bai (1981). Susan Varughese (1989) and George (1992) reported that the total chlorophyll and its fractions (Chlorophyll 'a' and chlorophyll 'b') of ginger increased steadily with increasing levels of shade at Vellanikkara, Thrissur. Ancy (1992) and Babu (1993) also observed the same trend with respect to chlorophyll content in ginger.

2.6. Yield and yield components

2.6.1 Green ginger yield

The environmental factors under which a plant grows control the productivity of the plant to a great extent. Of the various environmental factors, the 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 (Earley, *et al.*, 1966) sorghum (Pepper and Prine, 1972), rice (Rai and Murthy, 1977 and Vijayalakshmi *et al.*, 1987) and soybean (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 sun light. In tannia highest yield was recorded under 25 per cent shade with an almost equal yield at 50 per cent shade (Puspakumari, 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.

Ravisankar and Muthuswamy (1988) recorded that fresh rhizome yield increased when ginger was grown as an intercrop in arecanut plantation. Highest yield of ginger under low light intensity of about 25 per cent shade was also reported by Lalitha Bai and Nair (1982). The screening of ginger cultivars for shade tolerance at Vellanikkara revealed that most of the ginger cultivars were shade loving and gave more yield and dry matter production under 25 per cent shade (Susan Varughese, 1989). She reported that in turmeric a steady decrease in rhizome yield with increase in shade intensity was observed. But Jayachandran *et al.* (1992) revealed that the yield of turmeric at 25 per cent shade was on par with that under open condition.

According to Jayachandran *et al.* (1991) ginger cv. Rio-de-Janeiro is a shade loving plant and produced higher yield under 25 per cent shade and comparable yield with that of open and under 50 per cent shade. However shade intensity beyond 50 per cent decreased the yield. Ancy (1992) recorded highest green ginger yield under 25 per cent shade followed by 50, 0 and 75 per cent shade. Babu (1993) reported that the green ginger yield obtained from all shade levels (25, 50 and 75 per cent shade) were significantly superior to open condition.

2.6.2. 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 up to 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 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.

2.6.3. Dry ginger yield

Ravisankar and Muthuswamy (1986) reported a greater recovery of dry ginger from plants grown under shade. Jayachandran *et al.* (1991) as well as Jaswal *et al.* (1993), however recorded a greater recovery of dry ginger from plants grown in full sunlight.

Ancy (1992) reported a higher dry ginger yield at 25 per cent shade. The dry ginger yields at zero and 50 per cent shade was on par whereas that at 75 per cent shade was significantly lower compared to other shade levels. On the other hand, Babu (1993) reported significantly higher dry ginger yield in all shade levels. However maximum dry ginger yield was obtained from 25 per cent shade followed by 50 and 75 per cent shade.

2.6.4. 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 was found to be on par with 50 per cent. Bulking rate was significant lower 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.

2.7. Quality analysis

2.7.1. Volatile oil, non-volatile ether extract

Light regimes received by plant determine the productivity and quality of its produce (Tikhnomirov *et al.*, 1976). The quality of products of tea, coffee, cinchona and rauvulfia was found to be improved under shaded conditions (Feng, 1992).

Ravisankar and Muthuswamy (1987) repoprted that ginger cv. Rio-de-Janeiro grown as an inter crop 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 plantation compared to those grown in the open contrary to this finding, Susan Varughese (1989) reported a steady decrease in the oleoresin content up to 50 per cent level of shade. According to George (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) reported 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. On the contrary Babu and Jayachandran (1994) observed a decrease in non-volatile ether extract with increase in shade.

2.7.2. Starch and crude fibre

Decreased carbohydrate level due to shading was reported in leaves and roots of *Ficus benjamina* (Milks *et al.*, 1979). Prameela (1990) reported high starch content in open grown colocasia followed by that at 50 and 25 per cent shade levels.

Aclan and Quisumbing (1976) reported that in ginger crude fibre content was not affected by shading. The same result was also reported by Ravisankar and Muthuswamy (1987) in ginger. According to Ancy (1992) highest crude fibre content was obtained from those plants grown in open and was significantly high compared to all other shade levels. Babu (1993) also recorded the same result.

2.8 Study of translocation of photosynthates by $^{14}CO_2$ labelling techniques in ginger cv. Rio-de-Janeiro

Considerable use of isotopes have been made by plant physiologists in studies on the photosynthesis and plant productivity of several crop plants. Among the many isotopes used, the one which has been used in photosynthesis studies is ^{14}C. Of late ^{14}C studies have been conducted on different field crops as well as horticultural crops. The work done on some of major crops are reviewed here.

Distribution of labelled assimilates within an young apple tree after supplying $^{14}CO_2$ to a leaf or shoot was traced by radioautography (Janikiewicz *et al.*, 1967). It was observed that the transport of labelled assimilates from the young leaves of the leader was very meagre and was traceable only in parts of the stem and the leaves situated in the close vicinity of the treated leaves. The translocation and distribution of ^{14}C labelled assimilates within a single shoot and between two adjacent shoots were studied in one year old Golden delicious apple trees (Manolov, *et al.*, 1974). When $^{14}CO_2$ was introduced into an upper developed leaf the translocation of labelled assimilates was basipetal and when introduced into a lower leaf, acropetal. The major part of labelled assimilates moved from a middle leaf down the stem in a spiral. When whole shoots were exposed to $^{14}CO_2$, the labelled compounds were not translocated to an adjacent shoot, but moved into the roots.

In a study on the distribution and utilization of ^{14}C labelled assimilates in soybeans (Glycine max (L.) Merr.) individual soybean plants which were grown in the field during two years were allowed to assimilate $^{14}CO_2$ either during vegetative growth, at first flowering, at early pod development or during rapid seed development. Plant parts that were growing actively at the time of labelling accumulated more ^{14}C than those parts that were not growing actively. When the plants were growing vegetatively, most of the ^{14}C was incorporated into structural leaf and stem tissue. As labelling times became later, during ontogeny, stems contained decreasing amounts of ^{14}C and more ^{14}C accumulated in seeds by maturity. After rapid seed development began, roots and nodules accumulated little ^{14}C. If plants were labelled before vegetative growth was completed, 30 to 40 per cent of the ^{14}C present immediately after labelling was recovered in plants grown to maturity. Plants labelled during rapid seed development retained 65 per cent of the original ^{14}C

at maturity. Calculated losses of ^{14}C due to respiration averaged 20 per cent. Most of the ^{14}C lost by maturity was in abscised tissue (Hume and Criswell, 1973).

The translocation of ^{14}C photoassimilates from normal and mutant leaves to the pods of *Pisum sativum* was estimated by Harvey (1974). Assays of ^{14}C distribution made 48 hours after treatment, indicated that the leaf and the pod had a well defined respective source and sink relationship that was independent of leaf morphology. Thus the pods which comprised the main ^{14}C sinks depended on the leaf that had been fed with $^{14}CO_2$. With regard to the sink activity there was little difference between mutant and normal leaves. Lawrie and Wheeler (1974 traced the movement of photosynthetic assimilates to the nodules of *Pisum sativum* in relation to the fixation of nitrogen. It was seen that the accumulation of ^{14}C labelled photosynthates in the nodules of pea plants in nitrogen free culture, reached a maximum, shortly before flowering to fruiting. The accumulation of ^{14}C photosynthates in the nodules declined by 60 per cent whereas the photosynthesis of the plant was found doubled.

Uneven ripening and translocation of metabolites in 'Gulabi' grapes were studied by Vasundara (1981). Radioactive carbondoxide was fed to the leaves during the rapid growth stage of the cluster (45 days after anthesis). At this stage, there was small, medium and large sized berries within the cluster. In non-defoliated plants, the highest amount of $^{14}CO_2$ was recorded in the first two or three branches of the cluster that contained a higher sink number. When the source capacity was reduced by defoliation, the pattern of translocation from fed leaves into the sinks differed. The first branch of the cluster became the predominant sink. Hence, the total activity and the specific activity were higher in the first branches than in the other sinks.

Madore and Grodzinski (1985) studied the effect of carbondioxide enrichment on growth and photo-assimilate transport in dwarf cucumber. Dwarf cucumber plants of the cv. space master were grown for six weeks in a carbondioxide enriched atmosphere. Source leaves of different age were pulse labelled with $^{14}CO_2$. The distribution of ^{14}C in petiole extracts and phloem exudates of the fed leaves showed an increase of the label in transport sugars where as a decline of the label was observed on the aminoacids, particularly glycine and serine.

Fisher and Eschrich (1985) studied the import and unloading of ^{14}C assimilates into mature leaves of *Coleus blumei* $^{14}CO_2$ was fed to the apical leaves and the assimilate import ability of mature leaves (sink leaves) were estimated. Some of the sink leaves were kept exposed to light while others were kept under darkness. Autoradiographs showed that the label imported to sink leaves that were exposed to light was more concentrated in the major veins. In general, sink leaves kept under dark imported much less label. Micro autoradiography of midveins of the sink leaves indicated that ^{14}C was always translocated through the pholem.

Rate of photosynthesis and translocation of photosynthates were studied in cardamom using ^{14}C labelling at the Cardomom Research Station, Pampadumpara, Kerala during 1983-85. The studies based on fixation of $^{14}CO_2$ by leaves showed that the photosynthetic efficiency was more under subdued light intensities (30.86 - 106.63 μ E s^{-1} m^{-2}). A low light compensation point was found to favour the photochemical process in cardamom leaves. The pattern of translocation of labelled assimilates showed that rhizome was the major sink in a tiller. Fairly high proportion of labelled assimilates were also detected from panicles and roots. Translocation of ^{14}C photosynthates from radiolabelled leaves to non labelled leaves was found to be rather low (Vasanthakumar *et al.*, 1989).

MATERIALS AND METHODS

3. MATERIALS AND METHODS

A pot culture experiment was conducted at College of Agriculture, Vellayani, Thiruvananthapuram, Kerala with the objective of studying biomass production and its partitioning under different shade levels in ginger cv Rio-de-Janeiro.

3.1 Experimental site

The experiment was conducted at the Instructional Farm, College of Agriculture, Vellayani situated at 8^0 5' North latitude and 77^0 1' East longitude and at an altitude of 29 m above mean sea level.

3.1.1 Season

The experiment was conducted from March 1997 to November 1998.

3.2 MATERIALS

3.2.1 Planting material

Ginger cultivar Rio-de-Janeiro was used for the experiment. Healthy, disease and pest free rhizome bits weighing 15 g were used for planting.

3.2.2 Fertilizers

The recommended fertilizer dose of 75 : 50 : 50 kg N, P_2O_5 and K_2O per hectare as per package of practices (KAU, 1996) was followed. 1.75 g

Fig. 1. Layout plan - CRD

S_3R_1	S_3R_2	S_3R_2	S_3R_4
S_3R_2	S_3R_4	S_3R_3	S_3R_1
S_3R_4	S_3R_3	S_3R_1	S_3R_2
S_3R_3	S_3R_1	S_3R_4	S_3R_3

S_1R_3	S_1R_4	S_1R_1	S_1R_2
S_1R_4	S_1R_1	S_1R_2	S_1R_1
S_1R_1	S_1R_2	S_1R_3	S_1R_3
S_1R_2	S_1R_3	S_1R_4	S_1R_4

S_4R_2	S_4R_3	S_4R_4	S_4R_1
S_4R_1	S_4R_4	S_4R_2	S_4R_3
S_4R_3	S_4R_2	S_4R_1	S_4R_4
S_4R_4	S_4R_1	S_4R_3	S_4R_2

S_2R_3	S_2R_1	S_2R_2	S_2R_1
S_2R_2	S_2R_4	S_2R_4	S_2R_3
S_2R_4	S_2R_3	S_2R_3	S_2R_2
S_2R_1	S_2R_2	S_2R_1	S_2R_4

S_0R_4	S_0R_1	S_0R_3	S_0R_2
S_0R_1	S_0R_2	S_0R_4	S_0R_1
S_0R_2	S_0R_3	S_0R_1	S_0R_4
S_0R_3	S_0R_4	S_0R_2	S_0R_3

Treatments

Levels of shade	**Replication**
S_0 - 0 % shade	R_1 - Replication 1
S_1 - 20 % shade	R_2 - Replication 2
S_2 - 40 % shade	R_3 - Replication 3
S_3 - 60 % shade	R_4 - Replication 4
S_4 - 80 % shade	

urea, 2.75 g single super phosphate and 1 g murate of potash were applied to each pot. For all the treatments, full dose of P_2O_5 and half the dose of K_2O were given as basal dressing, half the dose of N two months after planting and remaining portions of N and K_2O four months after planting.

3.2.3 Mulching

Mulching was done immediately after planting with green leaves and repeated twice, first at two months and the second four months after planting.

3.3 METHODS

3.3.1 Layout of the experiment

The pot culture experiment was laid out in the completely randomised design with five treatments and four replications (Fig 1).

3.3.2 Preparation of potting mixture

Potting mixture was prepared by mixing one part fertile soil, one part coarse sand and one part dried and powdered cowdung. Mud pots of 30 x 30 cm size were used for the study.

3.3.3 Seed treatment

Rhizome bits each weighing 15 g were treated with a combination of Mancozeb 0.3% and Malathion, 0.1 % for 30 minutes. After the treatment the rhizome bits were dried under shade, by spreading them on a clear floor.

3.3.4 Planting

Treated rhizome bits weighing 15 g were planted at a depth of 5 cm with buds facing upwards. Then they were irrigated and kept under respective shades.

3.3.5 Artificial shading

Four shade levels (20,40,60, 80) were provided by using high density polyethylene nets spread over pandals. Quantum photosensors was used for calibration of the shade.

3.3.6 After care

The pots were irrigated everyday and hand weeding was done as and when necessary.

3.3.7 Plant protection

Leaf spot disease was observed during the initial stages of growth. The same was controlled by spraying Dithane M-45 (0.3 %). The crop was free from pest infestation.

3.3.8 Harvest

Destructive sampling was done at monthly intervals,starting from two months after planting of crop for taking different observations. For each treatment there were four replications and at a time a total of twenty plants were harvested. The observations on growth parameters and physiological characters were taken from these plants. At 180 DAP, ginger plants under various shades were taken to Central Tuber Crops Research Institute, Sreekaryam, Thiruvananthapuram for measuring photosynthetic rate and related parameters using leaf chamber analyser. Quality analysis for volatile oil, non-volatile ether extract (NVEE), starch and crude fibre were carried out at monthly intervals from 120 DAP. At final harvest top yield and green ginger yield were recorded.

3.4 Observations

Random sampling method was adopted to select the sample plants for studying various growth characters. At a time four plants were harvested at random from each treatment and various observations were carried out.

3.4.1 Morphological parameters

3.4.1.1 Growth characters

3.4.1.1.1 Plant height

The height of the plant was measured from the base of the plant to the base of the youngest fully opened leaf at monthly intervals from 60 DAP and were expressed in centimetre.

3.4.1.1.2 Number of tillers

The number of tillers per plant was counted at monthly intervals from 60 days after planting.

3.4.1.1.3 Number of leaves

The number of fully opened leaves were counted at monthly intervals from 60 days after planting.

3.4.1.1.4 Leaf area

The length and maximum width of leaves were measured at monthly intervals from 60 days after planting and the leaf area in cm^2 was calculated based on the length and breadth method (Ancy, 1992).

The following relationship was utilized for computing the leaf area.

$$Y = 0.6695 \ X - 0.7607$$

where

Y ,the leaf area

X ,the product of length and breadth

3.4.1.1.5 Leaf weight

Dry weight of the leaf was taken at monthly intervals from 60 days after planting after drying the leaves in hot air oven at 70 - 80^0C. It is expressed in g $plant^{-1}$

3.4.1.1.6 Leaf thickness

Leaf thickness at monthly intervals from 60 days after planting was measured by using micrometer. It is expressed in mm $leaf^{-1}$

3.4.1.2 Root characters

3.4.1.2.1 Root length

The plants were uprooted at monthly intervals from 60 days after planting and maximum length of roots were measured and mean length expressed in centimetre.

3.4.1.2.2. **Root spread**

Root spread was measured at monthly intervals from 60 days after planting 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 centimetre.

3.4.1.2.3. **Root weight**

Dry weight of the roots separated from individual plants at monthly intervals from 60 days after planting, was taken after drying in hot air oven at 70 - 80^{0}C. It is expressed in g $plant^{-1}$

3.4.1.2.4 **Root volume**

Root volume per plant was found out at monthly intervals from 60 days after planting by displacement method and expressed in cm^{3} $plant^{-1}$.

3. 4.1.3 Rhizome characters

3.4.1.3.1. **Rhizome spread**

The horizontal spread of rhizome was measured at monthly intervals from 90 days after planting and expressed in centimetre.

3.4.1.3.2. **Rhizome thickness**

Rhizome thickness was measured at monthly intervals from 90 days after planting using micrometer and expressed in cm.

3.4.2 Histological

3.4.2.1. Stomatal frequency

The number of stomata per unit leaf area was counted at 180 days after planting. For estimating the number of stomata per microscopic fields (40 X, 10 X) leaf impressions were taken by applying a thin coat of nail polish on the lower and upper leaf surfaces which were subsequently peeled off after drying. From these impressions ten microscopic fields were scored for number of stomata and the mean number per microscopic field was estimated.

3.4.3 Physiological

3.4.3.1 Dry matter production

Leaves, petioles, pseudostem, rhizomes and roots of the uprooted plants were separated and dried to constant weight at 70 - 80°C in a hot air oven at monthly intervals from 60 days after planting. The sum of these individual components gave the total dry matter production of the plant and expressed as g $plant^{-1}$.

3.4.3.2 Crop growth rate

Crop growth rate was worked out using the formula of Watson (1958) at monthly intervals from 60 days after planting and expressed as g m^{-2} day^{-1}.

$$CGR = NAR \times LAI$$

3.4.3.3 Relative growth rate

Relative growth rate was calculated as per the method of Blackman (1919) at monthly intervals from 60 days after planting and is expressed as g^{-1} 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.

3.4.3.4 Net assimilation rate

The procedure given by Watson (1958) as modified by Buttery (1970) was followed for calculating the NAR at monthly intervals from 60 days after planting. 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 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.

3.4.3.5. Specific leaf weight

Specific leaf weight was assessed at monthly intervals from 60 days after planting by dividing the individual leaf dry weights by corresponding leaf area. It is expressed as g cm^{-2} .

3.4.3.6. Leaf area index

Leaf area index was calculated at monthly intervals from 60 days after planting. Five sample plants were randomly selected for each treatment and the number of leaves was counted on each plant. Maximum length (from the base of leaf excluding the petiole of the leaf) and maximum width of leaves from all the sample plants were recorded separately and leaf area was computed based on length, breadth method.

Leaf area index (LAI) was computed from the following equation.

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

3.4.3.7. Leaf area duration

Leaf area duration (LAD) was calculated using the formula given by Power *et al.* (1967) at monthly intervals from 60 days after planting.

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

where ,

L_i = LAI at first stage

$L_i + 1$ = LAI at second stage

$t_2 - t_1$ = Time interval between these stages

3.4.3.8 Harvest index

Harvest index (HI) was calculated at final harvest as follows

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

Where

Y econ = total dry weight of rhizome

Y biol = total dry weight of plant

3.4.3.9. Relative water content

Relative water content of the leaf at monthly intervals from 150 days after planting was determined using the following formula suggested by Wealtherley (1950). Physiologically mature leaves were selected by visual observation. Leaf punches were taken from these leaves using a steel puncher having a diameter of 1.5 cm. These samples were taken at 1200 hrs IST and were used for estimation.

$$\text{RWC (\%)} = \frac{\text{Fresh weight - Dry weight}}{\text{Turgid weight - Dry weight}} \times 100$$

3.4.3.10. Root shoot ratio

Root shoot ratio was calculated at monthly intervals from 60 days after planting as the ratio between the average of root weight and shoot weight of each plant.

3.4.4 Photosynthetic rate and related parameters

3.4.4.1 Solar light intensity and photosynthetically active radiation (PAR) on the leaf surface

Portable photosynthesis system (LCA- 4) was used to record solar light intensity and photosynthetically active radiation on the leaf surface at the time when photosynthetic rate and related parameters were measured. They are expressed in μ mol m^{-2} s^{-1}

3.4.4.2 Atmospheric CO_2 concentration and leaf internal CO_2 concentration

Atmospheric CO_2 concentration was recorded at the time when photosynthetic rate and related parameters were measured using portable photosynthesis system (LCA- 4).

Leaf internal CO_2 concentration was also recorded using portable photosynthesis system (LCA- 4) on randomly selected leaves.

They are expressed in μ mol mol^{-1} .

3.4.4.3. Leaf temperature

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

3.4.4.4. Stomatal conductance

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

3.4.4.5. Stomatal resistance

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

3.4.4.6. Photosynthetic rate

Leaves were selected at random from each treatment and photosynthetic rate was measured using portable photosynthesis system (LCA- 4). The average is worked out and expressed in μ mol m^{-2} s^{-1}.

3.4.4.7. Transpiration rate

Transpiration rate was found out on randomly selected leaves from each treatment using portable photosynthesis system (LCA- 4). The average is reported and expressed in mol m^{-2} s^{-1}.

3.4.5 Biochemical

3.4.5.1 Chlorophyll (a, b and total)

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

3.4.6 Yield and yield components

3.4.6.1 Green ginger yield

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

3.4.6.2. Top yield

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

3.4.6.3. Dry ginger yield

Immediately after each harvest, at monthly intervals from 90 days after planting, rhizome samples were taken. The rhizomes were washed and kept to dry under sun for one week. After this it was kept in hot air oven at 70 - 80^{0}C. The dry weight of ginger was expressed in g $plant^{-1}$.

3.4.6.4. Bulking rate

The bulking rate in rhizome was worked out at monthly intervals from 90 days after planting on the basis of increase in dry weight of rhizome and expressed in g $plant^{-1}$ day^{-1}.

$$\text{Bulking rate} = \frac{W_2 - W_1}{t_2 - t_1}$$

where

W_1 = dry weight of rhizome at time t_1

W_2 = dry weight of rhizome at time t_2

3.4.7 Quality analysis

3.4.7.1. Volatile oil

The content of volatile oil was estimated at monthly intervals from 120 days after planting by Clevenger distillation method (A.O.A.C., 1975) and expressed as per centage in dry weight basis.

3.4.7.2. Non-volatile ether extract

Non-volatile ether extract (NVEE) was estimated at monthly intervals from 120 days after planting by Soxhlet distillation method (A.O.A.C., 1975) and expressed as per centage on dry weight basis.

3.4.7.3. Starch

Starch content was analysed at monthly intervals from 120 days after planting using copper reduction method (A.O.A.C., 1975) and expressed as per centage on dry weight basis.

3.4.7.4. Crude fibre

The crude fibre was estimated at monthly intervals from 120 days after planting by the A.O.A.C method (1975) and expressed as per centage on dry weight basis.

Plate 1 Plants kept in the glass chamber for $^{14}CO_2$ labelling

Plate 2 Radioactive labelling of ginger cv. Rio-de-Janeiro grown under shade with $^{14}CO_2$ in a glass chamber

Plate 3 Radioactive labelling of ginger cv. Rio-de-Janeiro grown under full sunlight with $^{14}CO_2$ in a glass chamber

3.4.8 Study of translocation of photosynthates by $^{14}CO_2$ labelling techniques

3.4.8.1 Method of feeding

A glass chamber of 75 x 75 x 100 cm^3 size was used for tagging ginger plants with radio active carbon. Sixteen ginger plants from each shade level were taken and kept in the glass chamber. Over the glass chamber shade nets of respective shade levels were spread. For the plants grown under open condition, no shade nets were spread at the time of release of $^{14}CO_2$ (Plate 1, 2 and 3).

The glass chamber was made air tight and inside the chamber $^{14}CO_2$ was made to release by adding hydrochloric acid to $Na_2\,^{14}CO_3$ kept in a petri dish. The reaction is as follows

$$Na_2\,^{14}CO_3 + 2\,HCl \rightarrow \,^{14}CO_2 \uparrow + 2\,NaCl + H_2O$$

The activity used per treatment was 100μ Ci. The $^{14}CO_2$ released inturn was fixed up by the plants kept inside the air tight chamber.

Once the tagging is over with one type of shade net, plants were taken off and allowed to grow. The experiment was repeated with plants kept under different shade nets.

3.4.8.2 Radioassay

After tagging, one set of samples were collected immediately. Subsequently, harvesting of the tagged plants were done once in sixty days after labelling. The upper and lower portion of the samples were collected separately. Then it was oven dried and stored in paper bags. For analysis the upper and lower portion were further ground and 0.1 mg each of the samples

Plate 4 **Positive print from the autoradiograph showing the translocation of more ^{14}C photosynthates to the main shoot compared to the leaves**

were oxidised in a biological oxidiser (OX 500) and $^{14}CO_2$ released was collected in 15 ml of scintillation cocktail. It was then counted in a LSC (LKP Wallac 1409).

The composition of cocktail solution used was as follows.

25 ml ethanol amine +

25 ml methanol +

50 ml scintillation grade cocktail

3.4.8.3 Autoradiography

In another set of samples, specimens of the treated plants were dried and pressed using a herbarium press. The specimens were then kept in contact with X-ray film in the dark. After an exposure for two months, the X-ray film was taken out in dark. It was then placed in developer for 7 - 8 minutes.

The composition of developer used was given below.

Metol - 4 g

Sodium sulphite - 300 g

Hydroquinone - 16 g

Sodium carbonate - 200 g

Potassium bromite - 10 g

Water to makeup to 2 l

It was then taken out and kept in stop bath. Stop bath is one per cent solution of acetic acid in distilled water. After 30 seconds in stop bath X-ray film was taken and rinsed in distilled water. Further it was kept in a fixer for 15 minutes.

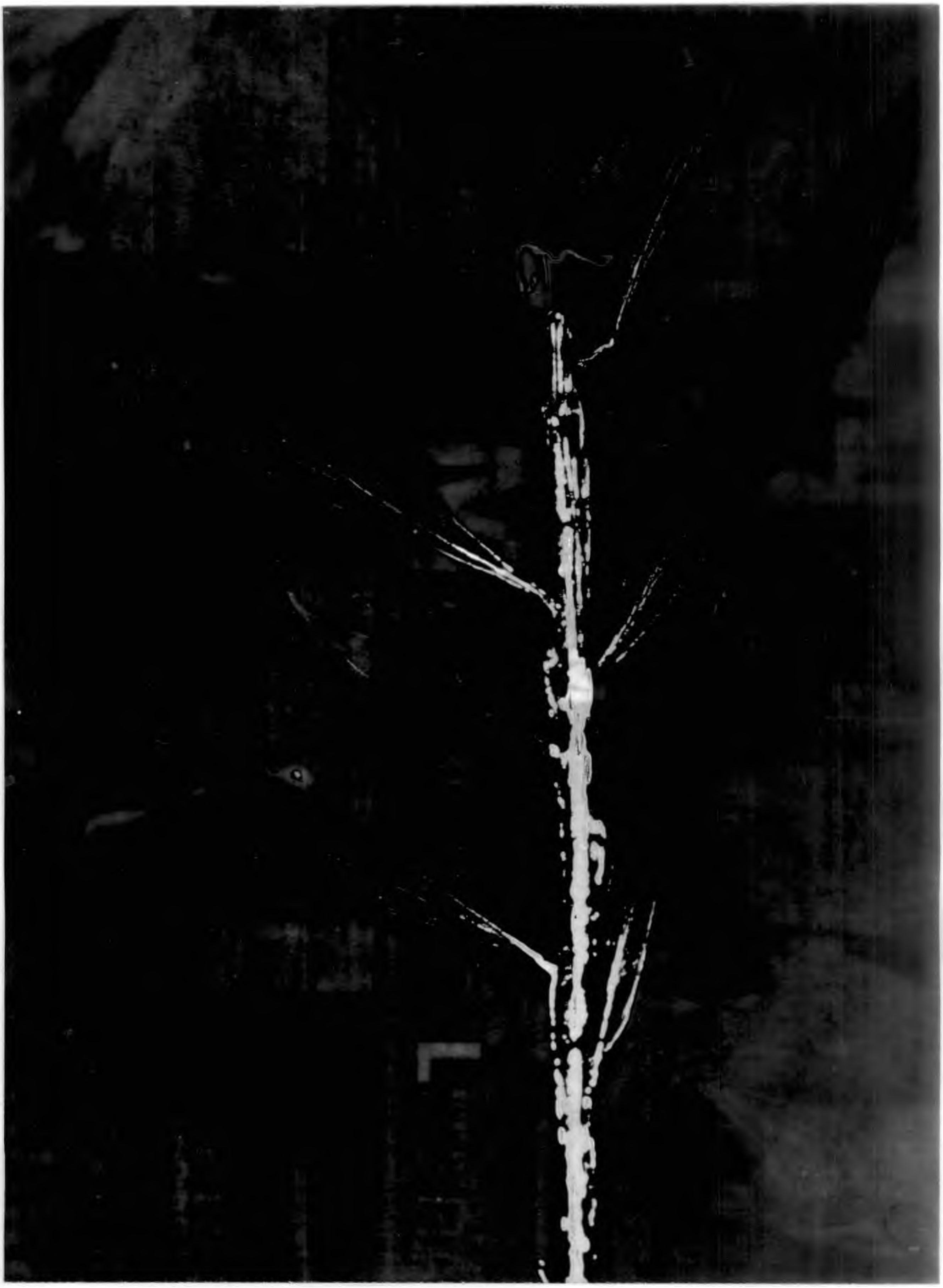
The composition of fixer (Hypo 60 per cent solution) used was as follows.

A. Sodium thiosulphate crystal - 1500 g in 2.5 l

B. Potassium metabisuphite - 200g in 2 l

C. Chromalum - 100 g + 20 ml glacial acetic acid in 2 l

Plate 4 Positive print from the autoradiograph showing the translocation of more ^{14}C photosynthates to the main shoot compared to the leaves



For use a mixture of 2 part A + 1 part B + 1 part C was taken. So a total of nine litre of fixer was made.

From the fixer the X-ray film was taken out and washed on running water for half an hour. Then it was hanged in air to dry.

Positive prints were taken of the X-ray film. Based on the relative whiteness of the various areas in the positive prints, the radioactivity accumulated in the tissues tested were assessed (Plate 4).

3.5 Statistical analysis

The experimental data were analysed statistically by applying the technique of analysis of variance for completely randomised design (Gomez and Gomez, 1984).

In the case were the effects were found to be significant, critical difference were calculated for comparing among the treatment means. For the observation taken from radioassay, the data pertaining to the effect of different shade level at different growth stages were compared using the analysis of variance for completely randomised design. In the case where the effects were found to be significant, Duncan's multiple range test was conducted and mean values compared.

To compare between the young and old part of main tiller, hierarchial test was carried out and where the effects were found to be significant critical difference was calculated to compare between various treatment means.

Logarithmic transformations were carried out in the data wherever necessary.

RESULTS

4. RESULTS

The results of the pot experiment on the biomass production and partitioning of photosynthates in ginger 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 show the effect of shade on the height of the plant.

Significant variation among shade levels was observed and the plant height showed an increasing trend with increasing shade levels at all growth stages. Minimum plant height was recorded from plants grown under open condition. S_4 was significantly superior compared to other shade levels except at 150 DAP, which was on par with S_3.

Ginger plants grown at 80 per cent shade showed higher plant height (59.85, 65.60 and 74.88 cm at 120,150 and 180 DAP respectively). S_3 recorded 71.43 cm followed by S_2 (67.16 cm), S_1 (63.94 cm) and S_0 (50.09 cm) at 180 DAP.

4.1.1.2 Number of tillers

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

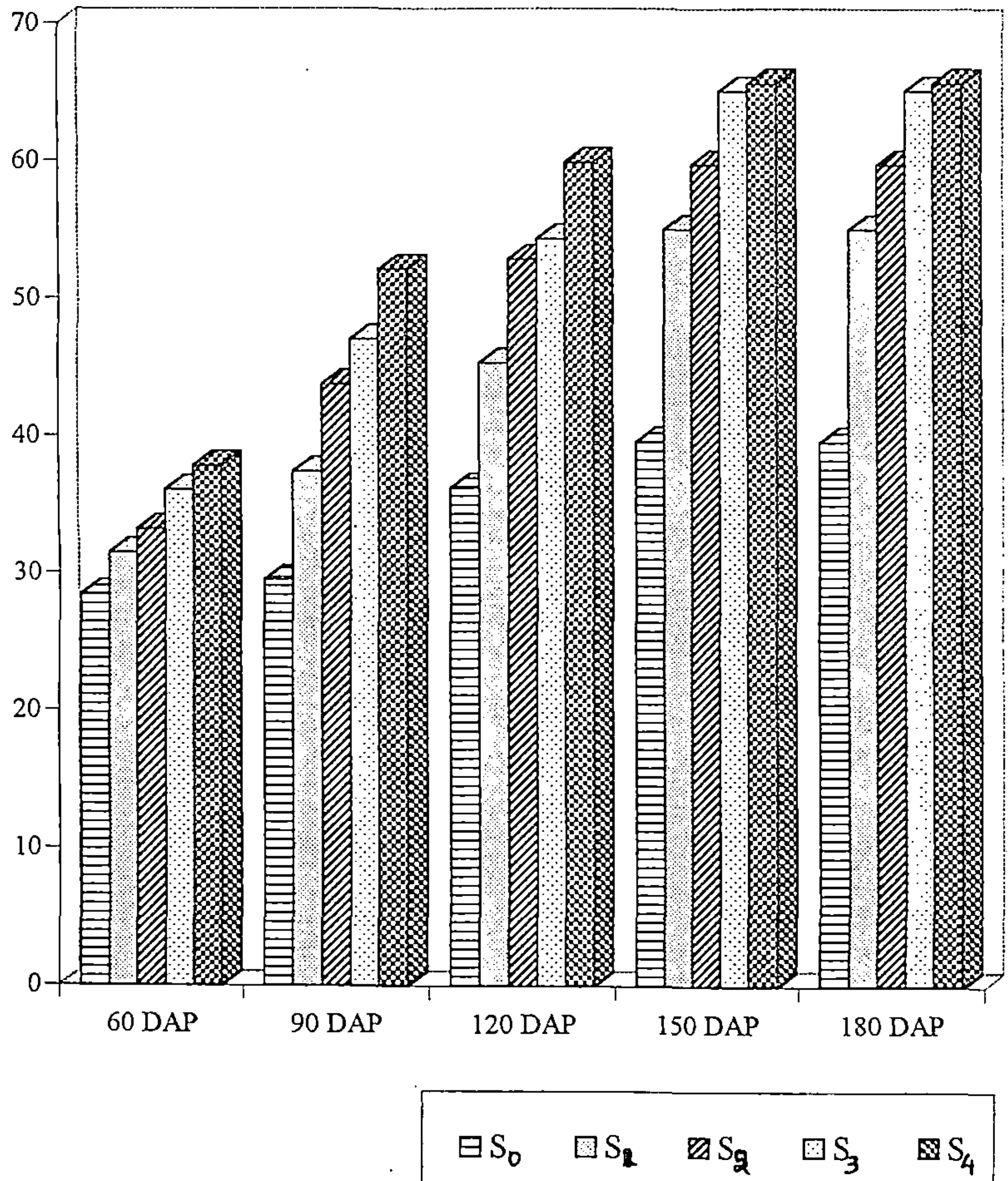
Table 1 Effect of shade on plant height (cm)

Shade levels	Periods				
	60 DAP	90 DAP	120 DAP	150 DAP	180 DAP
S_0	28.41	29.48	36.18	39.59	50.09
S_1	31.48	37.37	45.28	54.97	63.94
S_2	33.14	43.72	52.82	59.70	67.16
S_3	36.03	46.98	54.30	65.03	71.43
S_4	37.81	52.08	59.85	65.60	74.88
F test	S(S)	S(S)	S(S)	S(S)	S(S)
CD (0.05)	1.657	2.773	1.061	2.009	1.008

Table 2 Effect of shade on number of tillers

Shade levels	Periods				
	60 DAP	90 DAP	120 DAP	150 DAP	180 DAP
S_0	2.78	3.49	6.19	9.85	13.23
S_1	3.75	4.73	8.29	10.68	14.73
S_2	3.52	4.34	7.39	8.12	14.60
S_3	3.23	3.99	5.97	7.32	12.37
S_4	3.23	3.91	5.92	7.17	12.27
F test	S(S)	S (S)	S (S)	S(S)	S (S)
CD (0.05)	0.347	0.319	0.276	0.367	0.324

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



The number of tillers produced under different shade levels were found to be significantly superior at all growth stages. At all these stages the shade level S_3 was on par with S_4. The maximum tiller production was observed under S_1 (20 per cent shade) at all growth stages. The lowest number of tillers was recorded from S_4 at 120, 150 and 180 DAP. In open condition, more tiller number was observed compared to 60 and 80 per cent shade at 120, 150 and 180 DAP.

At 120 DAP, S_1 recorded a mean value of 8.29 ,S_2 (7.39), S_0 (6.19) S_3 (5.97) and S_4 (5.92). At 150 DAP maximum value was recorded from S_1 (10.68) followed by S_0 (9.85), S_2 (8.12), S_3 (7.32) and S_4 (7.17). However at 180 DAP mean number of tillers of 14.75 was observed from S_1 followed by S_2 (14.60), S_0 (3.23), S_3 (2.37) and S_4 (12.27).

4.1.1.3 Number of leaves

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

At all growth stages there was significant variation in number of leaves per plant with different shade levels.The leaf production was found to be maximum under 20 per cent shade (S_1) and was significantly superior to other shade levels. During early stages of growth, lowest leaf production was recorded under open condition but towards the later stages of growth i.e., at 120, 150 and 180 DAP lowest leaf production was seen from 80 per cent shade (S_4). Leaf production at 60 and 80 per cent shade (S_3 and S_4) were on par at all growth stages.

Table 3 Effect of shade on the number of leaves

Shade levels	Periods				
	60 DAP	90 DAP	120 DAP	150 DAP	180 DAP
S_0	24.47	33.25	64.55	145.95	192.48
S_1	31.50	48.80	82.22	153.22	200.25
S_2	28.62	41.85	70.95	137.57	179.07
S_3	25. 90	34.20	58.97	131.22	172.15
S_4	26.10	34.30	56.77	128.72	166.80
F test	S (S)	S (S)	S(S)	S(S)	S (S)
CD (0.05)	2.04	3.48	4.02	6.77	7.601

Table 4 Effect of shade on leaf area (cm^2)

Shade levels	Periods				
	60 DAP	90 DAP	120 DAP	150 DAP	180 DAP
S_0	1959.75	2508.25	3280. 25	4330.25	5950.00
S_1	2427.50	3318.75	4069.50	6015.25	7645.50
S_2	2284.75	3187.50	4037.00	5134.50	7366.75
S_3	2046.25	2877.75	3600.75	4848.50	6519.50
S_4	2065.00	2792.50	3490.50	4613.75	6146.00
F test	S (NS)	S (S)	S (S)	S (S)	S (S)
CD (0.05)	-	337.635	303.35	430.659	807.53

The mean number of leaves from S_1 at 120, 150 and 180 DAP were 82.22, 153.22 and 200.25 respectively. At 120 DAP, S_2 (70.95) followed S_1 (82.22) while at 150 and 180 DAP, S_0 (145.95 and 192.48) followed S_1 (153.22 and 200.25).

4.1.1.4 Leaf area

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

Significant difference was observed when leaf area under open condition and shade levels were compared, at 90, 120, 150 and 180 DAP. No significant difference was observed at 60 DAP when different shade levels and open condition were compared. Highest leaf area was recorded from 20 per cent shade (S_1) and lowest from open condition (S_0) at all growth stages. Leaf area under open condition and under 80 per cent shade (S_4) were on par at all stages.

At 120,150 and 180 DAP, S_1 recorded leaf area of 4069.50, 6015.25 and 7645.50 cm^2 followed by S_2, which recorded 4037, 5134.50 and 7366.75 cm^2 respectively.

4.1.1.5 Leaf weight

The data in Table 5 depict the effect of shade on leaf weight.

The data clearly shows that there was significant variation in leaf dry weight per plant with varying shade levels. Among the different shade levels, S_1 recorded maximum leaf dry weight at all growth stages. Minimum leaf dry weight was noted from plants grown under 80 per cent shade.

Table 5 Effect of shade on leaf weight (g)

Shade levels	Periods				
	60 DAP	90 DAP	120 DAP	150 DAP	180 DAP
S_0	1.25	2.23	8.22	12.72	20.37
S_1	1.67	2.63	10.80	14.42	22.45
S_2	1.51	2.45	9.25	14.05	19.37
S_3	1.20	2.15	7.42	13.05	15.75
S_4	1.12	2.10	7.07	9.67	12.55
F test	S (S)	S (S)	S (S)	S (S)	S (S)
CD (0.05)	0.199	0.218	1.473	1.37	1.475

Table 6 Effect of shade on leaf thickness (mm)

Shade levels	Periods				
	60 DAP	90 DAP	120 DAP	150 DAP	180 DAP
S_0	10.25	12.67	13.65	14.27	15.57
S_1	9.07	11.35	12.50	13.37	14.52
S_2	8.35	10.42	11.40	12.50	13.72
S_3	8.37	10.65	11.40	12.25	13.50
S_4	8.67	10.45	11.25	12.25	13.27
F test	S (S)	S (S)	S (S)	S (S)	S (S)
CD (0.05)	0.68	0.683	0.66	0.617	0.802

Plants grown under 60 per cent shade also showed low leaf dry weight. S_1 and S_2 were on par at 60, 90 and 150 DAP. But at 120 and 180 DAP S_1 and S_2 were found to be significant. Plants grown at 20 per cent shade was found to be significantly superior compared to other shade levels at 180 DAP.

Leaf weight at 120 and 150 DAP for S_1 was 10.80 and 14.42 g. At 180 DAP S_1 recorded a leaf weight of 22.45 g while S_0, S_2, S_3 and S_4 recorded 20.375, 19.375, 15.75 and 12.55 g respectively.

4.1.1.6 Leaf thickness

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

Significant variation was observed in leaf thickness with different shade levels. Leaf thickness was found to be significantly superior under open condition. S_2 recorded lowest leaf thickness at 60 and 90 DAP. At 120, 150 and 180 DAP S_2 , S_3 and S_4 were statistically on par. However at later stages of growth lowest leaf thickness was observed under highly shaded condition.

Maximum leaf thickness was observed from plants grown under open condition (13.65 mm at 120 DAP; 14.27 mm at 150 DAP; 15.57 mm at 180 DAP). This was followed by plants grown under 20 per cent shade representing a mean value of 12.50, 13.37 and 14.52 mm at 120,150 and 180 DAP. However at 150 DAP, S_3 and S_4 recorded same mean leaf thickness (12.25 mm) while at 180 DAP the leaf thickness of S_4 (13.27 mm) was less than that of S_3 (13.50 mm).

4.1.2 Root characters

4.1.2.1 Root length

Table 7 depicts the effect of shade on root length.

Root length showed significant difference among different shade levels. S_4 recorded maximum root length at all growth stages. Not much difference in root length was observed from plants grown under 20 and 40 per cent shade at all growth stages except 60 DAP. Root length was found to be minimum under open condition at all growth stages.

The root length was 39, 41.77 and 44.65 cm at 120, 150 and 180 DAP for plants grown under 80 per cent shade which was maximum. The root length decreased with decrease in shade intensities. Thus open condition recorded least root length with a mean value of 26.52, 30.37 and 31.87 cm at 120, 150 and 180 DAP.

4.1.2.2 Root Spread

The effect of shade on root spread is given by Table 8.

Root spread was found to be significantly different under different shade levels. Among different shade levels, S_1 recorded the maximum root spread. Only during 180 DAP, significant difference was observed in root spread among different shade levels. Here also S_1, S_0 and S_2 were on par. Lower values of root spread was obtained from heavy shade (60 and 80 per cent shade).

At 120 and 180 DAP, maximum root spread was seen in S_1 (11.40 and 14.85 cm) while at 150 DAP highest root spread was seen in S_0 (12.75 cm) followed by S_1 (12.67 cm).

Table 7 Effect of shade on root length (cm)

Shade levels	Periods				
	60 DAP	90 DAP	120 DAP	150 DAP	180 DAP
S_0	19.92	24.80	26.52	30.37	31.87
S_1	22.32	29.32	33.05	34.20	35.85
S_2	22.32	30.52	34.10	36.57	37.72
S_3	23.52	34.85	38.37	40.05	41.52
S_4	25.55	37.00	39.00	41.77	44.65
F test	S (S)	S (S)	S (S)	S (S)	S (S)
CD (0.05)	1.06	2.565	2.825	1.943	2.13

Table 8 Effect of shade on root spread (cm)

Shade levels	Periods				
	60 DAP	90 DAP	120 DAP	150 DAP	180 DAP
S_0	8.67	9.65	11.32	12.75	14.40
S_1	9.42	10.87	11.40	12.67	14.85
S_2	9.25	10.25	10.87	12.12	13.77
S_3	8.10	9.07	9.80	10.77	12.32
S_4	7.45	8.42	9.72	10.52	11.97
F test	S (NS)	S (NS)	S (NS)	S (NS)	S (S)
CD (0.05)	-	-	-	-	1.253

4.1.2.3 Root weight

The data presented in Table 9 show the effect of shade on root dry weight per plant.

Significant difference of root dry weight per plant was observed only at 180 DAP. At all other stages the effect of shade on root dry weight was non-significant. At 180 DAP a general increasing trend in root dry weight per plant was observed with increasing levels of shade.

Plants grown under open condition recorded least root dry weight at 180 DAP. S_3 and S_4 were statistically on par. Maximum root dry weight was observed from S_4 (4.52 g) followed by S_3 (4.42 g), S2 (4.12 g), S_1 (4.02 g) and S_0 (3.90 g).

4.1.2.4 Root volume

The data presented in Table 10 indicate the effect of shade on root volume.

Significant variation was observed among various shade levels and the root volume showed an increasing trend with increasing shade levels at all growth stages except at 180 DAP. At 180 DAP, highest root volume was recorded from 60 per cent shade (67.97 cm^3) followed by 80 per cent (63.82 cm^3). S_4 and S_3 were on par at 60, 90, 150 and 180 DAP. S_0 recorded the lowest root volume per plant at all growth stages. S_2 and S_1 were on par at 60, 90 DAP and 180 DAP.

Table 9 Effect of shade on root weight per plant (g)

Shade levels	Periods				
	60 DAP	90 DAP	120 DAP	150 DAP	180 DAP
S_0	0.65	1.40	2.16	3.45	3.90
S_1	0.67	1.47	2.34	3.45	4.02
S_2	0.65	1.57	2.40	3.37	4.12
S_3	0.70	1.65	2.79	3.75	4.42
S_4	0.77	1.75	3.27	3.97	4.52
F test	S (NS)	S (NS)	S (NS)	S (NS)	S (S)
CD (0.05)	-	-	-	-	0.249

Table 10 Effect of shade on root volume per plant (cm^3)

Shade levels	Periods				
	60 DAP	90 DAP	120 DAP	150 DAP	180 DAP
S_0	3.25	4.00	20.31	34.31	40.62
S_1	4.50	6.56	24.87	41.27	50.50
S_2	5.25	6.68	37.25	48.27	55.75
S_3	5.75	8.18	40.50	51.37	67.97
S_4	6.12	8.75	48.62	56.56	63.82
F test	S (S)	S (S)	S (S)	S (S)	S (S)
CD (0.05)	0.913	0.839	5.836	6.452	10.034

At 80 per cent shade root volume recorded was 48.62 and 56.56 cm^3 at 120 and 150 DAP. However at 180 DAP more root volume was observed from plants grown under 60 per cent shade (67.97 cm^3) followed by 80 per cent shade (63.82 cm^3).

4.1.3 Rhizome characters

4.1.3.1 Rhizome spread

The effect of shade on rhizome spread is depicted in Table 7.

Significant variation of rhizome spread was observed under different shade levels, at 150, 180 and 240 DAP. Open condition recorded the minimum rhizome spread, while maximum rhizome spread was observed from 20 per cent shade at these stages except at 150 DAP. The treatments S_3 and S_4 were on par at all growth stages. No significant variation in rhizome spread was observed when S_1 and S_2 were compared.

A mean rhizome spread of 11.02 cm was noticed in S_1 followd by S_2 at 150 DAP. S_1 and S_2 recorded same mean value (15.82 cm) at 180 DAP while at 240 DAP rhizome spread under 20 per cent shade was more (19.07 cm) compared to 40 per cent shade (18.40 cm).

4.1.3.2 Rhizome thickness

The data presented in Table 12 represent the effect of shade on rhizome thickness.

Significant variation in rhizome thickness was observed under different shade levels at 120 DAP. At all other growth stages not much variation was

Table 11 Effect of shade on rhizome spread (cm)

Shade levels	Periods					
	90 DAP	120 DAP	150 DAP	180DAP	210 DAP	240 DAP
S_0	3.30	5.72	8.52	12.77	15.67	16.90
S_1	4.50	7.47	11.02	15.82	17.97	19.07
S_2	4.30	7.27	11.05	15.82	17.62	18.40
S_3	3.67	6.35	10.62	15.82	17.70	18.27
S_4	4.12	7.10	10.41	14.95	17.15	18.20
F test	S (NS)	S (NS)	S (S)	S (S)	S (NS)	S (S)
CD (0.05)	-	-	1.34	0.979		0.868

Table 12 Effect of shade on rhizome thickness (cm)

Shade levels	Periods					
	90 DAP	120 DAP	150 DAP	180DAP	210 DAP	240 DAP
S_0	1.77	2.15	2.57	2.85	3.10	3.25
S_1	1.87	2.47	2.87	3.05	3.20	3.30
S_2	1.90	2.45	2.72	2.82	3.10	3.22
S_3	1.65	2.17	2.45	2.65	2.90	3.02
S_4	1.65	2.10	2.52	2.67	2.90	3.05
F test	S (NS)	S (S)	S (NS)	S (NS)	S (NS)	S (NS)
CD (0.05)	-	0.225	-	-	-	-

observed due to different shade levels. At 120 DAP, S_1 and S_2 were found to be significantly superior compared to all other shade levels. Maximum rhizome thickness was observed from 20 per cent shade and minimum from 80 per cent shade.

At 120 DAP the maximum mean value of rhizome thickness was observed from S_1 (2.47 cm) followed by S_2 (2.45 cm), S_3 (2.17 cm), S_0 (2.15 cm) and S_4 (2.10 cm).

4.2 Histological

4.2.1 Stomatal frequency

The data presented in Table 13 indicate the effect of shade on stomatal frequency.

Stomatal frequency recorded significant variation under different shade levels. Maximum stomatal frequency was recorded under open condition and minimum under 80 per cent shade at 180 DAP. S_0 is significantly superior compared to all other shade levels.

Plants grown under open condition showed a stomatal frequency of 3.57 followed by S_1 (3.28), S_2 (3.11), S_3 (2.29) and S_4 (2.08).

Table 13 Effect of shade on stomatal frequency at 180 DAP

Shade levels	Stomatal frequency
S_0	3.57
S_1	3.28
S_2	3.11
S_3	2.29
S_4	2.08
F test	S (S)
CD (0.05)	0.12

4.3 Physiological

4.3.1 Dry matter production

The data presented in Table 14 show the effect of shade on dry matter production.

Dry matter production (DMP) showed significant variation with respect to different shade levels. At all growth stages, ginger plants under low shade (20 per cent, S_1) produced highest DMP. The lowest DMP was observed from S_4 at all growth stages except at 60 DAP which was on par with S_3. No significant difference was noticed at 90 DAP.

At 150 and 180 DAP, S_1 recorded a DMP of 33.24 and 50.90 g followed by S_0 (31.95 and 47.25 g). But at 120 DAP, S_2 (21.56 g) followed S_1 (23.95 g). S_3 and S_4 recorded 38.35 and 37.15 g at 180 DAP respectively.

4.3.2 Crop growth rate

The effect of shade on CGR is represented in Table 15.

The effect of shade on CGR was found to be significant at three growth phases. The highest value of CGR was obtained from 20 per cent shade (S_1) followed by open condition (S_0). Between 60 - 90 DAP, maximum CGR was noticed in 20 per cent shade (S_1) followed by open, 40, 60 and 80 per cent shade. The same trend was observed during the next growth phase i.e., between 90 - 120 DAP. But between 120 - 150 DAP, the value of CGR at 80 per cent was found to be more than at 60 per cent shade. At the later phase (150 - 180 DAP) S_1 was found to have maximum CGR followed by open, 40, 60 and 80 per cent shade levels. At these phase, S_0, S_3 and S_2 were on par with each other.

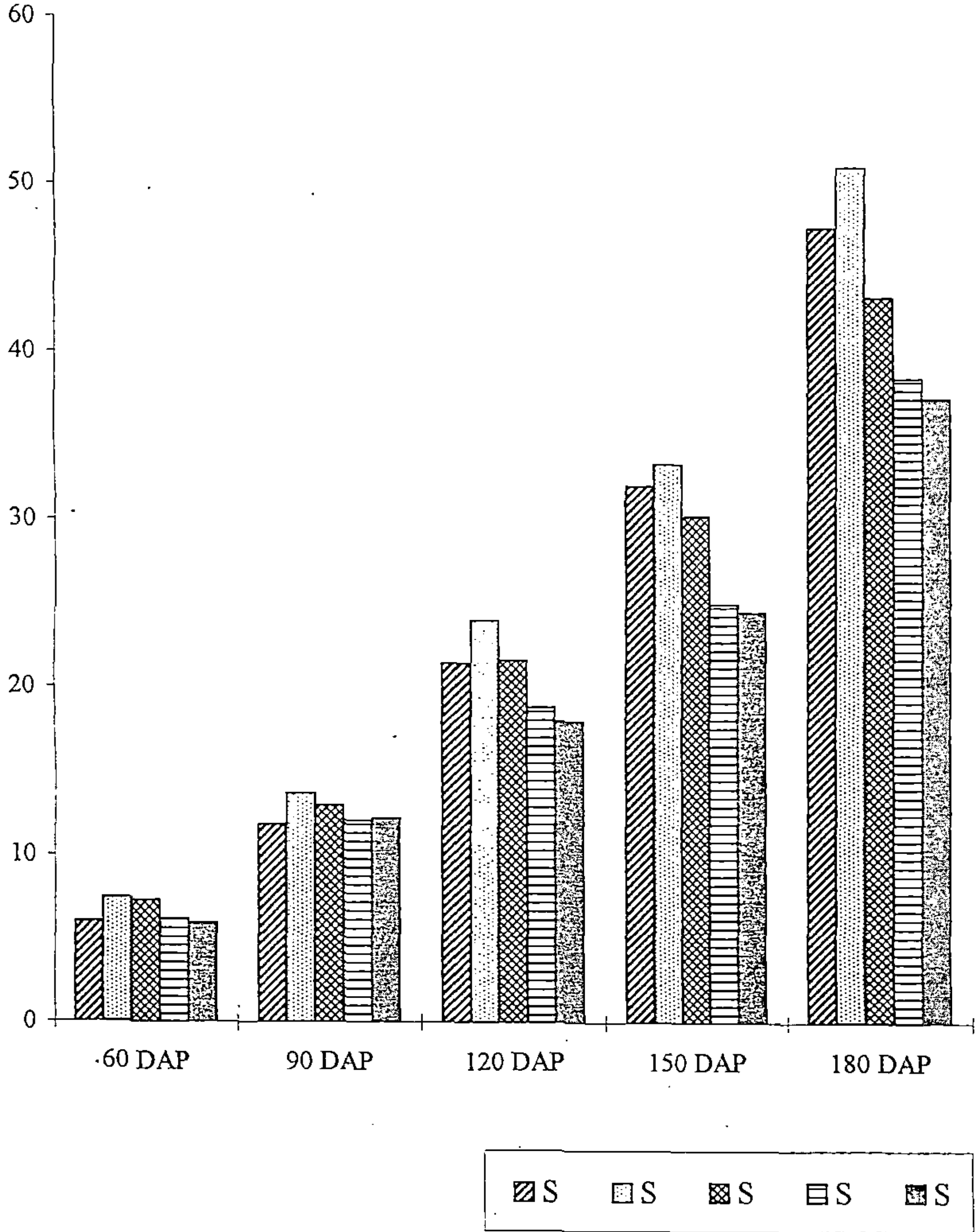
Table 14 Effect of shade on dry matter production (g plant^{-1})

Shade levels	Periods				
	60 DAP	90 DAP	120 DAP	150 DAP	180 DAP
S_0	6.01	11.82	21.36	31.95	47.25
S_1	7.43	13.64	23.95	33.24	50.90
S_2	7.27	12.95	21.56	30.15	43.12
S_3	6.18	12.02	18.78	24.92	38.35
S_4	5.91	12.16	17.93	24.41	37.15
F test	S (S)	S (NS)	S (S)	S (S)	S (S)
CD (0.05)	0.3427	-	2.032	1.9512	3.605

Table 15 Effect of shade on crop growth rate (g m^{-2} day^{-1})

Shade levels	Periods			
	60-90 DAP	90-120 DAP	120-150 DAP	150 - 180 DAP
S_0	0.194	0.292	0.318	0.464
S_1	0.207	0.312	0.344	0.625
S_2	0.188	0.284	0.283	0.430
S_3	0.152	0.214	0.204	0.451
S_4	0.154	0.194	0.209	0.398
F test	S (S)	S (S)	S (S)	S (S)
CD (0.05)	0.02	0.0398	0.0398	0.0563

Fig. 3. Effect of shade on dry matter production



CGR between 120 - 150 DAP was maximum at 20 per cent (0.344) followed by open (0.318), 40 (0.283), 80 (0.209) and 60 per cent (0.204) shade levels. Between 150 - 180 DAP, S_1 showed a mean value of 0.625 followed by S_0 (0.464), S_3 (0.451), S_2 (0.430) and S_4 (0.398).

4.3.3 Relative growth rate

The data presented in Table 16 show the effect of shade on relative growth rate.

The relative growth rate vary significantly over different periods except between 150 - 180 DAP. S_1 recorded maximum relative growth between 90 - 120 DAP (0.018 g day^{-1}) and 150 - 180 DAP (0.014 g day^{-1}). Between 150 - 180 DAP shade levels does not have any significance on relative growth rate.

Ginger plants grown at 60 per cent shade (0.075 g day^{-1}) were found to be significantly superior to other shade levels at 120 - 150 DAP.

4.3.4 Net assimilation rate

Table 17 present the effect of shade on NAR.

At all growth phases, the effect of shade on NAR was found to be significant. Among different shade levels, NAR was found to be more under open condition at all stages except between 150 - 180 DAP. S_3 and S_4 were on par at initial two growth phases. Likewise S_0 and S_1 were also on par at these periods.

Table 16 Effect of shade on relative growth rate (g day^{-1})

Shade levels	Periods			
	60-90 DAP	90-120 DAP	120-150 DAP	150-180 DAP
S_0	0.022	0.017	0.013	0.012
S_1	0.020	0.018	0.012	0.014
S_2	0.019	0.016	0.011	0.011
S_3	0.023	0.013	0.075	0.011
S_4	0.023	0.013	0.045	0.010
F test	S (S)	S (S)	S (S)	S (NS)
CD (0.05)	0.001	0.001	0.002	-

Table 17 Effect of shade on net assimilation rate (g m^{-2} day^{-1})

Shade levels	Periods			
	60-90 DAP	90-120 DAP	120-150 DAP	150-180 DAP
S_0	0.323	0.256	0.156	0.099
S_1	0.298	0.219	0.117	0.106
S_2	0.274	0.204	0.101	0.077
S_3	0.251	0.157	0.080	0.086
S_4	0.257	0.161	0.092	0.080
F test	S (S)	S (S)	S (S)	S (S)
CD (0.05)	0.0398	0.0398	0.0181	0.012

Between 120 - 150 DAP, S_0 recorded maximum net assimilation rate (0.156 g m^{-2} day^{-1}) followed by S_1 (0.117 g m^{-2} day^{-1}). But at later phase (150 - 180 DAP), NAR was found to be more for plants grown under 20 per cent shade (0.106 g m^{-2} day^{-1}).

4.3.5 Specific leaf weight

The data presented in Table 18 show the effect of shade on specific leaf weight.

Significant variation was noticed in specific leaf weight for plants grown under different shade levels at all growth phases. Specific leaf weight was found to be maximum under open condition followed by plants grown under 20 per cent shade. Plants grown under S_4 exhibited least specific leaf weight which was on par with S_3 at all stages. S_0 recorded significant superiority over other treatments at all stages, but during later stages not much variation was observed in other shade levels.

Specific leaf weight observed from plants grown under open condition was 0.0079, 0.0066, 0.0052 g cm^{-2} at 120, 150 and 180 DAP while for 20 per cent it was 0.0049, 0.0043 and 0.0040 g cm^{-2}. However heavier shade intensities the specific leaf weight was less.

4.3.6 Leaf area index

Table 19 shows the effect of shade on leaf area index.

Leaf area index at different shade levels exhibited significant variation from 90-180 DAP. At 60 DAP no significant difference was noticed among various shade levels.

Table 18 Effect of shade on specific leaf weight (g cm^{-2})

Shade levels	Periods				
	60 DAP	90 DAP	120 DAP	150 DAP	180 DAP
S_0	0.0073	0.0077	0.0079	0.0066	0.0052
S_1	0.0054	0.0052	0.0049	0.0043	0.0040
S_2	0.0038	0.0039	0.0039	0.0039	0.0040
S_3	0.0026	0.0031	0.0031	0.0031	0.0032
S_4	0.0024	0.0027	0.0025	0.0026	0.0026
F test	S (S)	S (S)	S (S)	S (S)	S (S)
CD (0.05)	0.0004	0.0005	0.0007	0.0006	0.0006

Table 19 Effect of shade on leaf area index

Shade levels	Periods				
	60 DAP	90 DAP	120 DAP	150 DAP	180 DAP
S_0	0.538	0.661	1.62	2.46	6.94
S_1	0.635	0.762	2.07	3.92	8.18
S_2	0.594	0.782	2.03	3.69	7.57
S_3	0.548	0.677	1.78	3.34	7.13
S_4	0.529	0.668	1.75	2.80	7.13
F test	S (NS)	S (S)	S (S)	S (S)	S (S)
CD (0.05)	-	0.0796	0.1436	0.3695	0.504

S_2 recorded maximum leaf area index at 90 DAP (0.782) which was on par with S_1 (0.762). During the following growing periods S_1 recorded maximum LAI values, followed by S_2. LAI under open condition recorded minimum values, at all growth stages, except at 60 DAP. Likewise treatments S_3 and S_4 were on par at all stages except at 150 DAP.

Maximum LAI was seen in S_1 (2.07) followed by S_2 (2.03) at 120 DAP. At 150 and 180 DAP, S_1 recorded 3.92 and 8.18 LAI respectively. S_2 followed S_1 at these periods with an LAI of 3.69 and 7.57.

4.3.7 Leaf area duration

The data presented in Table 20 show the effect of shade on leaf area duration.

Leaf area duration showed significant variation at all growth phases. S_2 recorded maximum LAD between 60 - 90 DAP and 150 - 180 DAP. But between 90 - 120 DAP and 120 - 150 DAP, S_1 recorded maximum value. LAD under open condition was minimum at all growth phases. S_3 and S_4 were on par between 150 - 180 DAP.

Maximum LAD was seen in S_1 (59.87 and 122.75) between 120 - 150 DAP and 150 - 180 DAP.The least LAD was observed from S_4 (117.82) between 150 - 180 DAP.

4.3.8 Harvest index

The data presented in Table 21 show the effect of shade on harvest index.

Table 20 Effect of shade on leaf area duration

Shade levels	Periods			
	60-90 DAP	90-120 DAP	120-150 DAP	150-180 DAP
S_0	10.17	24.75	37.79	99.69
S_1	11.73	31.49	59.87	122.75
S_2	12.03	30.77	56.36	119.67
S_3	10.46	27.15	52.99	118.95
S_4	10.28	26.62	42.99	117.82
F test	S (S)	S (S)	S (S)	S (S)
CD (0.05)	1.161	2.218	5.268	9.474

Table 21 Effect of shade on harvest index

Shade levels	240 DAP
S_0	0.700
S_1	0.676
S_2	0.665
S_3	0.608
S_4	0.594
F test	S (S)
CD (0.05)	0.017

The effect of shade on harvest index was found to be significant. Plants grown under 20 per cent shade (S_1) had higher harvest index (0.700) and was distinctly different from plants grown under open (0.676). Not much variation was observed, when plants grown under 0 and 40 per cent shade were compared. Harvest index at 240 DAP was 0.676 for S_0 while it was 0.665 for S_2. S_3 and S_4 recorded a minimum value of 0.608 and 0.594 respectively.

4.3.9 Relative water content

The data presented in Table 22 show the effect of shade on relative water content.

Relative water content was found to be significantly influenced by shade. At 150 DAP, S_4 recorded maximum RWC followed by S_2, S_3, S_0 and S_1. S_0 and S_3 were found to be on par on these days. During all growth stages S_4 recorded the maximum relative water content which was superior to all other shade levels. S_1 recorded lowest relative water content over different periods. At 180 DAP, maximum RWC was recorded from S_4 followed by S_3, S_2, S_0 and S_1. The same trend was seen in the following periods.

The relative water content was the highest under 80 per cent shade. It recorded a value of 89.46 and 90.36 at 210 and 240 DAP. The RWC was the lowest under 20 per cent shade at 150, 180, 210 and 240 DAP (81.90, 81.89, 81.71 and 81.46).

Table 22 Effect of shade on relative water content (%)

Shade levels	Periods			
	150 DAP	180 DAP	210 DAP	240 DAP
S_0	83.98	84.18	85.16	85.40
S_1	81.90	81.89	81.71	81.46
S_2	86.06	86.57	87.42	86.86
S_3	85.69	86.77	87.33	87.08
S_4	87.88	90.09	89.46	90.36
F test	S (S)	S (S)	S (S)	S (S)
CD (0.05)	0.86	0.853	0.588	0.533

Table 23 Effect of shade on root shoot ratio

Shade levels	Periods				
	60 DAP	90 DAP	120 DAP	150 DAP	180 DAP
S_0	0.141	0.147	0.149	0.137	0.135
S_1	0.117	0.128	0.125	0.117	0.089
S_2	0.089	0.100	0.098	0.090	0.081
S_3	0.089	0.095	0.086	0.079	0.062
S_4	0.085	0.096	0.076	0.070	0.058
F test	S (S)	S (S)	S (S)	S (S)	S (S)
CD (0.05)	0.0182	0.0182	0.0178	0.0178	0.0178

4.3.10 Root shoot ratio

The data presented in Table 23 show the effect of shade on root shoot ratio.

Significant variation in root shoot ratio was recorded at different shade levels. S_0 recorded maximum root shoot ratio followed by S_1. In all other shade levels there was not much variation in root shoot ratio. At 180 DAP, root shoot ratio was 0.135 for S_0 and 0.089 for S_1. Lowest value was recorded from S_4 (0.058). However S_2 showed a root shoot ratio of 0.081 while for S_3 it was 0.062 at 180 days after planting.

4.4 Photosynthetic rate and related parameters

4.4.1 Solar light intensity

Table 24a represents the data on solar light intensity at the time when the measurement was taken. Maximum solar light intensity was noticed at open condition followed by 20, 40, 60 and 80 per cent shade levels.

The solar light intensity under open condition recorded a mean value of 1708.50 μ mol m^{-2} s^{-1} while under S_1 it was 773.75 μ mol m^{-2} s^{-1}. At 40 per cent shade the solar light intensity at the time of measuring photosynthetic parameters was 335.25 μ mol m^{-2} s^{-1} and for 60 and 80 per cent shade it was 49.25 and 30.25 μ mol m^{-2} s^{-1} respectively.

4.4.2 Photosynthetically active radiation on leaf surface

The effect of shade on photosynthetically active radtion on leaf surface or actual light intensity on leaf surface is shown in Table 24a.

Photosynthetically active radiation on leaf surface varied significantly among different shade levels at 180 DAP. Highest PAR was noticed from S_0 (1279.50 µmol m^{-2} s^{-1}) followed by S_1 (657.75 µmol m^{-2} s^{-1}). No significant difference was noticed when S_2, S_3 and S_4 were compared. However, minimum PAR was recorded from S_4 (17 µmol m^{-2} s^{-1}).

4.4.3 Atmospheric CO_2 concentration

Table 24b shows the data on atmospheric CO_2 concentration at the time of measurement.

At the time when S_0, S_1 and S_2 was measured, atmospheric concentration of CO_2 was almost constant. But when S_3 and S_4 were measured there was slight difference noted compared to other shade levels. Atmospheric CO_2 concentration recorded low value when S_3 and S_4 were measured.

The atmospheric CO_2 concentration was 368.25 µ mol mol^{-1} under open and 20 per cent shade. The concentration was 367.67, 366.52 and 366.47 µ mol mol^{-1} under S_2, S_3 and S_4.

4.4.4 Leaf internal CO_2 concentration

The data presented in Table 24b show the effect of shade on leaf internal CO_2 concentration.

Table 24a Effect of shade on solar light intensity and photosynthetically active radiation on leaf surface at 180 DAP

Shade levels	Solar light intensity µmol m^{-2} s^{-1}	Actual light intensity on leaf or PAR µmol m^{-2} s^{-1}
S_0	1708.50	1279.50
S_1	773.75	657.75
S_2	335.25	276.00
S_3	49.25	38.25
S_4	30.25	17.00
F test	S (S)	S (S)
CD (0.05)	157.725	349.93

Table 24b Effect of shade on atmospheric CO_2 concentration and leaf internal CO_2 concentration at 180 DAP

Shade levels	Atmospheric CO_2 concentration (µ mol mol^{-1})	Leaf internal CO_2 concentration (µ mol mol^{-1})
S_0	368.25	159.53
S_1	368.25	181.05
S_2	367.67	166.30
S_3	366.52	303.40
S_4	366.47	297.60
F test	S (S)	S (S)
CD (0.05)	1.017	48.239

There was significant difference noted in leaf internal CO_2 concentration among different shade levels. Leaf internal CO_2 concentration was more under heavy shade (S_3 - 303.4 µmol mol^{-1} and S_4 - 297.6 µmol mol^{-1}). Open condition recorded the lowest value (159.52 µmol mol^{-1}) followed by plants grown under medium shade (S_2 - 166.3 µmol mol^{-1}). S_1 recorded a medium value (181.05 µmol mol^{-1}) which was more than under open and medium shade. S_3 and S_4 were on par. S_0 and S_2 were also on par.

4.4.5 Leaf temperature

The data presented in Table 24c show the effect of shade on leaf temperature.

No significant variation in leaf temperature was recorded among various shade levels.

4.4.6 Stomatal conductance

The data presented in Table 24d show the effect of shade on stomatal conductance.

Significant variation in stomatal conductance was noticed among different shade levels. S_0 (0.070 mol m^{-2} s^{-1}) was significantly superior compared to all other shade levels. S_4 represented least stomatal conductance (0.010 mol m^{-2} s^{-1}) at 180 DAP. Stomatal conductance seen in S_1 was 0.050 mol m^{-2} s^{-1} and for S_2 and S_3 it was 0.025 and 0.020 mol m^{-2} s^{-1}. A general decreasing trend in stomatal conductance was observed with increasing levels of shade.

Table 24c Effect of shade on leaf temperature

Shade levels	180 DAP
S_0	32.23
S_1	31.34
S_2	32.31
S_3	32.82
S_4	32.54
F test	S (NS)
CD (0.05)	-

Table 24d Effect of shade on stomatal conductance and stomatal resistance at 180 DAP

Shade levels	Stomatal conductance (mol m^{-2} s^{-1})	Stomatal resistance (m^2 s mol^{-1})
S_0	0.070	15.63
S_1	0.050	19.01
S_2	0.025	31.02
S_3	0.020	43.53
S_4	0.010	77.68
F test	S (S)	S (S)
CD (0.05)	0.0182	10.549

4.4.7 Stomatal resistance

The data presented in Table 24d indicate the effect of shade on stomatal resistance.

The effect of shade on stomatal resistance showed significant variation. Ginger plants grown under 80 per cent shade was found to be significantly superior compared to other shade levels. The plants grown at open condition recorded minimum stomatal resistance (15.62 $m^2s\ mol^{-1}$) while S_4 recorded maximum stomatal resistance (77.68 $m^2S\ mol^{-1}$). However stomatal resistance of S_0 and S_1 were found to be statistically on par.

4.4.8 Photosynthetic rate

The data presented in Table 24e show the effect of shade on photosynthetic rate.

Photosynthetic rate showed significant variation at different shade levels. Ginger plants grown under open showed maximum photosynthetic rate (7.76 $\mu mol\ m^{-2}\ s^{-1}$) which was on par with plants grown under 20 per cent shade (7.45 $\mu mol\ m^{-2}\ s^{-1}$). The lowest photosynthetic rate was registered under 60 per cent (0.680 $\mu mol\ m^{-2}\ s^{-1}$) which was on par with 80 per cent shade (0.765 $\mu mol\ m^{-2}\ s^{-1}$). S_2 recorded a mean photosynthetic rate of 4.893 $\mu mol\ m^{-2}\ s^{-1}$.

4.4.9 Transpiration rate

The data presented in Table 24e indicate the effect of shade on transpiration rate.

Table 24e Effect of shade on photosynthetic rate and transpiration rate at 180 DAP

Shade levels	Photosynthetic rate (μ mol m^{-2} s^{-1})	Transpiration rate (mol m^{-2} s^{-1})
S_0	7.76	2.27
S_1	7.45	1.60
S_2	4.89	1.02
S_3	0.77	0.79
S_4	0.68	0.41
F test	S (S)	S (S)
CD (0.05)	0.955	0.1952

The different treatments showed appreciable difference in transpiration rate at 180 DAP. Open condition recorded maximum transpiration rate (2.265 mol $m^{-2}s^{-1}$) and was found to be significantly superior to other shade levels. Under 80 per cent shade the transpiration rate (0.412 mol $m^{-2}s^{-1}$) was minimum. The next highest level of transpiration rate was recorded from S_3 (0.787 mol $m^{-2}s^{-1}$). S_1 recorded a transpiration rate of 1.595 mol $m^{-2}s^{-1}$ while S_2 recorded 1.015 mol $m^{-2}s^{-1}$ at 180 DAP.

4.5 Biochemical

4.5.1 Chlorophyll

Table 25 represent data of chlorophyll a, chlorophyll b and total chlorophyll as influenced by shade levels.

Fig. 4 Effect of shade on photosynthetic rate (mol m^{-2} s^{-1})

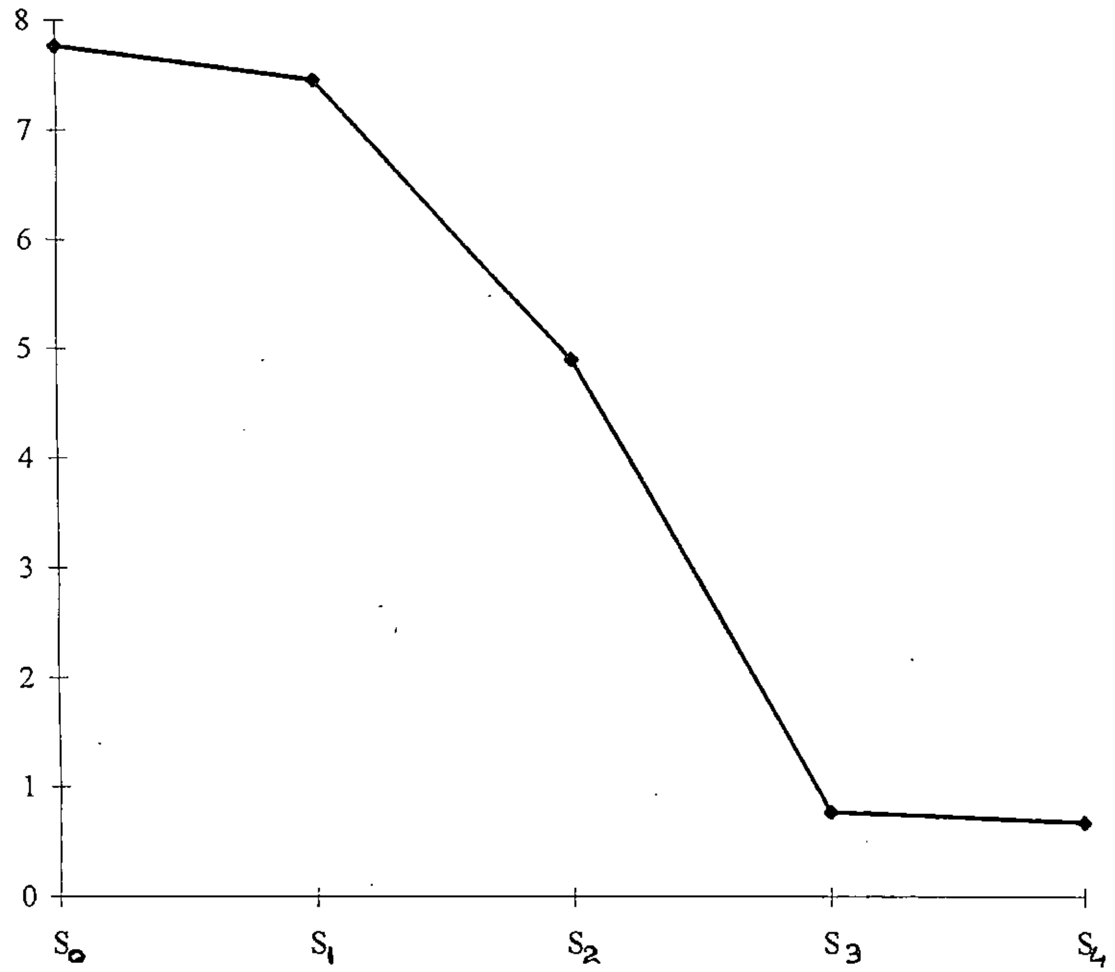
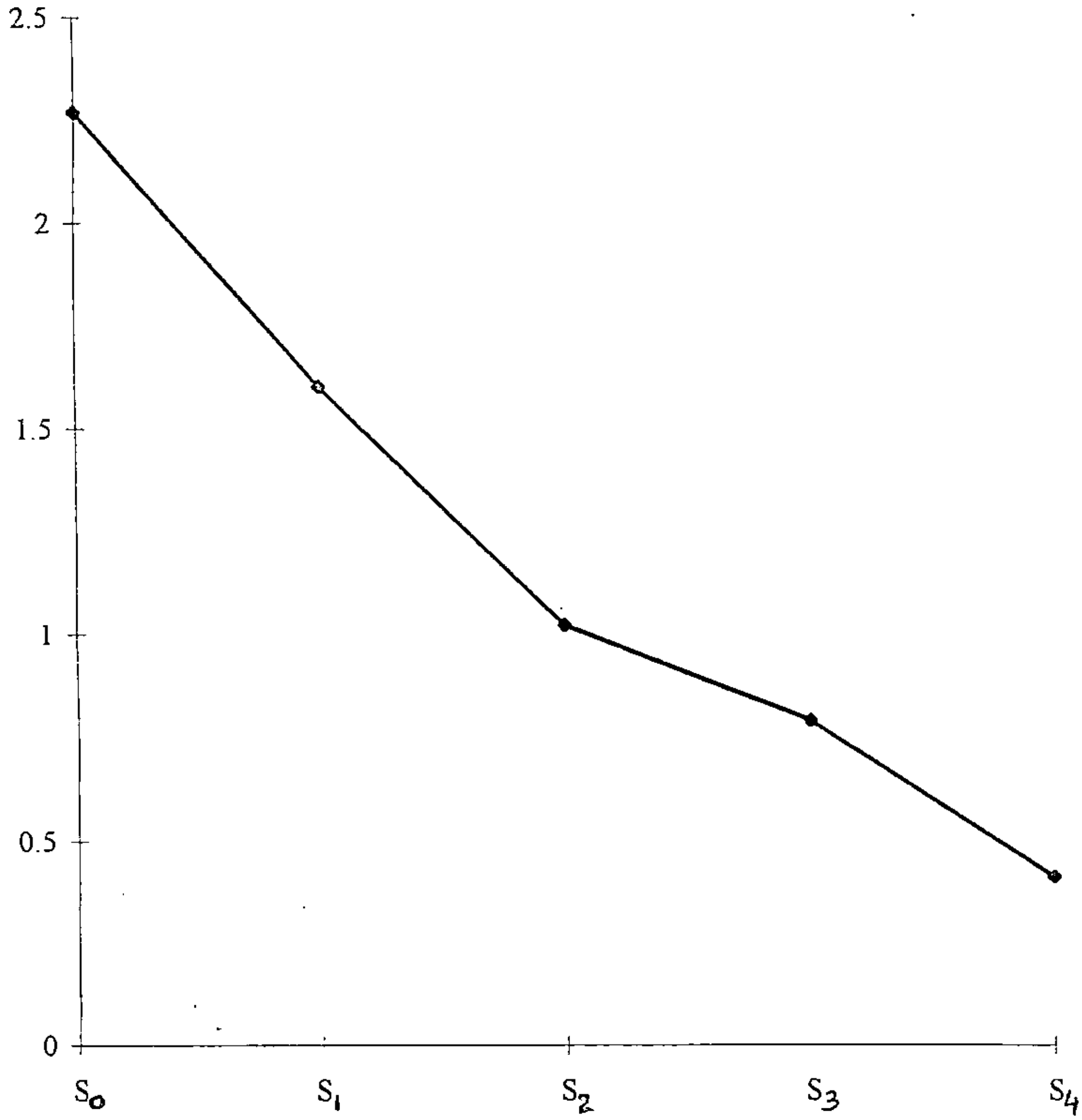


Fig. 5 Effect of shade on transpiration rate (mol m^{-2} s^{-1})



Chlorophyll 'a', chlorophyll 'b' and total chlorophyll varied significantly with different levels of shade. A progressively increasing trend in chlorophyll content with increasing levels of shade was seen.

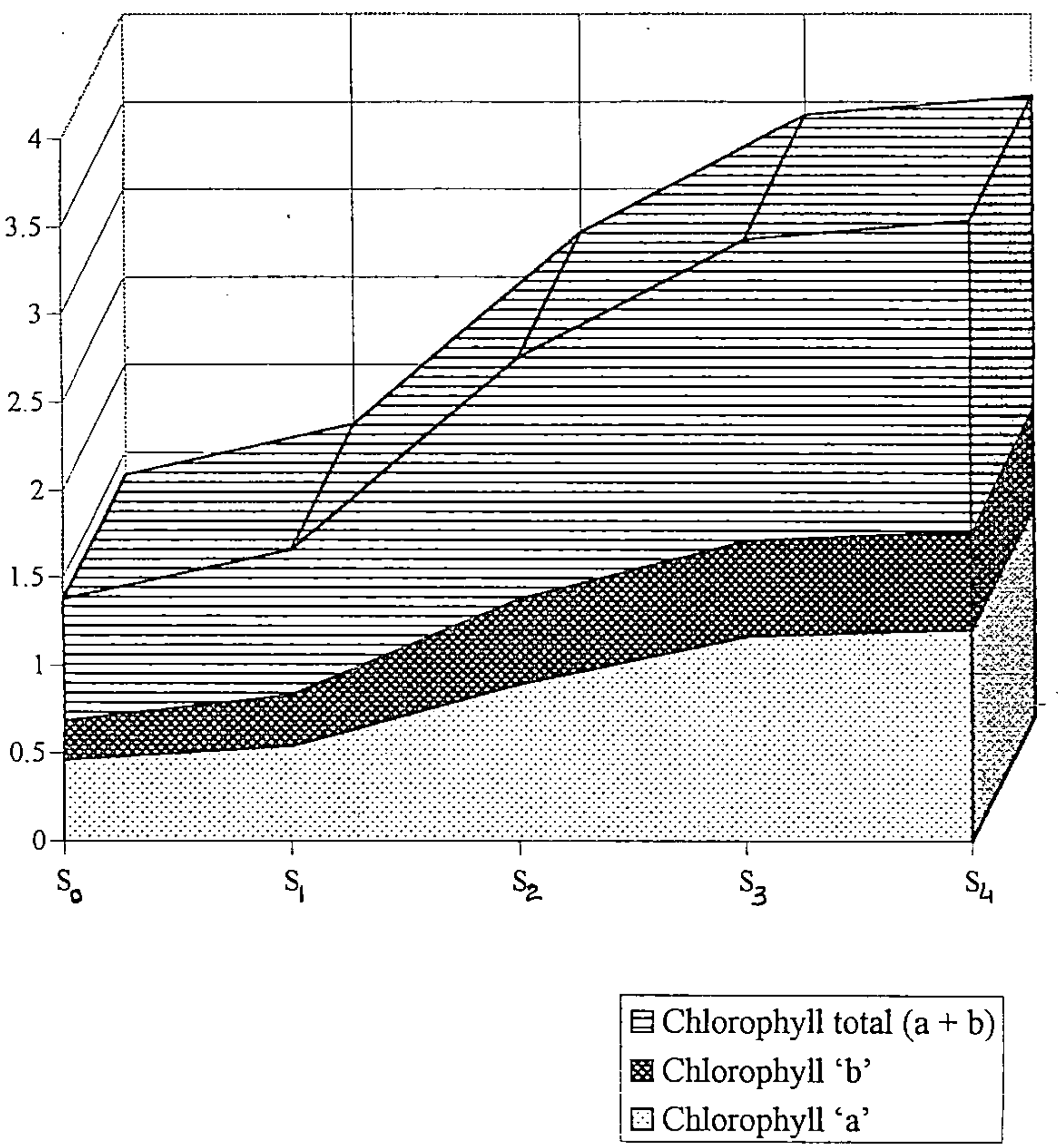
Table 25 Effect of shade on chlorophyll content (mg g^{-1}) on fresh weight basis at 180 DAP

Shade levels	Chlorophyll 'a'	Chlorophyll 'b'	Chlorophyll total (a + b)
S_0	0.460	0.227	0.686
S_1	0.540	0.291	0.831
S_2	0.891	0.486	1.377
S_3	1.162	0.550	1.713
S_4	1.203	0.563	1.766
F test	S (S)	S (S)	S (S)
CD (0.05)	0.1054	0.0178	0.1195

Maximum chlorophyll 'a' content was recorded from highly shaded condition (S_4 and S_3) followed by medium (S_2) low (S_1) and open condition (S_0). S_4 and S_3 were found to be statistically on par. S_0 recorded a minimum value of 0.460 mg g^{-1} while S_1 showed the next highest value of 0.540 mg g^{-1}.

The chlorophyll 'b' content under 80 per cent shade showed significant superiority over other levels of shade (0.563 mg g^{-1}). Chlorophyll 'b' content of ginger plants grown under open condition was found to be low (0.227 mg g^{-1}). While S_1 recorded 0.291 mg g^{-1}, S_2 and S_3 recorded 0.486 mg g^{-1} and 0.550 mg g^{-1}.

Fig. 6 Effect of shade on chlorophyll content on fresh weight basis at 180 DAP (mg g^{-1})



Similarly, an increasing trend in total chlorophyll with increase in shade levels was seen. The highest value of total chlorophyll was observed from S_4 (1.766 mg g^{-1}) and lowest from S_0 (0.686 mg g^{-1}).

4.6 Yield and yield components

4.6.1 Green ginger yield

The data presented in Table 26 show the effect of shade on green ginger yield per plant.

Green ginger yield showed significant variation with varying shade intensities. The highest green ginger yield was recorded under 20 per cent shade (342.5 g $plant^{-1}$) followed by open condition (258.25 g plant $^{-1}$). Shade levels S_0 and S_2 were on par but superior to S_3 and S_4. Treatments S_3 and S_4 were found to be statistically on par. However lowest green ginger yield was noticed in 80 per cent shade (146.25 g $plant^{-1}$). Green ginger yield obtained from 40 and 60 per cent shade levels was 230 and 153 g $plant^{-1}$ respectively.

4.6.2 Top yield

The data on Table 27 indicates effect of shade on top yield per plant.

The top yield varied significantly with shade levels. S_1 recorded maximum top yield (32.6 g $plant^{-1}$) followed by S_0 (28.12 g $plant^{-1}$). With increase in light intensity there was a progressive decrease in top yield after 20 per cent shade (25.2 g $plant^{-1}$ for 40 per cent; 18.47 g $plant^{-1}$ for 60 and 80 per cent). However top yields under 80 and 60 per cent shade level was found to be on par.

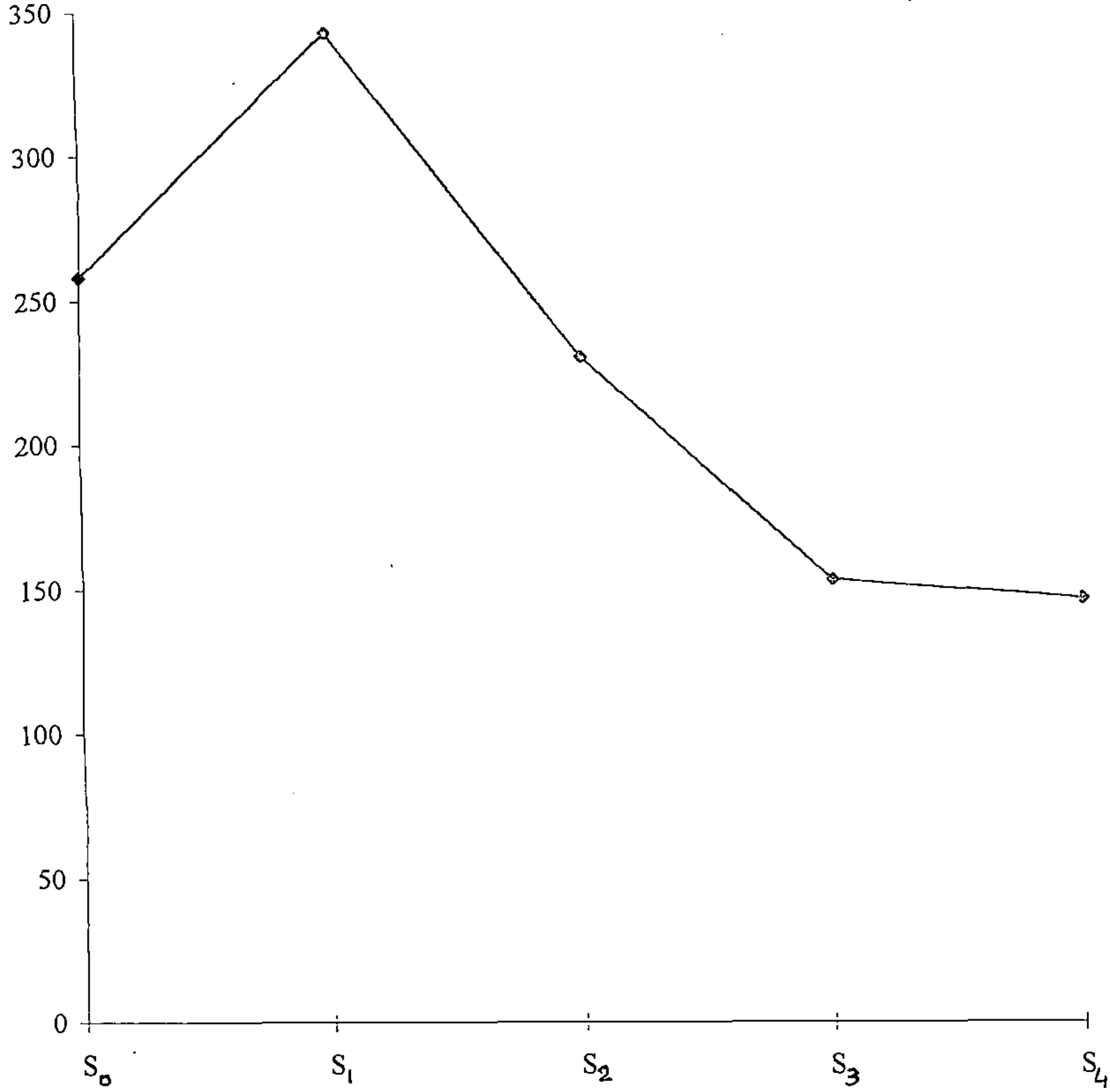
Table 26 Effect of shade on green ginger yield (g $plant^{-1}$)

Shade levels	240 DAP
S_0	258.25
S_1	342.50
S_2	230.00
S_3	153.00
S_4	146.25
F test	S (S)
CD (0.05)	36.39

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

Shade levels	240 DAP
S_0	28.12
S_1	32.60
S_2	25.20
S_3	18.47
S_4	18.47
F test	S (S)
CD (0.05)	5.576

Fig. 7 Effect of shade on green ginger yield at 240 DAP (g plant^{-1})



4.6.3 Dry ginger yield

The data presented on Table 28 show the effect of shade on dry ginger yield per plant.

Significant variation was noticed among shade levels with respect to total dry ginger yield per plant on all the growth stages. Highest dry ginger yield per plant was recorded from 20 per cent shade right from the initial period to the last stage. Dry ginger yield per plant failed to show any significant difference between 20 per cent and open condition in 90 and 120 DAP. At 120 DAP not much variations in dry ginger yield was observed in S_2, S_3 and S_4. The dry ginger yields at zero and 40 per cent shade was statistically on par whereas 80 per cent shade was significantly lower compared to other shade levels on 150, 180, 210 and 240 DAP.

Dry ginger yield obtained from 20 per cent shade at 180,210 and 240 DAP were 25.32, 40.45 and 57.57 g $plant^{-1}$ respectively which was highest among treatments. At final harvest S_1 recorded 57.57 g $plant^{-1}$ while S_0 recorded 44.22 g $plant^{-1}$ followed by S_2 (39.1 g $plant^{-1}$),S_3 (26.05 g $plant^{-1}$) and S_4 (21.37 g $plant^{-1}$).

4.6.4 Bulking rate

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

Significant variation in bulking rate was observed among different shade levels at all growth phases. Among different shade levels, S_1 showed maximum bulking rate followed by S_0. S_4 recorded minimum bulking rate at all phases. Between 180 - 210 and 210 - 240 DAP not much variation in bulking rate was observed among S_3 and S_4.

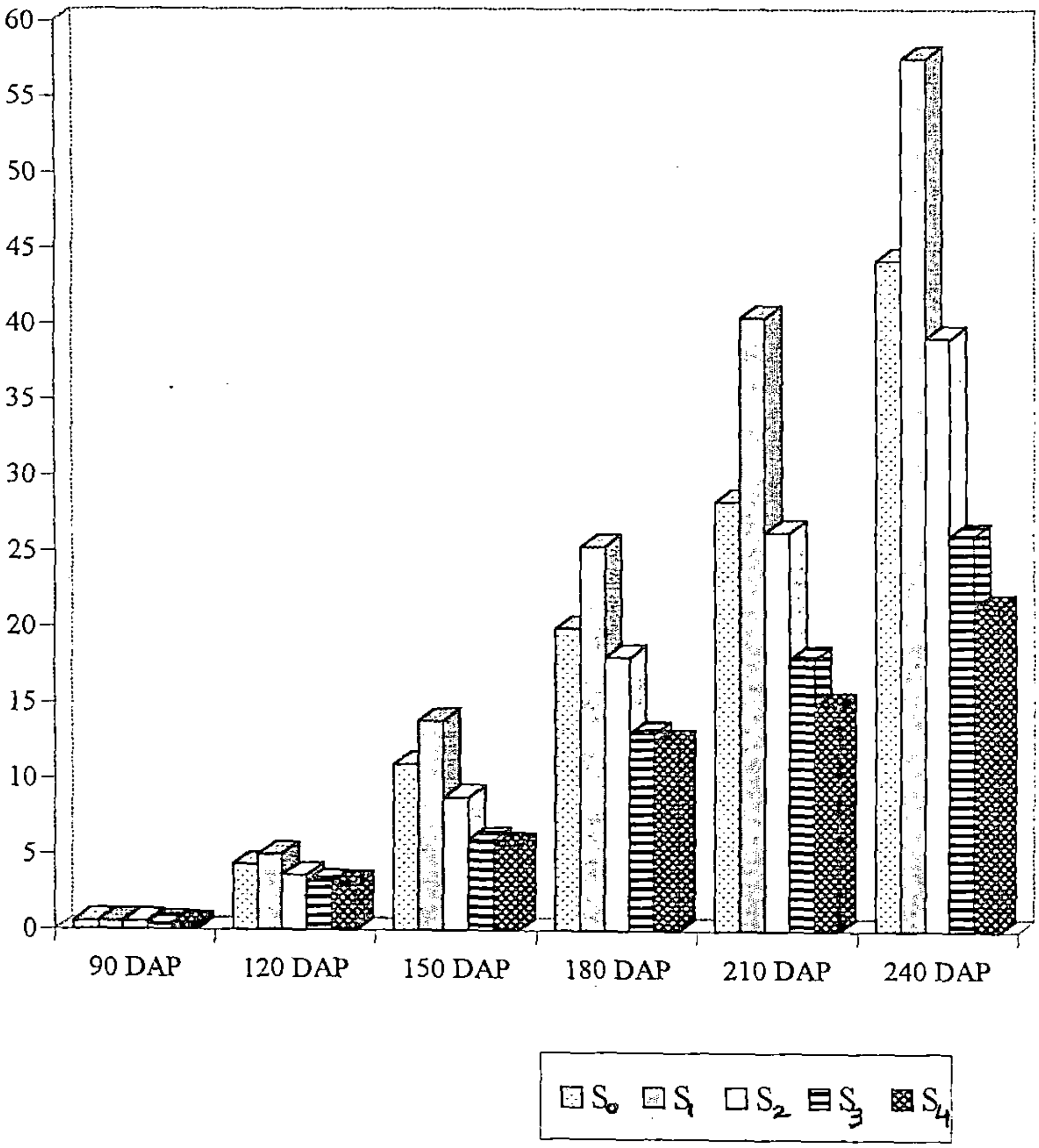
Table 28 Effect of shade on dry ginger yield (g plant^{-1})

Shade levels	Periods					
	90 DAP	120 DAP	150 DAP	180 DAP	210 DAP	240 DAP
S_0	0.574	4.33	10.97	19.91	28.30	44.25
S_1	0.594	5.01	13.85	25.32	40.45	57.57
S_2	0.538	3.60	8.80	18.05	26.30	39.10
S_3	0.438	3.18	6.00	13.05	17.98	26.05
S_4	0.367	3.07	5.62	12.45	14.90	21.37
F test	S (S)	S (S)	S (S)	S (S)	S (S)	S (S)
CD (0.05)	0.132	0.7949	2.419	4.680	4.680	7.875

Table 29 Effect of shade on bulking rate

Shade levels	Periods				
	90-120 DAP	120-150 DAP	150-180 DAP	180-210 DAP	210-240 DAP
S_0	0.125	0.221	0.298	0.280	0.531
S_1	0.147	0.295	0.383	0.504	0.549
S_2	0.102	0.173	0.313	0.275	0.430
S_3	0.091	0.094	0.235	0.164	0.269
S_4	0.089	0.085	0.228	0.081	0.215
F test	S (S)	S (S)	S (S)	S (S)	S (S)
CD (0.05)	0.021	0.056	0.0891	0.1195	0.1127

Fig. 8 Effect of shade on dry ginger yield (g plant^{-1})



Bulking rate showed significant difference for S_1 (0.504 and 0.549) between 180 - 210 DAP and 210 - 240 DAP.

4.7 Quality analysis

4.7.1 Volatile oil

The data presented in Table 30 show the effect of shade on volatile oil.

Effect of shade on volatile oil content was found to be significant at all stages measured. The highest content of volatile oil was observed from heavier shades during initial period of growth (120 - 150 DAP). But in 180 DAP S_3 recorded maximum oil content followed by S_2. At 210 and 240 DAP, S_4 recorded maximum volatile oil content followed by S_3. However at all these stages, plants grown under open conditions recorded least volatile oil.

Volatile oil content at 180 DAP was maximum under 60 per cent shade (2.78 per cent) followed by 40 per cent (2.65 per cent). But at 210 and 240 DAP volatile oil content for S_3 (2.40 and 2.42 per cent) followed by 80 per cent shade (2.43 and 2.45 per cent). The minimum volatile oil was obtained from open grown plants (2.18 per cent) at 240 DAP.

4.7.2 Non-volatile ether extract

The data on Table 31 represents the effect of shade on NVEE.

With respect to non volatile ether extract significant variation among different shade levels were observed. Heavier shades showed lower NVEE. However during later periods of growth low NVEE was seen under open condition also. Maximum NVEE was observed in plants grown under low shade (20 per cent), during most of the stages except at full maturity.

Table 30 Effect of shade on volatile oil content of ginger rhizome (v/w %) on dry weight basis

Shade levels	Periods				
	120 DAP	150 DAP	180 DAP	210 DAP	240 DAP
S_0	1.46	2.35	2.22	2.06	2.18
S_1	1.94	2.79	2.57	2.20	2.26
S_2	2.24	2.51	2.65	2.26	2.31
S_3	2.44	3.35	2.78	2.40	2.42
S_4	2.47	3.57	2.54	2.43	2.45
F test	S (S)	S (S)	S (S)	S (S)	S (S)
CD (0.05)	0.069	0.097	0.039	0.089	0.098

Table 31 Effect of shade on non-volatile ether extract (NVEE) content of ginger rhizome (%) on dry weight basis

Shade levels	Periods				
	120 DAP	150 DAP	180 DAP	210 DAP	240 DAP
S_0	5.35	6.85	6.50	6.10	6.08
S_1	6.34	9.13	9.11	8.16	7.04
S_2	6.84	8.47	8.32	7.85	7.07
S_3	3.99	6.09	6.04	5.74	5.70
S_4	3.82	4.74	4.65	4.65	4.95
F test	S (S)	S (S)	S (S)	S (S)	S (S)
CD (0.05)	0.132	0.159	0.120	0.159	0.144

At full maturity S_2 recorded 7.07 per cent which was on par with S_2 (7.04 per cent). Under open condition it was 6.05 per cent. Minimum NVEE was observed in S_4 (4.95 per cent) while S_3 recorded 5.70 per cent.

4.7.3 Starch

The data presented in Table 32 show the effect of shade on starch.

Significant variation in starch was recorded under different shade levels. Maximum starch was recorded from plants grown under open condition. A general decreasing trend in starch content was recorded with increasing shade levels.

At full maturity, maximum starch content was observed in plants grown under open condition (46.85 per cent) followed by S_1 (40.42 per cent) S_2 (38.80 per cent) S_3 (34.65 per cent) and S_4 (33.5 per cent).

Table 32 Effect of shade on starch content of ginger rhizome (%) on dry weight basis

Shade levels	Periods				
	120 DAP	150 DAP	180 DAP	210 DAP	240 DAP
S_0	24.25	26.75	29.36	33.03	46.85
S_1	23.08	22.57	25.35	28.47	40.42
S_2	21.52	24.20	27.15	28.02	38.80
S_3	19.50	21.70	24.42	26.87	34.65
S_4	19.27	21.82	24.20	25.25	33.50
F test	S (S)	S (S)	S (S)	S (S)	S (S)
CD (0.05)	1.478	2.422	2.293	2.117	2.368

Table 33 Effect of shade on crude fibre of ginger rhizome (%) on dry weight basis

Shade levels	Periods				
	120 DAP	150 DAP	180 DAP	210 DAP	240 DAP
S_0	1.948	2.748	3.510	5.077	5.775
S_1	1.817	2.597	3.065	4.890	5.485
S_2	1.535	2.350	2.752	4.495	5.343
S_3	1.362	2.158	2.515	4.255	4.993
S_4	1.260	2.077	2.425	4.135	4.910
F test	S (S)	S (S)	S (S)	S (S)	S (S)
CD (0.05)	0.069	0.138	0.232	0.252	0.195

4.7.4 Crude Fibre

The data presented in Table 33 show the effect of shade on crude fibre content.

Crude fibre content showed significant variation with various shade levels. S_0 recorded significant superiority over other shade levels at 120, 150, 180and 240 DAP. S_4 recorded lowest crude fibre content which was found to be on par with S_3 at all growth stages except at 120 DAP.

At final harvest maximum crude fibre content was seen in S_0 (5.77 per cent) followed by S_1 (5.48 per cent) S_2 (5.34 per cent) S_3 (4.99 per cent) and S_4 (4.91 per cent).

4.8 Study of translocation of photosynthates by $^{14}CO_2$ labelling techniques in ginger cv. Rio-de-Janeiro.

4.8.1 Comparison of count rate of younger and older part of main tiller at different growth stages and shade levels

The data presented in Table 34 show the comparison of count rate (cpm) of ^{14}C in younger and older part of main tiller at different growth stages of various shade levels.

The counts for ^{14}C in young and old parts differed significantly at 120 and 180 DAP while there was no such variation for counts at 60 and 240 DAP. At 120 DAP plants grown at open, 20 and 40 per cent shade showed significant variation among young and old part of main tiller. But plants grown under 60 and 80 per cent shade did not show any significant variation between young and old part. While the young part of open grown plants shown 169.67 cpm , the old part showed only 33 cpm. However the plants grown under 20 and 40 per cent shade showed greater counts in old part (384.33 cpm for 20 per cent and 377 cpm for 40 per cent shade) compared to young part (27.33 cpm for 20 per cent and 94 cpm for 40 per cent shade).

At 180 DAP significant difference in count rate among young and old part of open and 80 per cent shade grown plants were observed. Thus while the younger part of both open and 80 per cent shade showed greater counts (2141.67 and 47.67 cpm respectively) its older part showed only lesser counts (38 and 14.3 cpm respectively).

During initial and final stages not much variation was seen among younger and older part of main tiller.

Table 34 Comparison of count rate of younger and older part of main tiller at different growth stages and shade levels (cpm)

Shade levels	60 DAP		120 DAP		180 DAP		240 DAP	
	Young	Old	Young	Old	Young	Old	Young	Old
S_0	56.67 (1.70)	24 (1.29)	169.67 (2.05)	33 (1.31)	2141.7 (2.86)	38 (1.58)	539.3 (2.38)	49.67 (1.3)
S_1	272.67 (2.36)	92.67 (1.91)	27.33 (1.32)	384.33 (2.23)	22.3 (1.3)	35 (1.54)	174 (2.01)	1037.3 (2.77)
S_2	201.33 (2.07)	175.67 (2.23)	94 (1.92)	377 (2.48)	53.3 (1.63)	184.67 (2.01)	26.3 (1.28)	280.3 (1.84)
S_3	45.67 (1.44)	55.67 (1.64)	20.33 (1.30)	10.67 (0.89)	48.33 (1.64)	47.67 (1.67)	14 (1.13)	16 (1.12)
S_4	48.67 (1.69)	30.67 (1.68)	23.3 (1.35)	11.33 (1.01)	47.67 (1.66)	14.3 (1.14)	12.33 (1.01)	14.67 (1.14)
F test	NS		S		S		NS	
CD			0.58		0.53			

(Transformed values in bracket)

4.8.2 Comparison of count rate of younger part of main tiller at different growth stages and shade levels (cpm)

The data presented in Table 35 showed the comparison of counts of younger part at different stages of growth and shade levels.

Significant variation in count rate between various shade levels was observed at all growth stages except at 60 DAP in young leaves. At 120 DAP S_0 was significantly superior when compared to S_1, S_3 and S_4. S_0 and S_2 were on par. Likewise S_1, S_3 and S_4 were also on par. S_0 showed a count rate of 169.67 cpm while S_2 showed only 94 cpm. S_1 (27.33 cpm), S_3 (20.33 cpm) and S_4 (23.3 cpm) recorded comparatively lesser values.

At 180 DAP also S_0 was significantly superior compared to other shade levels. Not much variation was seen among other shade levels. S_0 recorded highest count of 2141.67 cpm while S_1 recorded least (22.3 cpm).

At 240 DAP S_0 showed significant variation from S_2, S_3 and S_4. S_0 and S_1 were on par at this stage. Here also S_0 showed a highest count of 539.3 cpm. S_1 showed a count of 174 cpm while S_4 the least (12.33 cpm).

Table 35 Comparison of count rates of younger part of the main tiller at different growth stages and shade levels (cpm)

Shade levels	60 DAP	120 DAP	180 DAP	240 DAP
S0	56.67 (1.70)	169.67 (2.05)	2141.67 (2.86)	539.3 (2.38)
S1	272.67 (2.36)	27.33 (1.32)	22.3 (1.3)	174 (2.01)
S2	201.33 (2.07)	94 (1.92)	53.3 (1.63)	20.3 (1.28)
S3	45.67 (1.44)	20.33 (1.30)	48.33 (1.64)	14 (1.13)
S4	48.67 (1.69)	23.3 (1.35)	47.67 (1.66)	12.33 (1.01)
F test	NS	S	S	S

(Transformed values in bracket)

4.8.3 Comparison of count rates of older part of main tiller at different growth stages and shade levels (cpm).

The data presented in Table 36 represent the comparison of counts of older part of main tiller at different growth stages and shade levels.

Older leaves showed significant variation in count rate at various shade levels at all growth stages except at final stage (240 DAP). At 60 DAP significant difference was noted among various shade levels. Highest count rate was observed from 40 per cent shade (175.69 cpm) followed by 20 per cent shade (92.67 cpm). The plants grown at 40 per cent was significantly superior compared to open, 60 and 80 per cent shade. However S_1 and S_2 were on par. The least count was recorded from open grown plants (24 cpm).

At 120 DAP also S_1 and S_2 were on par but they differed significantly from S_0, S_3 and S_4. Here the least count was seen in 80 per cent shade (11.33

cpm) and highest in 20 per cent shade (384.33 cpm).

At 180 DAP significant variation was noted among plants grown under 40 and 80 per cent shade. Not much difference was observed when plants grown in open, 20 and 60 per cent shade were compared. S_2 showed a value of 184.67 cpm while S_4 showed 14.3 cpm.

Table 36 Comparison of count rates of older part of main tiller at different growth stages and shade levels

Shade levels	60 DAP	120 DAP	180 DAP	240 DAP
S_0	24 (1.29)	33 (1.31)	38.64 (1.58)	49.67 (1.30)
S_1	92.67 (1.91)	384.33 (2.23)	35 (1.54)	1037.33 (2.77)
S_2	175.69 (2.23)	277 (2.48)	184.67 (2.01)	280.33 (1.84)
S_3	55.67 (1.64)	10.67 (0.89)	47.67 (1.67)	16 (1.12)
S_4	30.67 (1.68)	11.33 (1.01)	14.3 (1.14)	14.67 (1.14)
F test	S	S	S	NS

(Transformed values in bracket)

4.8.4 Autoradiography

Pictorial information of ^{14}C accumulation by the younger and older part of the main tiller and the translocation of the radioactivity was obtained by autoradiography. (Plate 4)

At each growth stage, one plant was taken from each shade level for autoradiography. The X-ray film developed showed a clear impression in the initial stage only. For the following growth periods counts may have been diluted and hence it required more exposure time to get a clear picture. Our exposure time was same for all the growth stages and hence we could not get a clear picture at later stages.

DISCUSSION

5. DISCUSSION

Photosynthesis and partitioning of photosynthates into economically important plant parts are primary determinants of plant yield. Understanding the photosynthetic carbon contribution of leaves to vegetative and reproductive processes is important in defining yield productivity. The yield of the plant is mainly determined by light. Apart from this a lot of other environmental and plant nutritional factors also decide the yield.

Studies conducted at various locations in India and elsewhere established the shade loving nature of ginger. Though many studies have established the shade loving nature of ginger, the mechanism of shade loving is not clearly understood. Thus to make use of shade for increasing production and productivity, a clear cut information becomes necessary.

A study conducted at vellayani revealed that ginger under open condition showed higher CO_2 uptake but the yield was less compared to plants kept under 20 and 40 per cent shade levels. This indicates that the carbohydrates prepared at the initial stage is not translocated to the rhizomes as expected.

The present study was thus envisaged to analyse the morphological, physiological and biochemical aspects involved and to understand the photosynthetic partitioning under different shade 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 80 per cent was observed in ginger cv. Rio-de-Janeiro at all growth stages (Table 1). This finding was in agreement with the results of Aclan and Quisumbing (1976) in ginger, Lalitha Bai and Nair (1982) in coleus, sweet potato, ginger and turmeric. The finding of Susan Varughese (1989), Jayachandran *et al.* (1991), Ancy (1992) and Babu (1993) in ginger also support the result of the present study.

The results when examined showed 50.09 cm for plants grown under open and 74.88 cm for plants under 80 per cent shade at 180 DAP. According to Meyer and Andersen (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

Significant difference in the number of tillers under varying shade levels was observed (Table 2) in ginger cv. Rio-de-Janeiro. A reduction in tillering due to shade was observed by Oshima and Murayama (1960) in rice, Moursi *et al.*, (1976) in wheat, Susan Varughese (1989) in ginger and turmeric. However Prameela (1990) in colocasia and Beena (1992) in different ginger cultivars observed no significant effect of shade on tiller production. Highest tiller production was seen in 20 per cent shade at all growth stages. Ancy (1992) and Babu (1993) also reported the same result.

During later stages at higher shade intensities less tiller production was seen. Under heavy shade there was less incident radiation available per tiller and this may be partly responsible for the decrease in tiller production (Attridge, 1990). At high shade intensity an increase in plant height is seen and this may have resulted in the diversification of energy for that rather than to increase the tiller number. Thus the reduced photosynthate availability under heavy shade may be suppressing the growth and development of tillers.

5.1.1.3 Number of leaves

Leaf production under 20 per cent shade was found to be significantly superior compared to other shade levels. During the initial stages of growth (60 to 90 DAP) leaf production was comparatively lower, as the days advanced, heavy shade recorded less leaves per plant (Table 3).

The increased leaf production under 20 per cent shade may be due to increased number of tillers. The decrease in the number of leaves under shade appears to be because of shade induced decrease in tillering. The low availability of photosynthates which resulted from the low irradiance might be the reason for the retarded growth under heavy shade (Meyer and Andersen, 1952).

5.1.1.4 Leaf area

Ginger plants grown under 20 and 40 per cent shade levels produced higher leaf area at all growth stages. But with further increase in shade leaf area was found to be decreased. Minimum leaf area was noticed in plants grown under open condition (Table 4). Contrary to this finding, Lalitha Bai (1981) reported that leaf area was not influenced by different intensities of shade in ginger, turmeric and coleus. An increased leaf area under reduced light intensity was reported in ginger by Ravishankar and Muthuswamy (1988), Ancy (1992) and George (1992).

Leaf area showed significant increase with increase in light levels. This can be attributed to the influence of light intensity on cell enlargement and differentiation which thus influenced the growth and leaf size of the plants (Thompson and Miller, 1963). Reduced irradiation may prevent scorching or wilting of leaves under low shade which was caused by marked increase in temperature within the leaf tissue from high sunlight (Aasha, 1986) and thereby increase leaf area under shade resulting the retention of more number of leaves. The increased leaf area under shade may be a plant adaptation to expose larger photosynthetic surface under limited illumination (Attridge, 1990).

5.1.1.5 Leaf weight

The effect of shade on leaf dry weight per plant was found to be significant (Table 5). Plants grown at 20 and 40 per cent shade levels recorded more leaf dry weight per plant except at 180 DAP. Thomas and Teobe (1983) in a fertilizer cum shade trial on container grown plants of *Ficus macrophylla* observed higher foliar dry weight at 20 per cent shading.

The plants grown under 20 and 40 per cent shade levels recorded maximum number of tiller and leaf area during this period and this may be the reason for maximum leaf dry weight. Likewise less tiller production and less leaves resulted in lesser leaf dry weight under heavier shade.

5.1.1.6 Leaf thickness

Leaf thickness under open condition was significantly superior compared to shaded condition (Table 7). With increasing levels of shade decreasing trend in leaf thickness was noted.

Plants grown at high light intensities have a different leaf morphology from those grown at low light intensities. High light causes a stronger development of the palisade and spongy mesophyll regions, resulting in thicker leaves. For example, *Atriplex patula* grown at 20 mW cm^{-2} had up to seven cells across a leaf section, compared with three or four cells for leaves grown at 2 mW cm^{-2} (Bjorkman, *et al.*, 1972). The cells were smaller and more densely packed in the leaves grown in low light and there were fewer vascular strands.

It is generally stated that shade plants in their native habitats often have thin leaves with a lower fresh weight per leaf area and a higher content of total chlorophyll expressed on a weight basis than do sun species (Rabinowitch, 1945; Bjorkman, 1968; Good Child *et al.*, 1972).

5.1.2 Root characters

5.1.2.1 Root length

Significant variation in root length was reported among various shade levels. A general increase in root length with increasing shade levels was observed (Table 7).

Minimum root length was observed from plants grown under open condition. Soil temperature is one of the factors which limits the root growth. Thus under open, the high soil temperature might have limited their root growth. 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 shade the retention of water at the depth was more and this might have resulted in more root length in shade.

At 150 and180 DAP, the rate of increase in root length was found to be decreasing compared to the previous months. This might be due to the branching pattern of the rhizomes. According to Jayachandran (1993), the number of roots originating from the first daughter rhizome was more than that from the later produced daughter rhizomes. The reason for the rate of reduction in root length may be 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.

5.1.2.2 Root spread

The effect of shade on root spread was found to be significant only at 180 DAP. At all other periods no significant difference in root spread among various shade levels were seen (Table 8).

The root spread was found to be maximum at 20 per cent shade. The congenial shade might have resulted in maximum spread of roots under 20 per cent shade. At heavier shade root spread was less. General growth of the plants under heavy shade was less and this would have affected the root spread.

5.1.2.3 Root weight

Root dry weight per plant was found to show significant variation only at 180 DAP. Not much variation in root dry weight per plant was observed up to 120 DAP (Table 9).

Plants grown under heavier shade produced more root dry weight compared to medium and low shade. Root length at higher shade was found to be more and this may be reason for more root dry weight at these shade levels.

5.1.2.4 Root volume

Root volume per plant was found to be significant at all growth stages (Table 10). At all shade levels root volume per plant was found to be more in plants grown under 80 per cent shade up to 120 DAP. At 180 DAP, more root volume per plant was reported from plants grown under 60 per cent shade.

Root volume under heavier shade was more. The root length, root spread as well as the root weight determine the root volume. Under heavier shade the root length as well as the root weight was high compared to open. This may be the reason for high root volume under heavy shade levels.

5.1.3 Rhizome characters

5.1.3.1 Rhizome spread

The effect of shade on rhizome spread was found to be nonsignificant during the initial period. But during the later period of growth (150, 180 and 240 DAP) significant variation was noted among various shade levels (Table 11).

Rhizome spread at 210 DAP also showed no significant variation among shade levels. At 210 and 240 DAP, 20 and 40 per cent shade levels recorded maximum rhizome spread. Lowest rhizome spread was recorded from plants grown under open condition. While Ancy (1992) observed highest rhizome spread at 50 per cent shade, Babu (1993) recorded more rhizome spread at 25 per cent shade.

Among the shade levels, low to medium shade level produced more rhizome spread, which may be due to congenial soil temperature which helped in higher rate of accumulation of photosynthates. Under open condition, relatively high soil temperature may have resulted in low spread.

5.1.3.2 Rhizome thickness

Significant variation of rhizome thickness was noted only at 120 DAP. At all other growing period not much significant variation was seen. S_1 recorded maximum rhizome thickness followed by S_2 at 120 DAP (Table 12).

Favourable low light intensity may have helped in more accumulation of carbohydrates which may be the reason for more rhizome thickness under these conditions. Low shade (20 per cent) was found to be favourable for the accumulation of carbohydrates and this may have resulted in more rhizome thickness.

5.2 Histological

5.2.1 Sotmatal frequency

The effect of shade on stomatal frequency was found to be significant at 180 DAP. Ginger plants grown under open conditions recorded maximum stomatal frequency (Table 13).

High light intensity during growth increased the stomatal frequency but there were 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 area per unit area of leaf is correlated with the maximum stomatal conductance (Holmgren, 1968; Bjorkman *et al.*, 1972; Edwards and Ludwig, 1975; Crookston *et al.*, 1975).

For *Atriplex patula*, there were three times as many stomata on the upper epidermis and almost twice as many on the lower epidermis in plants grown at high light compared with those in low light (Bjorkman *et al.*, 1972).

5.3 Physiological

5.3.1 Dry matter production

The effect of shade on dry matter production was found to be significant except at 90 DAP. Maximum dry matter production was reported from 20 per cent shade, followed by plants grown under open condition at 150 and 180 DAP (Table 14). Caesar (1980) reported an increase in dry matter accumulation at higher shade levels in *Xanthosoma sagittifolium*. A similar increase in DMP was observed by Susan Varghese (1989), Ancy (1992), George (1992). Babu (1993) observed increased dry matter production in ginger under 25 per cent shade.

DMP was found to be low under heavy shade in the present experiment. Under heavy shade LAI was found to be more compared to open condition Shading caused by this may have resulted in less photosynthetically active radiation falling on the leaf surface compared to that under open condition. This may have led to less development of tillers, leaves and subsequently lower dry matter production.

5.3.2 Crop growth rate

The variation observed in crop growth rate under different shade levels revealed significant variation at all growth phases. Maximum CGR was reported from ginger plants grown under 20 per cent shade followed by plants grown under open condition (Table 15). Minimum CGR was observed in plants grown under intense shade (80 per cent) between 150 and 180 DAP. According to Ancy (1992) and Babu (1993) maximum CGR was reported from plants grown under 25 per cent shade.

Low shaded condition (20 per cent shade) seems to be very favourable for enhanced CGR. The higher leaf area index and other favourable conditions might have reflected in the higher CGR. The value of CGR at 20 per cent was followed by CGR under open. This shows that 20 per cent shade is more favourable for the crop growth. Open condition shows less CGR compared to 20 per cent shade. It is also seen that high shade reduces crop growth rate which shows that high shade intensity may not be suitable for the growth of the crop.

5.3.3 Relative growth rate

The effect of shade on relative growth rate was found to be significant (Table 16) at all growth phases except between 150-180 DAP. The relative growth rate was found to be maximum for S_1 between 90-120 DAP and 150 - 180 DAP. Shade levels, 60 and 80 per cent, recorded low values of RGR during all stages except between 60-90 DAP. Contrary to this finding, Jadhav (1987) reported a positive correlation of shade with relative growth rate in rice.

5.3.4 Net assimilation rate

NAR was found to differ significantly under different shade levels.

During all growth phases high NAR was recorded from open condition except between 150 - 180 DAP. Maximum NAR between 150-180 DAP was reported from low shade level (Table 17). Shade beyond 20 per cent showed less NAR. This finding is in agreement with the results of Ancy (1992).

Blackman and Wilson (1951), Newton (1963) and Coombe (1966) reported a positive correlation between NAR and irradiance. The high rate of NAR may be due to higher rate of photosynthesis. At later stage of growth low NAR in open compared to 20 per cent may be due to increased rate of respiration. With increase in shade level the photosynthetically active radiation falling on leaf surface may be less compared to open and 20 per cent shade and this may have reflected in the low net assimilation rate.

5.3.5 Specific leaf weight

Significant variation in specific leaf weight under different shade levels was reported. Open condition recorded more specific leaf weight compared to other shade levels. Shade levels, 60 and 80 per cent, recorded lowest specific leaf weight (Table 18). This is in agreement with the findings of Syvertsen and Smith (1984), who reported highest SLW under full sun and lowest under 90 per cent shade in citrus.

Specific leaf weight is dependent on the leaf weight and leaf area. Leaf weight is in turn associated with leaf thickness. Under open condition more leaf weight and less leaf area was seen and hence this resulted higher SLW under open.

5.3.6 Leaf area index

The effect of shade on leaf area index was found to be significant at all growth stages except at 60 DAP. Ginger plants grown under 20 per cent shade recorded more LAI and plants grown under open condition recorded least LAI (Table 19). On the contrary, Lalitha 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.

The tendency to increase the LAI was more under low to medium shade. According to Attridge (1990) this may perhaps be an adaptation to expose larger photosynthetic surface under limited illumination.

5.3.7 Leaf area duration

LAD showed significant variation with respect to different shade levels. LAD was more under various shaded condition compared to plants grown under open condition. However maximum LAD was reported from S_1 (Table 20) except between 60 and 90 DAP.

Reduced radiation under shaded conditions may prevent scorching or wilting of leaves caused by marked increases in temperature within the leaf tissue from strong sunlight (Aasha, 1986) and thereby increase the leaf life under shade resulting in the retention of more number of leaves.

5.3.8 Harvest index

At full maturity harvest index showed significant variation with different shade levels (Table 21). Thus at 240 DAP S_1 recorded a maximum value of 0.700

followed by S_0 (0.676). Ancy (1992) and Babu (1993) also observed a similar pattern.

Harvest index of ginger plants grown under 20 per cent was significantly superior compared to other shade levels. This shows that the photosynthates produced was assimilated efficiently into the rhizome. Thus the rhizome yield was high and hence higher HI. Under open, the rhizome yield was not as high as that of plants under 20 per cent shade and hence it showed less HI compared to 20 per cent. Vegetative growth as well as rhizome yield was suppressed with increasing levels of shade.Under heavier shade less photosynthates was produced and the dry matter accumulation was low.

5.3.9 Relative water content

The effect of shade on relative water content was found to be significant. Relative water content was more under shaded condition except under 20 per cent shade. S_2 and S_3 were on par at all stages recorded. Open condition also recorded more RWC. Highest RWC was reported from 80 per cent shade level (Table 22).

At shade stomata are partially closed and hence water loss from the plant is at a reduced rate. RWC at heavier shade (60 and 80 per cent) was thus high.

5.3.10 Root shoot ratio

Root shoot ratio was found to be significant at all growth stages. Open condition recorded more root shoot ratio and 80 per cent the least (Table 23). Cripps (1971) in apple reported high root shoot ratio at open condition.

Under open condition moisture stress in the soil may have reduced the growth of shoot and resulted in high root shoot ratio at open condition.

5.4 Photosynthetic rate and related parameters

5.4.1 Solar light intensity

The solar light intensity was measured at the time when photosynthetic related parameters were observed. Naturally, open condition recorded maximum solar light intensity followed by 20, 40, 60 and 80 per cent shade (Table 24a).

5.4.2 PAR on leaf surface

PAR on leaf surface varied significantly at different shade levels. Open condition recorded highest photosynthetically active radiation while 80 per cent recorded the least (Table 24a).

The photosynthetic characteristics of many species of plants both C_3 and C_4 are influenced by the light intensity under which the plant is grown. The economic yield as well as DMP of a plant is determined by the photosynthesis. The rate of dry matter production in crops depends on the efficiency of the interception of photosynthetically active radiation (Montieth, 1969; Biscoe and Gallgher, 1977). The difference in PAR on leaf surface was due to the difference in the shade level provided.

5.4.3 Atmospheric CO_2 concentration

The atmospheric CO_2 concentration was measured at the time when photosynthetic related parameters were observed. A slight low concentration of atmospheric CO_2 concentration was seen at the time, when plants grown at 40, 60 and 80 per cent shade was measured (Table24b).

5.4.4 Leaf internal CO_2 concentration

Leaf internal CO_2 concentration showed significant variation with respect to different shade levels. Under heavier shade levels (60 and 80 per cent) more leaf internal CO_2 was recorded. Leaf internal CO_2 concentration was seen under open condition (Table 24b).

A prime factor governing a leaf's photosynthetic productivity is its position in the plant canopy, its light environment and its rate of net CO_2 uptake. In a study on the *Atriplex patula* leaves, grown under three light intensities (20, 6.3 and 2 m W cm^{-2}) the rate of net CO_2 uptake at rate limiting light intensities was highest for the plants grown under the lowest light intensity. The light compensation point where CO_2 uptake was balanced by CO_2 production, occurs at a lower intensity as the light intensity during growth was lowered (Bjorkman *et al.*, 1972). The differences in rate of net CO_2 uptake and in the light compensation point are due to different rates of respiration. The differences in photosynthetic rates are not only influenced by photorespiration, but other factor also.

5.4.5 Leaf temperature

Leaf temperature did not show any significant variation under various shade levels (Table 24c).

We may assume that leaf temperature may be different for open and shade grown plants. But here we get no significant difference in leaf temperature. It may be due to the fact that the atmospheric conditions (especially light intensity as well as radiation) may not be the same when open and shade grown plants were exposed.

5.4.6 Stomatal conductance

Under different shade levels, the stomatal conductance showed significant variation. The plants grown under open condition exhibited significant superiority over the shade levels (Table 24d). The tendency of the plants to decrease the stomatal conductance with increase in shade levels was observed.

High light intensity during growth increased the stomatal frequency, but there were 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 area per unit area of leaf correlated with the maximum stomatal conductance (Holmgren, 1968; Bjorkman *et al.*, 1972; Edwards and Ludwig, 1975; Crookston *et al.*, 1975).

Ginger plants grown under open condition recorded more stomatal frequency and hence more stomatal conductance. This was substantiated by Ludlow and Wilson (1971) who reported a four fold increase in stomatal conductance in *Panicum maximum* at high light intensity. 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.

5.5.7 Stomatal resistance

Stomatal resistance showed significant variation with different shade levels. S_4 and S_3 recorded more stomatal resistance compared to other shade levels. Least stomatal resistance was reported from open condition (Table 24d). Stomata of leaf are open when exposed to light and hence it offers least stomatal resistance. The conductance is thus higher under open condition.

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.

5.4.8 Photosynthetic rate

Photosynthetic rate showed significant variation under different shade levels (Table 24e). Photosynthetic rate under open condition was more followed by 20 per cent shade. But the yield was high at 20 per cent compared to open. However heavier shades recorded less photosynthetic rate. Better performance of ginger under slight shade than in open is reported by Aclan and Quisumbing (1976), Lalitha Bai (1981), Susan Varughese (1989), Ancy (1992) and Babu (1993).

Photosynthetic rate was found to increase with increasing levels of PAR. Photosynthetically active radiation was high in open and hence high photosynthetic rate. With increase in shade levels, there was a decrease in PAR and thus low 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 may 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 though the photosynthetic rate was high. Under 20 per cent shade the photosynthetic rate was less than that under sun but it seems that the photosynthates produced may be efficiently assimilated to contribute to yield. The results from the radioactive labelling also shows this. Though radioactive count was more in young part of main tiller on open grown plants, the basipetal translocation was comparatively poor. But under 20 per cent shade the efficient translocation is found to begin by 90-120 DAP. Under intense shade photosynthesis was comparatively poor and this may have resulted in less yield.

5.4.9 Transpiration rate

The effect of shade on transpiration rate was found to be significant. Transpiration rate under open condition was found to be significantly higher compared to other shade levels. Naturally, transpiration rate under more shaded level were found to be less (Table 24e).

Stomatal frequency affect the rate of transpiration. Apart from this root shoot ratio, the area and structure of the leaf and environmental factors have considerable influence on the loss of water from plants.

Parker (1949) found that transpiration increases with increase in root shoot ratio. In the present investigation, open grown plants showed more root shoot ratio and hence high transpiration rate.

Open grown plants were comparatively smaller and smaller plants often transpire at a greater rate than larger plants. Though larger plants loose more water , the amount of water loss per unit area was greater in the smaller plants (Miller, 1938).

5.5 Biochemical

5.5.1 Chlorophyll content

The chlorophyll 'a', chlorophyll 'b' and total chlorophyll were found to show significant variation under different shade levels. A general increasing trend in chlorophyll content with increasing shade levels was seen (Table 25). This result is in agreement with the finding of Lalitha Bai (1981). Ramanujam and Jose (1984), Susan Varghese (1989), Ancy (1992) and Babu (1993).

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 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.

5.6 Yield and yield components

5.6.1 Green ginger yield

The effect of shade on green ginger yield was found to be significant. shade level (20 per cent) recorded maximum green ginger yield followed by open condition (Table 26). Green ginger yield under open condition and 40 per cent shade were on par with each other. Susan Varughese (1989), Jayachandran *et al.*, (1991)Ancy (1992), George (1992) and Babu (1993) reported maximum green ginger yield under 25 per cent shade.

Yield is a function of DMP and BR and hence this has to be analysed to understand their contribution to yield. Both followed the same trend as that of rhizome yield recorded from shaded condition. Thus, though photosynthetic rate was more under direct sun the yield was less compared to 20 per cent shade. Kochhar (1978) reported a direct inhibitory effect of strong light on photosynthesis where in photooxidation of certain cell constituents take place with the use of oxygen and the release of CO_2. This is found to reduce the photosynthetic efficiency. This may be one of the reason for the poor performance of ginger plants in open compared to low shade (20 per cent).

The efficient photosynthetic assimilation at 20 per cent shade may have resulted in highest yield. At intense shade, the availability of light may become the decisive factor and that limits the rhizome yield.

5.6.2 Top yield per plant

The effect of shade on top yield per plant was found to be significant. Top yield per plant at 20 per cent was found to be on par with open condition (Table 27). Likewise no significant difference in top yield was noted when plants grown under 40 per cent shade and open were compared.

Ancy (1992) reported maximum top yield under 50 per cent shade while Babu (1993) reported maximum top yield under 25 per cent shade. Low top yield at heavier shade may be due to intense shade which is not congenial to shoot growth.

5.6.3 Dry ginger yield

Dry ginger yield was found to show significant variation at various shade levels at all growth stages. 20 per cent shade recorded maximum dry ginger yield followed by open condition (Table 28).

Better performance of crop under 20 per cent may be attributed to the higher rate of photosynthesis and its efficient assimilation as indicated by high dry matter accumulation, net assimilation rate and harvest index. Hardy (1958) attributed the better performance of the crop under shade to the presence of a threshold illumination intensity beyond which the stomata of the shade loving plants tend to close.

Understanding the yield response of agronomic crops to continuous light is valuable both from a carbon partitioning and a production stand point. In controlled environment continuous may allow the plants to partition more carbohydrate to the grain (Volk and Mitchell, 1995).

Table 24e shows high photosynthetic rate under open compared to 20 per cent shade. But the ginger yield was less at open compared to 20 per cent. Thus the photosynthetic rate was more under open, the efficient translocation may not have taken place. The results from the study of translocation of photosynthates by $^{14}CO_2$ labelling techniques have shown that the younger part of main tiller, of open grown plants recorded high radioactive carbon counts but the older parts showed only lesser value. For plants grown under 20 per cent shade, older parts recorded higher radioactive carbon counts. This also support the above result. The efficient partitioning of photosynthates to the economic part may have taken place at 20 per cent and this may have resulted in the highest yield. The yield produced at open comparable to 40 per cent shade . From this it can be inferred that the crop can tolerate light intensity up to 40 per cent shade. But further increase in shade reduces the yield.

5.6.4 Bulking rate

Significant variation of bulking rate with different shade levels was noticed at all growth phases. Maximum bulking rate was reported from 20 per cent shade (Table 29). According to Babu (1993) bulking rate was maximum under 25 per cent shade.

Bulking rate at open was more than 40 per cent shade except between 150 - 180 DAP in the present experiment. This is because in all these stages the accumulation of photosynthates in the economic part was at a higher rate compared to 40 per cent except between 150 - 180 DAP. Intense shade reduced BR and this may be attributed to reduced photosynthetic efficiency as evidentfrom 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 same results.

5.7 Quality analysis

5.7.1 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 least volatile oil content. Light regimes received by plant determine the productivity and quality of its produce (Tikhnomirov *et al.*, 1976). Ginger cv. Rio-de-Janero grown as intercrop in a six year old arecanut plantation recorded highest volatile oil followed by those grown in two year old plantation compared to those grown in the open (Ravisankar and Muthuswamy, 1987).

Shade grown plants showed higher volatile oil content. This may be due to the accumulation of secondary metabolites such as resin, resin acids and unoxidised sugars and the retention of volatile oil moiety which otherwise undergoes oxidation, degradation, isomerisation and polymerisation (Zachariah and Gopalan, 1987).

5.7.2 Non-volatile ether extract

Significant variation of NVEE under different shade levels was reported at all growth stages. NVEE was maximum under 40 per cent shade followed by 20 per cent at full maturity (Table 31). This may be due to the accumulation of secondary metabolites under shade which otherwise undergoes oxidation,degradation,isomerisation and polymerisation (Zachariah and Gopalan, 1987)

NVEE in ginger under intercropped conditions was found to be more by Ravisankar and Muthuswamy (1987). However a progressive decrease in oleoresin content up to 50 per cent shade was reported in ginger by Susan Varughese (1989). While Ancy (1992) reported a positive correlation of non volatile ether extract with shade. Babu (1993) observed a decrease in NVEE with increase in shade.

5.7.3 Starch

Significant variation of starch under different shade levels were reported. Starch under open condition recorded maximum value and minimum under 80 per cent shade (Table 32).

Decreased carbohydrate level was reported in leaves and roots of *Ficus benjamina* (Milks *et al.*, 1979). Prameela (1990) also reported a reduction in starch content with shading and an appreciable decline under 75 per cent shade.

5.7.4 Crude fibre

The effect of shade on crude fibre content of ginger plants was found to be significant crude fibre content under open condition was more compared to other shade levels (Table 33).

According to Aclan and Quisumbing (1976) ginger crude fibre content was not affected by shading. Ravisankar and Muthuswamy (1987) also reported the same result. But Ancy (1992) reported highest crude fibre content from plants grown in open and was significantly high compared to all other shade levels. Babu (1993) also recorded the same result.

5.8. Study of translocation of photosynthates by $^{14}CO_2$ labelling techniques in ginger cv..Rio-de-Janeiro

Ginger cv. Rio-de-Janeiro is a shade loving plant producing higher yield under low shade intensity (25 per cent) and comparable yield with that of open under medium shade intensity (50 per cent). However shade beyond 50 per cent decreased the yield (Jayachandran et al., 1991). Summary report of ICAR ad-hoc scheme about shade studies on coconut based inter cropping conducted from

1988 to 1991 at Vellanikkara rated ginger as a shade loving crop and highly suitable for shaded intercropping situations (KAU, 1992). A study conducted at the department of Horticulture, Vellayani revealed that ginger under open condition showed higher CO_2 uptake but the yield was less compared to plants kept under 20 and 40 per cent shade. This indicates that carbohydrates prepared at the initial stage is not translocated to the rhizomes as expected. A systematic attempt to obtain an explanation about this have not been made so far. Thus the present study is aimed at this.

The results of the present investigation clearly indicate that the efficiency of the $^{14}CO_2$ fixation by ginger leaves was high under 20 per cent shaded condition. At 120 and 180 DAP the younger part of the main tiller of open grown plants showed high ^{14}C count while the older part showed only lesser counts (Table 34). This shows that under open though initially more $^{14}CO_2$ has been fixed, the efficient translocation of the fixed photosynthates to the older part of the main tiller may not have taken place. However in plants grown under 20 and 40 per cent shade, the greatest counts were noted in older part of the main tiller. From this we can infer that 20 per cent shade intensity may be more favourable for the crop to transfer the photosynthates efficiently. From the other studies it has been found that photosynthesis is more under open but the yield is less compared to 20 per cent shade. This may be because of the poor assimilate transfer under open as revealed from the result of the above experiment. In certain forage grasses, increased efficiency of lower canopies of leaves to utilise diffused light has been observed by Sheehy and Cook (1977). Jacob (1984) observed efficient $^{14}CO_2$ fixation by the lower leaf canopies of sorghum. A simlar instance of efficient $^{14}CO_2$ fixation by the lower leaf canopies was reported by Vasanthakumar (1986) in cardamom.

Significant variation in ^{14}C assimilation was observed when the plants grown under different growth stages and shade levels were compared. But not much significant variation was noticed in the plants at 60 DAP (Table 35). At 120, 180 and 240 DAP the young leaves of open grown plants showed significantly high count while under different shade levels less counts were observed. Plants grown under open and 40 per cent shade were on par. The count of other shade levels when compared were also on par. The initial quantity fed to all the plants was equal. But in the younger part of the main tiller the quantity of $^{14}CO_2$ absorbed was more under open condition.This is in agreement with the results of photosyntheic rate. Under open the photosynthesis is more compared to shade levels. But we cannot assume that all these photosynthates may go to add the economic yield. In 20 per cent shade young leaves showed only ^{14}C count of 27.33 cpm. The count of ^{14}C at open as well as at 40 per cent shade were on par. Thus under 40 per cent shade and open the absorption of ^{14}C was more or less similar and higher than 20 per cent. 60 and 80 per cent shade levels showed only low values.

The highest count rate at 180 DAP (2141.7 cpm) under open the younger part of the main tiller may be due to the higher photosynthetic rate. The count rate was found to be the least in 20 per cent shade (22.3 cpm) in younger part of the main tiller at this stage. The older part also showed less value (35 cpm). This is probabily due to the efficient translocation of photosynthates and metabolites to the rhizomes which must have happened at an earlier stage. This is evident from the counts observed at in young (27.33 cpm) and older part of main tiller

(384.33 cpm) which shows the gradual translocation process. The data in Table 30, showing the effect of shade on bulking rate also supports this observstion. The bulking rate increased gradually from 0.147 at 90-120 DAP to 0.383 at 150-180 DAP. That is the photosynthates were being basipetally translocated. A predominently basipetal transport of the metabolites in rhizomatous plants has been documented much earlier by Zimmermann (1961).

As shade increases the count rate increases in younger part of main tiller at 180 DAP. In the case of older part the count rate decreases as the shade increases thus showing a declining trend of translocation. 240 DAP also shows the same trend. As the final stages approached there was no significance in ^{14}C count in older shoot under different shade levels. This may be because the translocation of photosynthates from younger leaves contributing to rhizome yield may be over by final stage. A ^{14}C labelled study in Lai-wu ginger revealed that at seedling stage the labelled assimilates were translocated to main shoots and leaves while as plants aged, proportionally more of the label was transferred to the rhizomes than to the above ground parts (Zhao *et al.*, 1987).

5.8.2 Autoradiography

The autoradiographs (Plate 4) indicated that the ^{14}C assimilates accumulated more strongly in the main shoot rather than the leaves. This shows that the photosynthates have moved out of the leaves to the main shoot. This inturn suggest the existence of phloem transport of leaf assimilates. The tracing of the transport of metabolites using autoradiography is well established in several horticultural crops. (Wareing and Phillips, 1973; Street and Opik, 1976; Baron, 1979; Ramulu, 1982).

SUMMARY

6. SUMMARY

An experiment was conducted at the College of Agriculture, Vellayani to study the biomass production and partitioning of photosynthates in ginger under different shade levels (0, 20, 40, 60 and 80 per cent shade). Thus a complete randomized design was adopted with five various shade levels and four replications. The salient findings are summarised below.

The height of the ginger plant was found to increase with increasing shade intensity from 0 to 80 per cent.

Ginger plants grown under low shade (20 per cent) showed higher tiller production, whereas shade when increased further the tiller production was decreased.

Leaf production was found to be significantly superior at 20 per cent compared to other shade levels. Heavy shade recorded less leaf production at later states.

Leaf area index at 20 and 40 per cent shade levels was higher at all growth stages. But further increase in shade reduced the leaf area. Plants grown under open condition recorded lowest leaf area.

Leaf dry weight per plant was found to be significantly high at 20 per cent shade.

Leaf thickness was found to be significantly superior under open condition. With increasing levels of shade decreasing trend in leaf thickness was noted.

Root length showed significant variation under different shade levels while open grown plants showed minimum root length, plants grown under 80 per cent shade recorded maximum root length.

Significant variation of root spread was reported only at 180 DAP. Not much variation in root spread was recorded during other growing periods. Plants grown under 20 per cent shade recorded maximum root spread.

Root dry weight per plant also showed significant variation only at 180 DAP. Shade level (80 per cent) produced more root dry weight compared to medium and low shade.

A positive response of root volume per plant was noticed under various shade levels. Root volume per plant was highest in 80 per cent shade at all stages except at 180 DAP where 60 per cent shade recorded more root volume per plant.

While rhizome spread during the initial period was found to be nonsignificant, the later stages except at 210 DAP (150, 180 and 240 DAP) showed significant variation among different shade levels. Minimum rhizome spread was reported under open condition and maximum from 20 per cent shade at 210 and 240 DAP.

Rhizome thickness showed significant variation only at 120 DAP. The highest rhizome thickness was noted from 20 per cent followed by 40 per cent shade at 120 DAP.

Significant variation of stomatal frequency was noted at 180 DAP. While open condition recorded maximum stomatal frequency, 80 per cent shade recorded minimum.

Dry matter production showed significant variation except at 90 DAP. At all growth stages 20 per cent shade showed maximum DMP and heavier shade produced less DMP. The DMP under open condition was found to be less than that at 20 per cent but more than that under other shade levels at 150 and 180 DAP.

Crop growth rate showed significant variation at all phases and maximum CGR was reported from ginger plants grown under 20 per cent shade. Shade level (80 per cent) showed least CGR between 150 and 180 DAP.

Relative growth rate was found to be significant except between 150 and 180 DAP. Between 150 and 180 DAP, S_1 recorded maximum RGR followed by open. Shade level (80 per cent) recorded least RGR between these days.

Net assimilation rate showed significant variation among various shade levels. Open condition recorded higher NAR except between 150 to 180 DAP. At this phase (150 - 180 DAP) S_1 recorded highest NAR.

A positive response in specific leaf weight under various shade levels was reported. While open condition recorded maximum specific leaf weight, the least was recorded under 60 and 80 per cent shade.

Significant variation on leaf area index was seen except at 60 DAP. While ginger plants grown under 20 per cent shade recorded maximum LAI, open condition recorded least LAI. The tendency to increase the LAI was more under low to medium shade.

The highest leaf area duration was reported from S_1 at all growth phases except between 60 - 90 DAP. Open condition recorded least LAD.

Harvest index of ginger plants grown under open condition showed significant superiority compared to other shade levels. A diversing tendency of harvest index with increasing shade levels was observed.

Relative water content showed significant variation with respect to different shade levels. RWC at 20 per cent was highest RWC under 40 and 60 per cent were on par at all stages recorded.

A general decrease in root shoot ratio with increasing shade levels was recorded at later stages of growth.

The solar light intensity as well as PAR on leaf surface was recorded at 180 DAP. PAR on leaf surface was highest under open and least under 80 per cent shade.

The atmospheric and leaf internal CO_2 concentration was measured using leaf chamber analyser at 180 DAP. While open condition recorded least internal CO_2 concentration, 60 per cent shade showed maximum value.

No significant variation was seen in leaf temperature under various shade levels.

Significant superiority of stomatal conductance was seen in ginger plants grown under open condition. A decreasing trend in stomatal conductance with increasing shade levels was observed.

Stomatal resistance showed significant variation with different shade levels. While least stomatal resistance was reported from open condition, 80 and 60 per cent shade levels showed more stomatal resistance.

Photosynthetic rate recorded under open condition was more followed by S_1. A decrease in photosynthetic rate with increasing shade levels was seen.

Significant superiority of transpiration rate was recorded under open conditions. Transpiration rate decreased with increase in shade levels.

Chlorophyll 'a', chlorophyll 'b' and total chlorophyll showed significant variation under different shade levels. Chlorophyll content was found to increase with increasing levels of shade. Thus least chlorophyll content (a, b as well as total) was resulted from plants grown under open condition.

Green ginger yield was found to be maximum under 20 per cent shade followed by open condition. Not much variation in green ginger yield was recorded from 60 and 80 per cent shade.

Top yield per plant was found to be highest under 20 per cent shade followed by zero and 40 per cent shade. Shade levels (60 and 80 per cent) showed least top yield.

Dry ginger yield showed significant variation at all growth stages. Maximum dry ginger yield was recorded from 20 per cent shade followed by open condition. Dry ginger yield was found to be least under 80 per cent shade at all these stags.

Bulking rate showed significant variation at various shade levels at all growth phases. Highest bulking rate was recorded from S_1 and lowest from S_4.

Volatile oil was found to be highest under 80 per cent shade at all growth stages, followed by 60 per cent shade. Plants grown under open condition recorded least volatile oil.

NVEE showed maximum value at 20 per cent shade from 150 DAP onwards Shade level, 80 per cent recorded least NVEE.

Starch content showed significant variation at different shade levels. maximum starch content was seen from ginger plants grown under open condition and minimum from 80 per cent shade.

Crude fibre showed significant variation at various shade levels. Ginger plants grown under open condition showed highest crude fibre content. The least crude fibre content was observed in 80 per cent shade.

The results from the comparison of count rate of younger and older part of main tiller at different growth stages showed significant variation at 120 and 180 DAP. Younger part of open grown plants recorded higher values at both growth stages.

Significant variation in count rate between various shade levels were observed at all growth stages except at 60 DAP. Here also plants grown under open condition recorded higher value.

Older leaves showed significant variation in count rate at various shade levels at all growth stages excepted final stage. At 120 DAP highest count rate was recorded from 20 per cent shade. While at 60 and 180 DAP, 40 per cent shade recorded higher values.

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*Originals not seen

BIOMASS PRODUCTION AND PARTITIONING OF PHOTOSYNTHATES IN GINGER (*Zingiber officinale* R.) UNDER DIFFERENT SHADE LEVELS

BY

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ABSTRACT OF THE THESIS
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ABSTRACT

A pot culture experiment was conducted at the College of Agriculture, Vellayani during the year 1997 - 1998 to study the effect of shade on biomass production and partitioning of photosynthates in ginger cv. Rio-de-Janeiro. The experiment was laid out in completely randomised design with five shade levels (open, 20, 40, 60 and 80 per cent) and four replications. Artificial shade was provided using high density polyethylene shade nets and calibrated using quantum photosensors. Two months after planting, ginger plants were labelled using ^{14}C . After tagging, one set of samples were collected immediately. Subsequently, harvesting of the tagged plants were done once in sixty days after labelling. Monthly observations of various growth parameters were taken from two months after planting. At six months after planting photosynthetic related parameters were measured using leaf chamber analyser.

The various growth parameters like number of tillers, leaf area, leaf dry weight, dry matter production, crop growth rate, relative growth rate, net assimilation rate at final stage, leaf area index which contributed to yield was highest under 20 per cent shade. This shows that the plant prefers low shade intensity compared to open. The yield recorded under 20 per cent shade was significantly superior compared to open. But the yield at open and 40 per cent shade were on par. Higher shade levels decreased the yield. This shows that the crop can tolerate shade up to 40 per cent.

Different shade levels influenced the quality of ginger rhizomes. While volatile oil was maximum under heavier shade levels in general (60 and 80 per cent), non-volatile ether extract was higher under 20 per cent shade. Starch as well as crude fibre content was more in plants grown under open condition.

The photosynthetic rate and related parameters of ginger were measured at six months after planting using leaf chamber analyser. Photosynthetically active radiation on leaf surface as well as stomatal conductance was high under open condition. But leaf internal carbon dioxide concentration as well as stomatal resistance was high under heavier shade levels (60 and 80 per cent). Photosynthetic rate as well as the transpiration rate was maximum in plants grown in open. Though, at 20 per cent shade, the photosynthetic rate was less, the yield was high. This might be because of the photooxidation that has taken place at high light intensities or due to the inefficient translocation of the photosynthates in open condition compared to 20 per cent shade.

Radio tracer analysis done using labelled ^{14}C has shown that under open condition, though initial intake of carbon dioxide was more, most of the carbon dioxide taken are seen in the above portion itself. While in 20 per cent shade most of the carbon dioxide taken in has translocated to the lower portion. This shows that under low light intensity the photosynthates produced has translocated efficiently to the lower portion while in open condition efficient translocation has not taken place.

The results indicate that 20 per cent shade level is favourable for growing ginger plants to get higher rhizome yield. The yield at 40 per cent was on par with that of open. This shows that crop can tolerate shade upto 40 per cent. Thus the partially shaded coconut gardens can be exploited for increasing the area under ginger which may help in doubling the production.