PRODUCTION DYNAMICS OF GINGER *(Zingiber officinale* R.*)* UNDER VARYING LEVELS OF SHADE, NUTRIENTS AND TRIAZOLE

BY

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THESIS

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DECLARATION

I hereby declare that this thesis entitled "**Production dynamics of ginger (*Zingiber officinale* R.) under varying levels of shade, nutrients and triazole**" 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 of any degree, diploma, associateship, fellowship or other similar title, of any other university or society.

Vellayani,
30-11-1999

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CERTIFICATE

Certified that this thesis entitled "**Production dynamics of ginger (*Zingiber officinale* R.) under varying levels of shade, nutrients and triazole**" is a record of research work done independently by Mr. K. Ajithkumar under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to him.

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LIST OF ABBREVIATION

ml	-	Millilitre
cm	-	Centimetre
m	-	Metre
%	-	Per cent
mg	-	Milligram
g	-	Gram
kg	-	Kilogram
t	-	Tonnes
cv	-	Cultivar
N	-	Nitrogen
P	-	Phosphorus
K	-	Potassium
M	-	Mulch
T	-	Triazole
ha^{-1}	-	Per hectare
µg	-	Microgram
s	-	Second
@	-	At the rate of
B : C ratio	-	Benefit : Cost ratio
DMP	-	Dry matter production
CGR	-	Crop growth rate
RGR	-	Relative growth rate
NAR	-	Net assimilation rate
LAD	-	Leaf area duration
LAI	-	Leaf area index
SLW	-	Specific leaf weight
RWC	-	Relative water content
NVEE	-	Non-volatile ether extract
HI	-	Harvest index
DAP	-	Days after planting
RBD	-	Randomised block design
CRD	-	Completely randomised design

INTRODUCTION

1. INTRODUCTION

Ginger is one of the most important spices obtained from the rhizome of the plant, *Zingiber officinale* R. belongs to the family Zingiberaceae. It is a herbaceous perennial which is commercially cultivated as an annual. Ginger is mainly used as a spice and flavoring agent in a wide variety of foods. It is also having excellent therapeutic values, and finds use in various pharmaceutical preparations of different systems of medicine. Among the major spices grown in the country ginger occupies third position after pepper and chilli.

In India, ginger occupied an area of 70910 ha with a production and productivity of 2.83 lakh tonnes and 3278 kg ha^{-1} respectively during 1996-97 (George, 1999). The export of ginger was 28550 tonnes with a value of 6781 lakh rupees during 1997-98 (Peter *et al.* 1999). In Kerala, it occupies an area of 13200 ha with a production and productivity of 46370 tonnes and 3513 kg ha^{-1} respectively during 1996-97 (FIB, 1999). Traditionally, Kerala contributed 50 per cent area under ginger on all India basis which declined gradually to 19 per cent. Though the area under ginger in the state for the last 10 years remained almost static, the emergence of non-traditional North Indian states as ginger producers is one of the reasons for declining the states' share from 50 to 25 per cent. Though ginger is produced in a number of States, the ginger produced from North India is generally unsuitable for export due to poor quality (Vigneshwara, 1990). The ginger produced in Kerala are superior as they have better intrinsic quality and more acceptable in global markets. Therefore the role of Kerala in ginger cultivation is more vital in upholding the global markets.

Possibility of area expansion under monocropping in Kerala is limited. Therefore utilizing the shaded situation under coconut is one feasible approach to achieve the target production of 12 per cent growth rate (Chadha and Rethinam, 1994). In this way, Kerala with 9.02 lakh hectares under coconut can provide additional area for the cultivation of ginger.

Studies conducted in India and elsewhere revealed that ginger is a shade tolerant / loving crop (Aclan and Quisumbing, 1976 ; Bai, 1981 ; Ravisankar and Muthuswamy, 1987 ; Susan Varughese, 1989 ; Jayachandran *et al.*, 1991 and George, 1992). Findings of shade studies on coconut based intercropping situations, rated ginger as a shade loving crop and highly suitable for intercropping in coconut gardens. (KAU, 1992). The coconut palm utilizes only 25 per cent of the land area and 30 cm surface soil is practically free of functional roots (Nair, 1979) and over 80 per cent of the active roots are confined to within an area of 2.0 m radius around the palm (Wahid *et al.*, 1993). Ginger being a shallow rooted crop, 85 per cent of the roots are distributed within a depth of 20 cm and 10 per cent roots between the depths of 20 and 30 cm (Jayachandran, 1993b). Hence ginger and coconut constitute a compatible crop combination (Jayachandran *et al*, 1998). Since the area excluding 2.0 m radius around the coconut alone is used for intercropping, root competition and competition for other inputs will be minimum.

Studies under artificial shade revealed that ginger was a shade loving crop and the nutrient requirement was higher than the existing recommendation of 75 : 50 : 50 N, P_2O_5 and K_2O kg ha^{-1} (Ancy , 1992). The mulch and planting material requirements were also less under shaded situations (Babu, 1993 and Nizam, 1995). Under coconut when ginger is grown as an intercrop leaf spot disease was found to be of lesser intensity (Jayachandran and Nizam, 1997).

Thus, the input requirement under open and shade vary significantly. The existing package of practices recommendations (KAU, 1996) formulated based on the trials conducted at open conditions needs modifications to suit such shaded situations. Shade loving nature of ginger is an added advantage and can be further exploited to increase production of ginger utilizing inter spaces of coconut gardens.

Stress affects physiological processes leading to a reduction in crop yield. There are several chemicals used to tolerate the stress in plants. Triazole (triadimefon) is one of such chemicals used against water stress. Triazole (triadimefon) at 30 ppm was found to be effective in cucumber during water stress (KAU, 1995). The beneficial effects of triazole as plant growth regulator, as stress tolerant chemical and yield stimulant were demonstrated by many workers (Fletcher and Hofstra, 1985 and Asare- Boamah *et al.*, 1986).

The present investigation, "Production dynamics of ginger under varying levels of shade, nutrients and triazole" was taken up with the following objectives :-

1. To examine the production potential of ginger under open and different shade levels.
2. To analyse the morphological, physiological and biochemical characters associated with shade loving nature.
3. To standardise the requirement of nutrients and mulch for ginger intercropped in coconut garden.
4. To evaluate the efficacy of triazole in the improvement of yield and other desirable characters.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

The investigations on the "Production dynamics of *ginger (Zingiber officinale* R.) under varying levels of shade, nutrients and triazole" were taken up to study the production potential of ginger under open and different shade levels and to analyse the mechanism involved in its shade loving nature. It is also aimed to standardise optimum dozes of nutrients and mulch for ginger intercropped in coconut garden and efficacy of triazole in the improvement of yield and other desirable characters.

The relevant literature on the effect of shade, nutrients, mulch and triazole on the morphological, physiological, biochemical, yield and quality of ginger are reviewed. Research information on other crops are also reviewed wherever pertinent literature in ginger is lacking.

2.1 Response of crop to varying intensities of shade

Solar radiation is one of the primary factors governing the ultimate yield of any crop. The growth, yield and quality of crops are influenced by shade at various stages of growth and development. Differential response of crop varieties to shade has been studied for various crops.

2.1.1 Growth characters

2.1.1.1 Plant height

George (1982) observed an increase in plant height due to shading in groundnut. Positive effect of shade on plant height was also reported by Xia (1987) in broad bean.

Bai and Nair (1982) 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 open to 75 per cent (Susan Varughese, 1989 ; Jayachandran *et al.*, 1991 ; Ancy, 1992 and Babu, 1993).

2.1.1.2 Number of tillers

Decrease in the number of tillers with increasing levels of shade in turmeric was observed by Susan Varughese (1989) and Jayachandran *et al.* (1992).

Aclan and Quisumbing (1976) reported that tillering was not affected by shade in ginger.

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. Jayachandran *et al* (1991) reported that the number of tillers was maximum under open conditions and minimum under 50 per cent shade.

George (1992) reported a higher tiller production in ginger cv. Rio-de-Janeiro at 25 per cent shade. Babu (1993) observed a higher tiller production at 120 and 180 days after planting under 25 per cent shade in ginger cv. Rio-de-Janeiro.

2.1.1.3 Number of leaves

Sreekumari *et al.* (1988) reported that in cassava the leaf size increased and leaf number decreased and leaf longevity increased when grown under shade in coconut garden.

According to Aclan and Quisumbing (1976) reduced number of leaves per tiller in ginger grown under full sunlight was observed compared to different levels of shade. Ancy (1992) observed maximum number of leaves per plant in ginger under 25 per cent shade at all the growth stages and the lowest number of leaves were recorded at 75 per cent shade. 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 days after planting.

2.1.1.4 Leaf weight

In a fertilizer cum shade trial on container grown plants of *Ficus macrophylla*, Thomas and Teoh (1983) observed higher foliar dry weight at 20 per cent shading.

2.1.1.5 Root characters

Studies conducted by Jayachandran (1993b) have shown that ginger (cv. Rio-de-Janeiro) has a shallow root system. Till 90 DAP, the roots were confined to within 30 cm soil depth and within 10 cm laterally. By 150 DAP, root grew beyond 30 cm vertically and 10 cm laterally. At 210 DAP, 94.8 per cent of the roots were found within a depth of 30 cm. The lateral spread of these roots extended up to 17.5 cm. The root extending vertically beyond 30 cm constituted only 5.2 per cent and the lateral spread of these roots did not exceed 10 cm. Only a very small percentage (0.5) of roots was seen growing beyond 15 cm, away from the plant. More than 89 per cent of roots lay within an area of 10 cm radially around the plant.

Influence of varieties and seed sizes were significant in root growth of ginger (Nizam, 1995). The influence of varieties were distinctly different from one another with respect to root length. The effect of plants derived from 5 g seed rhizome size was the least. However the effects of plants obtained from 10 and 15 g seed rhizome size were superior and were on par on root growth.

The turmeric (*Curcuma domestica*) has a shallow root system with three types of roots viz., thick, thin and hairy roots (Jayachandran, 1992). At 30 DAP, the maximum root penetration of turmeric cultivars was found to vary from 10.0 to 28.1 cm in depth and 5.2 to 13.2 cm in lateral spread. The maximum root depth 210 DAP ranged from 47.3 to 65.2 cm and lateral spread from 21.0 to 26.9 cm. Eventhough some of the roots penetrated up to a depth of 65.2 cm and had a spread up to 26.9 cm, majority of the roots (60.2 to 72.5 per cent) accounting on fresh weight basis, were present at the top layer of the soil 10 cm vertically and 10 cm laterally from the plant.

The mango-ginger (*Curcuma amada* Roxb.) has a shallow root system with three types of roots viz., succulent, thin and hairy roots (Jayachandran, 1993 a). Maximum vertical root penetration extended up to 21.7 cm from the base of the plant. Though root depth and spread extended up to 44.2 and 21.7 cm respectively. 74.3 per cent of the total roots on fresh weight basis is confined to top layer of soil 10 cm vertically and 10 cm laterally from the plant.

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).

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.

2.1.2 Rhizome characters

2.1.2.1 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. The rhizome spread at 25 per cent shade was higher than on any other shade levels in ginger (Babu, 1993). Plants under open condition recorded the lowest rhizome spread.

According to Nizam (1995) under open condition the effect of the size of seed rhizome was significant in rhizome spread. Plants derived from 15 g seed material resulted in the highest rhizome spread (24.65 cm) and was on par with the effect of plants from 10 g (23.90 cm). The rhizome spread was influenced by varieties too. The variety Rio-de-Janeiro recorded the lowest rhizome spread (21.60 cm) and was on par with Nedumangadu. But under intercropped conditions, Rio-de-Janeiro recorded the highest rhizome spread (21.41 cm) followed by Nedumangadu and were on par.

2.1.3 Anatomical characters

2.1.3.1 Leaf thickness

Leaf morphology is strongly influenced by light levels during development. 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 by those grown in 90 per cent shade (Syvertsen and Smith, 1984).

In a pot trial, beans (*Phaseolus vulgaris*) grown at different light intensities showed that leaf thickness increased with increasing light intensity (Silva and Anderson, 1985). Nobel *et al.* (1975) reported increase in mesophyll thickness in higher light intensity in *Plectranthus* sp.

In sweet potato, shade reduces the leaf thickness or the number of chloroplasts per unit leaf area, which in turn limited dry matter production because of low assimilatory potential (Roberts - Nkrumah *et al.*, 1986). In cotton, non-shaded leaves were thicker than shaded leaves because they formed longer palisade parenchyma (Salisbury and Ross, 1978; Dhopte *et al.*, 1991). An examination of leaf vascular bundle and midrib of shaded leaves revealed to be larger in area and thinner than in control (100 per cent light). The non shaded leaves were typically thicker than shaded leaves because they formed longer palisade parenchyma (Salisbury and Ross, 1978).

2.1.3.2 Stomatal density

Higher light increased stomatal density in *Phaseolous vulgaris* (Knecht and O'learly, 1972).

2.1.4 Physiological attributes

2.1.4.1 Dry matter production

Monteith (1969) reported that the maximum amount of dry matter production by a crop was strongly correlated with the amount of light intercepted by its foliage.

In ginger dry matter production followed a quadratic pattern with an optimum shade of 20.11 per cent (Bai and Nair, 1982). Ravisankar and Muthuswamy (1988) reported an increased level of dry matter production with decreased light intensity in ginger. This was further confirmed by Susan Varughese (1989), who recorded the highest dry matter production at 25 per cent shade in ginger. Babu (1993) observed the highest dry matter production at 25 per cent shade thus confirming the studies of Susan Varughese.

Ancy (1992) observed significant variations among shade levels with respect to the dry matter production (DMP). Shade levels, 25 and 50 per cent, were found to be on par with each other but significantly superior to zero and 75 per cent shade. There was a drastic reduction in DMP at 75 per cent shade both in 135 and 180 days after planting, the extent of decrease being 17.8 and 22.2 per cent respectively of that under open condition.

Nizam (1995) conducted studies on the suitability of ginger variety for intercropping. He found that the ginger variety Nedumangadu recorded the highest DMP and yield of fresh ginger in the intercropped conditions. Higher vegetative growth might have resulted in a significant interaction under shade.

Pushpakumari and Sasidhar (1996) reported in greater yam, lesser yam, tannia and elephant foot yam the total dry matter production at 25 per cent shade was superior to all other treatments throughout the growth stages except in harvest stage, wherein the open treatment (0 per cent shade) recorded maximum dry weight which was on par with 25 per cent shade. In sweet potato, deep shade (>55 per cent) reduces total dry matter production due to suppression of both initiation and growth of storage roots (Ravi and Indira, 1999).

2.1.4.2 Crop growth rate

The maximum individual CGR recorded in the study conducted by Whiley (1980) in ginger was 39.78 g m^{-2} day^{-1}. Ramanujam and Jose (1984) found that the CGR of cassava grown under shade were reduced significantly when compared to those plants grown under normal light.

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

The crop growth rate was found to be maximum under 25 per cent shade at growth phases (90-135 DAP and 135-180 DAP) followed by that under 50 per cent shade and open condition in ginger (Ancy, 1992). Babu (1993) observed significantly superior crop growth rate under 25 per cent shade in ginger.

2.1.4.3 Relative growth rate

Jadhav (1987) observed a positive correlation of shade with leaf area ratio and relative growth rate in rice.

2.1.4.4 Net assimilation rate

In sweet potato, Laura *et al.* (1986) observed a low net assimilation rate (NAR) under shade. Pandey *et al.* (1980) reported that the NAR of chickpea decreased with decrease in light intensities. Ramanujam and Jose (1984) found that NAR of cassava grown under shade was reduced significantly when compared to those plants grown under normal light. Ramadasan and Satheesan (1980) observed the highest NAR with three turmeric cultivars grown in open condition compared to shaded condition.

George (1992) reported that significant differences in net assimilation rate between shade levels at both 60 and 120 days after planting in ginger. The highest value of NAR was observed at 50 per cent shade.

Ancy (1992) found that the net assimilation rate under 25 and 50 per cent shade levels were significantly high but showed a drastic decrease under heavy shade in ginger.

Babu (1993) found that during the first phase of study (60-120 DAP) the high net assimilation rate was recorded from open condition, but at second phase (120-180 DAP) maximum NAR was obtained from low shade level.

2.1.4.5 Leaf area duration

The highest leaf area duration at 25 per cent shade followed by 50 and 75 per cent shade was observed in ginger (Babu, 1993). Leaf area duration was the lowest under open conditions in ginger.

2.1.4.6 Leaf area index

Positive influence of shade on various growth ratio had been reported by many workers. Low leaf area index (LAI) was observed at high light intensities in cotton (Bhat and Ramanujam, 1975). Fukai *et al.* (1984) reported an increase in specific leaf area as against a decrease in leaf area in cassava with high shade levels.

Bai (1981) reported that leaf area indices of ginger, turmeric and coleus were observed to be not influenced by different shade intensities. A high leaf area index was reported by Ravisankar and Muthuswamy (1988) when ginger was grown as an intercrop in six year old arecanut plantation.

Ancy (1992) observed that the leaf area index in ginger was significantly lower under open condition compared to other shade levels in all growth stages. The highest leaf area index was recorded at 25 per cent shade.

As an intercrop, Rio-de-Janeiro recorded the highest LAI (7.287) and was on par with Nedmangadu (Nizam, 1995).

2.1.4.7 Specific leaf weight

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

2.1.4.7 Root : shoot ratio

Schuurman (1983) investigated the responses of oats, lucerne, sugar beet and barely, found that an almost parallel response of roots and shoot weights to an improvement in soil conditions was observed, but roots showed a quicker response than shoots, so that shoot : root ratios generally increased.

The effect of an increasing shoot-root ratio can be compensated by increasing physiological efficiency of root uptake under favourable conditions.

2.1.4.8 Photosynthesis

Shading greatly reduced the photosynthetic rate in crops like alfalfa (Wolf and Blaser, 1972) ; bean (Crockson *et al.*, 1975) ; grapes (Vasundara, 1981) ; cotton (Singh, 1986) and potato (Singh, 1988).

According to Hardy (1958) shade loving plants had a threshold illumination, beyond which the stomata tends to close. A linear relationship between photosynthesis and light intensities was reported by Gastra (1963). Crockson *et al.* (1975) recorded 38 per cent reduction in photosynthesis of bean leaves due to shading, may be due to the increase in stomatal and measophyll resistance to diffusion of CO_2.

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

Tao and Zhang (1986) found that at 28 ^{0}C the net photosynthetic rate of tea plants increased with light intensity and the light saturation and light compensation points of shaded plants were lower than that of unshaded plants. Although the photosynthetic efficiency of plants under open condition at higher light intensity was slightly above that of shaded plants, their photorespiration at 80 k. Lx, 34-38 ^{0}C and 40-60 per cent relative humidity were higher, so that the net photosynthetic rate decreased markedly.

High light intensity warms the leaves and may increase respiration. If warming become too high the temperature rise may be sufficient to cause thermal inactivation of enzymes. This effect was reported in many plants (Miginiac Maslow *et al.*, 1990). The chloroplast enzyme NADP Malate Dehydrogenase was totally inactivated. These were seen when chloroplast of peas, maize and spinach were illuminated with high light intensity (Miginiac Maslow *et al.*, 1990).

Zhao *et al.* (1991) studied the photosynthetic characteristics of ginger and found that the rate was highest in the middle leaves of the plant and lower in the apical leaves than the basal leaves. It was also found that the rate decreased as the temperature increased from 20 to 40 ^{0}C and was low at a light intensity of 500 Lx., increasing with increasing light intensity to 30,000 Lx. and then decreasing slightly with further increase to 60,000 Lx. Wilting markedly decreased the rate of photosynthesis (Zhao *et al.*, 1991).

2.1.4.9 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 pore area per unit area of leaf correlated with the maximum stomatal conductance (Holmgren,*et al.*, 1968 ; Bjorkman *et al.*, 1972 ; Crockson *et al.*, 1975). In *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). In *Shorea worthingtonii* seedlings grown under the high light treatment (PAR > 800 µ mol m^{-2} s^{-1}) had lower rate of transpiration and stomatal conductance than those of *S. worthingtonii* seedlings from the middle light levels (Ashton and Berlyn, 1992). In hirsutum cotton, the stomatal conductance was reduced by 0.61 cm s^{-1} in lower light intensity (40 per cent light intensity) as against 0.69 cm s^{-1} in open condition. This had resulted in reduced transpiration rate by 8.6 and 7.9 per cent in 80 and 40 per cent light intensity respectively (Dhopte *et al.*, 1991).

2.1.4.10 Stomatal resistance

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 Monivel (1987) recorded lower stomatal resistance in tea under full sun compared to leaves under shade. In rice, low light intensity increases the mesophyll resistance (Raven and Glidewell, 1981) and stomatal resistance (Peet, 1976). The progressive increase in diffusion resistance with decrease in light intensity was observed by Akita and Moss (1973). Low light intensity is reported to decrease water potential and transpiration rate and to increase diffusion resistance of the peanut leaves progressively at all the stages of crop growth (Jadhav, 1992).

2.1.4.11 CO_2 uptake

Photosynthesis is measured by the rate of absorption of CO_2 per unit area of leaves of a plant in unit time. Robert and Allen (1971) reported that the exchange of equal amount of CO_2 absorbed and oxygen (O_2) released in photosynthesis which occurs maximum when temperature lies 10.35^{0}C and minimum at -30^{0}C. Thus, variation occurs in this process due to temperature and availability of CO_2.

2.1.5 Biochemical aspects

2.1.5.1 Chlorophyll content

Seybold and Egle (1937) observed an increase in chlorophyll 'b' content under low light intensity. Concentrations 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 ; Radha (1979) in colocasia ; Sorenson (1984) in winged beans ; Anderson *et al.* (1985) in tobacco ; Singh (1988) in potato and Prameela (1990) in colocasia.

An inverse relationship of shade and chlorophyll content had been reported in peanut (Rao and Mittra, 1988) and Maize (Bhutani *et al.*, 1989).

Instances where the chlorophyll content was unaffected by shading were also observed in crops like chickpea (Pandey *et al.*, 1980) and Kiwi fruit (Grant and Ryng, 1984).

In ginger chlorophyll content increased steadily with increasing levels of shade (Susan Varughese, 1989 ; George, 1992 ; Ancy, 1992 ; Babu, 1993).

2.1.5.2 Proline content

Proline accumulation have been shown to be adaptive mechanism to stress tolerance. But conflicting results claim a positive or a negative association with drought resistance. The accumulation of proline under water stress has been reported in cocoa (Balasimha, 1982 b), coffee (Vasudeva, *et al.*, 1981), tea (Rajesekhar *et al.*, 1988) and coconut (Voleti *et al.*, 1990). In cocoa, the proline accumulation was negatively correlated with relative water content (Balasimha, 1982 a).

Significant accumulation of stress induced proline was observed in 8 cultivars of tomato studied at 0, 4, 7 and 10 days of stress (Thakur, 1991).

2.1.5.3 Yield

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

In turmeric, the highest yield was recorded under 25 per cent shade (Susan Varughese, 1989). Yield of turmeric at 25 per cent shade was on par with open condition and therefore turmeric can be considered as a shade tolerant crop (Jayachandran *et al.*, 1992).

Ravisankar and Muthuswamy (1988) observed that fresh rhizome yield increased when ginger was grown as an intercrop in arecanut plantation. Susan Varughese (1989) obtained highest yield under 25 per cent shade. According to Jayachandran *et al.* (1991) 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 intensity beyond 50 per cent decreased the yield. Ancy (1992) recorded the highest green ginger yield under 25 per cent shade followed by 50, zero and 75 per cent shade. Babu (1993) recorded maximum green ginger and dry ginger yield from low shade (25 per cent) followed by medium (50 per cent) and heavy shade (75 per cent).

Field trials on the performance of mango-ginger (*Cucuma amada*) under varying levels of shade revealed that rhizome yield under open and 25 per cent shade were on par indicating that the crop is shade tolerant (Jayachandran and Nair, 1998).

2.1.5.4 Harvest index

Highest harvest index (HI) at 25 per cent shade was noticed in colocasia and with further increase in shade, the HI decreased significantly (Premeela, 1990).

Susan Varughese (1989) observed no significant difference between shade levels with respect to HI in ginger. The highest HI was observed under open condition (Ancy, 1992) and a steady decrease in HI with increase in shade levels was resulted. However, George (1992) recorded highest HI at 25 per cent shade which was comparable with open condition. In ginger, the HI under open condition was found highest compared to shaded conditions (Babu, 1993).

2.1.5.5 Quality of the produce

The content of oleoresin under open and 25 per cent shade was higher than intense shade level (George, 1992 ; Babu, 1993). Ancy and Jayachandran

(1993) found that the non-volatile ether extract content under 25 and 50 per cent shade was on par with each other and significantly superior to that under zero and 75 per cent shade.

George (1992) found an increase in volatile oil content with increase in shade intensity and the highest value recorded was under 75 per cent shade. Ancy (1992) recorded the highest volatile oil content under 25 per cent shade followed by that under 50 per cent shade. Babu (1993) found that volatile oil content showed an increasing trend with increasing levels of shade.

Ancy (1992) and Babu (1993) found that higher percentage of fibre at open condition. According to Aclan and Quisumbing (1976) the fibre content of rhizome was not affected by light intensities.

2.1.5.6 Content and uptake of NPK

Kraybill (1922) observed higher content of N in shaded apple trees. According to Maliphant (1959) in cocoa, shading increased nitrogen content of leaf but the phosphorus content was decreased. The K content of grass species when grown under 80-90 per cent shade was nearly double than that grown under open (Rodriguez *et al.*, 1973). Prameela (1990) recorded highest N, P and K contents under 25 per cent shade in colocasia. The N content in the leaf increased as shade increased up to 25 per cent and then showed declining trend with further increase in shade levels, while P and K were higher under 75 per cent shade in clocimum (Pillai, 1990).

Bai (1981) observed an increase in the contents of N, P and K in coleus, colocasia, sweet potato, turmeric and ginger, with increase in shade. In ginger, George (1992) observed significant difference with respect to NPK content in haulm. The uptake of N, P and K in ginger increased from zero to 50 per cent shade and then showed a decrease at 75 per cent (Ancy, 1992).

2.2 Response of crops to varying levels of nutrients

2.2.1 Growth characters

Nitrogen application was found to significantly increase the number of shoots per plant in ginger (Muralidharan *et al.*, 1974). According to Aclan and Quisumbing (1976), there was a progressive increase in plant height and number of tillers per plant with an increase in the amount of N applied up to 90 kg ha^{-1}.

In turmeric, an increasing trend in the number of tillers as well as leaf production with increasing fertilization up to 40 : 40 : 80 kg NPK ha^{-1} in the shade was observed. However NPK 30 : 30 : 60 kg ha^{-1} recorded the maximum height in the shade and NPK 20 : 20 : 40 kg ha^{-1} in the open (KAU, 1983).

Pushpakumari (1989) reported leaf number and plant height / vine length of lesser yam, tannia and elephant foot yam were not significantly influenced by the fertilizer levels but for greater yam there was significant increase in the plant height with increase in fertilizer levels.

Ancy (1992) found that in ginger under all shade levels (25 per cent, 50 per cent, 75 per cent) fertilizer treatments showed a positive influence on plant height and no interaction between shade and fertilizer treatments. The tillering and leaf number were also found to increase with increasing dose of fertilizers.

2.2.2 Leaf area index

The leaf area index was found to be increased by N application in sweet potato (Bourke, 1985).

In greater yam, LAI was found to be significantly influenced by different fertilizer levels at 190 days after planting and maximum LAI was observed for the highest fertilizer dose (80 : 60 : 80 kg NPK ha^{-1}) (Pushpakumari, 1989). She also reported that in tannia, fertilizer treatments did not show any significant influence on the LAI at any of the growth stages.

In ginger an increasing trend in LAI with increasing fertilizer levels in shaded conditions (Ancy, 1992).

2.2.3 Physiological attributes

2.2.3.1 Dry matter production

Nambiar *et al.* (1976) observed no significant effect on the weight of vine in sweet potato due to increased fertilizer application . In sweet potato, N application increased total plant dry weight of all plant components and K application was found to increase total plant dry weight (Bourke, 1985). In a study with potato variety Kufri, Jyothi, the dry matter production increased significantly due to the application of different levels of N, P and K (Rajanna *et al.*, 1987). Total dry weight at harvest stage did not vary significantly due to fertilizer levels in crops like lesser yam, tannia and elephant foot yam but in greater yam dry matter production was found to be the highest at the highest fertilizer dose of 80 : 60 : 80 kg NPK ha^{-1} (Pushpakumari, 1989).

Johnson (1978) reported that higher levels of N produced a significant effect on DMP in ginger. Ancy (1992) found that DMP in ginger showed a general trend of increase with increase in fertilizer dose under zero, 25 and 50 per cent shade.

2.2.3.2 Net assimilation rate

Ancy (1992) found that net assimilation rate (NAR) showed a positive response to fertilizer treatments under zero. 25 and 50 per cent shade levels.

2.2.3.3 Crop growth rate

In sweet potato, N applications increased CGR (Bourke, 1985). In tannia there was no significant difference in CGR among the fertilizer treatments but in greater yam the effect was significant and CGR was found to be the lowest for the highest fertilizer dose (80 ; 60 : 80 kg NPK ha^{-1}), CGR ranged from 1.80 to 2.89 g m^{-2} day^{-1} and from 0.65 to 1.14 g m^{-2} day^{-1} during the first and second years respectively (Pushpakumari, 1989).

In ginger fertilizer treatments under all shade levels (0, 25, 50, 75 per cent shade) gave a regular trend of increase in CGR (Ancy, 1992).

2.2.3.4 Chlorophyll content

Ancy (1992) examined the chlorophyll content at shade and fertilizer level. Under all shade level, increasing levels of fertilizer produced a general trend of increasing in chlorophyll content and its fractions. Similar effect of fertilizer treatment on chlorophyll content was reported by Moursi *et al.* (1976) in wheat, Collard *et al.* (1977) in *Ficus benjamina*.

2.2.4 Yield

Samad (1953) reported no significant response to fertilizer application in ginger grown in Malabar region though there was an increase in yield with 60 kg N ha^{-1}. Aiyadurai (1966) reported that N fertilization of crop with 50 to 100 kg N ha^{-1} significantly increased yield by 18 to 32 per cent. Nair (1975), in his studies on the effect of foliar application of urea and planofix, observed that urea at 2 per cent and planofix at 400 ppm were better than the individual application of the above chemicals. Muralidharan *et al.* (1974) reported that application of 70 kg N ha^{-1} increased significantly the number of tillers and yield of rhizome.

Muralidharan and Ramankutty (1975) studied the performance of 12 clones of ginger under varying levels of N application , N at 60 kg ha^{-1} decreased the yield of green ginger of the varieties, Himachal Pardesh and Thinalium irrespective of the time of application . Johnson (1978) reported that there was yield reduction when the fertilizer N level was increased from 80 to 120 kg ha^{-1}. Sadanandan and Sasidharan (1979) found that the effect of N on yield of ginger was significant and the highest yield was recorded at 50 kg N ha^{-1}. Lee (1981a) reported that rate of application of 200 - 300 kg ha^{-1} was required for maximum yield. Nitrogen use efficiency decreased with increasing rate of nitrogen application . Patil and Konde (1988) reported that the yield of ginger at 50 kg N ha^{-1} plus inoculants (Azotobacter or Azospirillum) was on par with that of 75 kg N ha^{-1} without inoculants, indicating a saving of 25 kg N ha^{-1} through inoculation.

Poor response to K application has been reported by Muralidharan and Kamalam (1973). They recommended that 60 kg of K_2O ha^{-1} applied in two split doses was the best for ginger. Potassium application (0 to 90 kg ha^{-1}) increased rhizome yield significantly by increasing various yield contributing characters up to 60 kg ha^{-1}. The optimum dose worked was 76 kg K_2O ha^{-1} (Singh *et al.*, 1993).

Roy *et al.*, (1992) reported that yield per plant as well as per hectare was recorded maximum when the plants were sprayed with all the three micronutrients Zn + Fe + B.

Lokanath and Dash (1964) reported that the application of 60 kg N, 40 kg P_2O_5 and 60 kg K_2O ha^{-1} resulted in significant increase in yield under the agro-climatic conditions of Orissa whereas Thomas (1965) obtained no significant response with 4 levels of N (0, 50, 100 and 150 kg ha^{-1}) and 3 levels of P_2O_5 (0, 45 and 90 kg ha^{1}). Trials with N, P and K conducted at Regional Research Station, Kandaghat for four years indicated that the combination of 100 kg N, 50 kg P_2O_5 and 50 kg K_2O ha^{-1} was the best (Randhawa and Nanpuri, 1965). Kannan and Nair (1965) recommended 36 kg N, 36 kg P_2O_5 and 72 kg K_2O ha^{-1} for optimum yield of ginger. Application of N and P each at 57 and 114 kg ha^{-1} increased the total yield by 18-32 per cent and 13-19 per cent respectively in ginger (Aiyadurai, 1966). Nair (1969) and Paulose (1970) recommended 60 : 60 : 150 kg NPK ha^{-1} for economic yield of ginger.

In an experiment to study the effect of 3 levels each of N (50, 75 and 100 kg ha^{-1}), P_2O_5 (50, 75 and 100 kg ha^{-1}) and K_2O(100, 150 and 200 kg ha^{-1}) on the yield of ginger variety Rio-de-Janeiro, it was observed that the application of N above 50 kg ha^{-1} reduced the yield of ginger significantly. P and K had no effect on the yield at the levels studied (Muralidharan, 1973). The yield of ginger doubled with the application of 30 kg N ha^{-1}. Yield also increased slightly with that of potassium but not with phosphorus (Aclan and Quisumbing, 1976). Mohanty *et al.* (1992) found that in Orissa, NPK of 125 : 70 : 70 kg ha^{-1} gave maximum yield of the variety Suruchi.

Shah (1989) reported that application of 90 kg N, 60 kg P_2O_5 and 90 kg K_2O ha^{-1} produced maximum rhizome yield.

Gowda and Melanta (1998) found that in Karnataka, N, P_2O_5 and K_2O of 150 kg, 75 kg and 50 kg ha^{-1} resulted in higher yield.

Under 25-50 per cent shade the normal fertilizer dosage of 75 : 50 : 50 kg NPK ha^{-1} (open condition) should be raised to 150 per cent to get good yield (Ancy and Jayachandran, 1996).

Pushpakumari (1989) observed that greater yam responded linearly to fertilizer levels recording maximum yield at the highest dose (80 : 60 : 80 : kg NPK ha^{-1}) when grown as an intercrop in coconut garden whereas in lesser yam maximum yield was at medium fertilizer level and in elephant foot yam at lowest level. Also reported that in greater yam and elephant foot yam recorded significantly lower top yields at lowest fertilizer levels ie., 40 : 30 : 40 and 40 : 30 : 50 kg NPK ha^{-1} respectively.

Panigrahi and Patro (1985) found that the highest yield (229.5 q ha^{-1}) was obtained from the cv. PGS 35 receiving N : K_2O at 90 : 90 kg ha^{-1} (85 q ha^{-1}) in the non fertilized control.

Xu *et al.* (1993) reported that the N fertilizer [(NH_4) $2SO_4$] utilization by ginger (*Zingiber officinale*) plants increased with delay in application, being the greatest with application as a dressing during the middle of the vigorous plant growth stage.

Pawar and Patil (1987) found that during the first year the highest yield of green ginger (164.16 q ha^{-1}) was obtained from plots receiving N, P_2O_5, K_2O @ 225, 20, 180 kg ha^{-1} + 30 t FYM ha^{-1} and in the second year (174.72 q ha^{-1}) from plots receiving NPK as above + 20 t FYM ha^{-1}.

Cho *et al.* (1987) reported that ginger yield were high as soils with good drainage and with a soil depth of above 100 cm and was positively correlated with soil organic matter content.

Application of neem-cake @ 2 t ha^{-1} along with N, P and K @ 75, 50 and 50 kg ha^{-1} significantly increased availability in soil and ginger yield by 33 per cent (Peter, 1996).

At seedling stage in ginger, labelled assimilates were translocated mainly to shoot and leaves. As the plant aged, proportionally more of the labelled assimilates was transferred to the rhizomes than to the above - ground parts. The main shoots contributed most to rhizome formation and hence to the crop yield. Secondary shoots were not so efficient and the youngest shoots contributed little to assimilation or export of ^{14}C (Zhao,*et. al.* 1987).

2.2.5 Quality of the produce

Mandel *et al.* (1969) noticed that crude protein content showed an increase up to 80 kg N and 40 kg K_2O ha^{-1} in *Dioscorea esculenta.* The application of nitrogen and phosphorus at 90 kg ha^{-1} each enhanced the protein content and starch content in coleus (Geetha, 1983). Rao *et al.* (1983) opined that N has considerable influence on the yield of coriander seed and its essential oil content. Percentage essential oil content of coriander seeds was found to be increasing with the increase in N application from 0 to 60 kg ha^{-1} (Rahaman *et al.*, 1990).

Aclan and Quisumbing (1976) reported that none of the three elements N, P and K influenced fibre content of ginger rhizomes. No significant effect of fertilizers on crude protein and fibre contents of sweet potato was reported by Carveho *et al.* (1983). In lesser yam, crude fibre content was not influenced by different levels of fertilizers (Nair, 1985).

Ancy (1992) found that under all shade levels (25, 50 and 75 per cent), effect of fertilizer treatments on Non- Volatile Ether Extract , volatile oil and fibre contents was found to be not significant.

2.2.6 Uptake of nutrients

Pena (1967) observed that application of N increased the N content of taro leaves, but decreased their P and K contents. At the same time application of P increased the P content but decreased the K content and application of K increased K content but decreased Ca and Mg contents. Sobulo (1972) estimated that a yam crop of 26 t ha^{-1} removed 133, 10 and 84 kg ha^{-1} of N, P and K respectively.

Dasavadhi *et al.* (1971) stressed the importance of N in ginger at the active growth and tillering stage during which N consumption was high and leaves contained about 3 per cent N. The total N in ginger shoots and rhizomes increased with increasing fertilizer N application (Lee *et al.*, 1981b). According to Lee *et al.* (1981a) leaf N concentrations and the yield of ginger shoots and rhizomes increased with the total amount of N applied up to the highest level (336 kg N ha^{-1}).

Forage N content increased with decreasing light intensity from 1.0 to 1.6 and from 1.2 to 1.9 per cent without and with N respectively. Phosphorus and potassium contents tended to be higher under shade and higher with applied N except of P (Erikson and Whitney, 1981). The NPK concentration in plant tops and tubers of potato increased with increase in NPK and irrigation rates (Roy and Tripathi, 1986). Sharma and Grewal (1991) reported that N, P and K uptake by potato crop increased progressively with increase in their rate of application and the nutrient uptake was found closely linked with productivity.

Muralidharan *et al.* (1994) found that the nitrogen content of leaves varied from 2.18 (Jorhat) to 3.78 per cent (Kurappampady). The highest leaf N content coincided with the highest yield. The yield was found to be higher in cultivars having higher leaf N content. The leaf P content ranged significantly among the cultivars and varied from 0.288 to 0.428 per cent. The leaf P content did not appear to be related with the yield. In the case of leaf K content, the higher K per cent was found to be associated with higher yields, and the values ranged from 3.14 (Calcutta) to 4.68 per cent (Nadia). The study indicate that a significant positive correlation of N and K with the yield of ginger.

Sushama and Jose (1994) reviewed the nutrition of ginger and grouped ginger as an exhausting crop and hence responded greatly to manure application.

2.3 Response of crop to mulching

The microclimate of any cropping system assumes special importance. One of the methods by which we can manage the micro climate is by the use of mulches.

The favourable effects due to mulching like soil moisture conservation, reduction of soil temperature, suppression of weed growth, reducing soil erosion and improvement of soil physical properties (Jha *et al.*, 1972 ; Mohanty, 1977 ; Mishra and Mishra, 1986 and Korla *et al.*, 1990).

2.3.1 Soil moisture status

Mandal and Vamadevan (1975) reported that in multiple cropping even in rainfed lands and such system needs conserving soil moisture through mulching.

According to Bever (1960) the artificial mulches greatly retard the evaporation and protect the soil surface from direct rays of sun and wind current and ultimately the soil was kept cool and the vapour pressure of air in the mulches was nearly the same as that of soil air. In winter vegetables, the mulches reduced soil moisture losses and thus considerably reduced the irrigation requirement (Kashyap and Jyothishi, 1967). Donald and Joe (1970) found that the mulched plots have higher soil moisture content throughout the growing season than the unmulched plots for 0-10 and 10-20 cm depth. In the same study they also reported that mulching indirectly influenced the water holding capacity and moisture release character of the soil. Umrani *et al.* (1973) have also reported that there was more moisture in the mulched plots and reduced evaporation loss from soil surface and increased infiltration, which reduced run off also. According to Mathan *et al.* (1984) the total porosity was significantly influenced by mulching.

In vanilla, mulching is an important cultural practice aimed at conserving soil moisture (Muralidharan, 1975). Ragothama (1981) reported that the soil moisture content in the root zone have direct influence on tillering of cardamom and this can be efficiently managed by suitable mulching.

Mishra and Mishra (1986) reported that the soil moisture content was always higher in green leaves mulched plots in ginger. Green leaves have significant effect on moisture conservation than other materials tried and have direct influence on tiller production in ginger (Jha *et al.*, 1972).

2.3.2 Soil temperature

Kashyap and Jyothishi (1967) established that the diurnal variation of soil temperature was less under mulched condition and the available N and P contents were increased. According to Srivastava *et al.* (1973) the natural organic mulches like oak leaves, pine needles and hay, in general, reduced the soil temperature, while synthetic polyethylene resulted in increased soil temperature, which indicates that organic mulches reduced the soil temperature when compared with black polyethylene. Mehata and Prihar (1973) reported progressive decrease in maximum soil temperature with increasing rate of wheat straw mulch from 2 to 6 t ha^{-1} and mulching reduced the temperature by 1^0C at a depth of 5 cm. According to Prihar *et al.* (1977) the straw mulch decreased the soil temperature.

It was proved that better soil moisture and more favourable soil temperature regimes as a result of mulching enhance nitrification (Myer, 1975). Moreover the mulching increased the root density and caused greater lateral spread of roots (Chaudhari and Prihar, 1974 and Singh *et al.*, 1976). All these factors may improve the water and nutrient availability.

According to Dhesai *et al.* (1964) the potato crop grows best when the temperature ranges from 60 -75^0F and high temperature increases respiration and thus reduces the available carbohydrates for translocation and tuber formation. In banana, low soil temperature and high relative humidity developed as a result of mulching (Bhattacharaya and Rao, 1985).

2.3.3 Soil physical properties

Mulching improves the soil physical properties, soil nutritional status, increased availability of plant nutrients and increased availability of soil microfauna (Lal, 1975, 1983 ; Lal *et al.*, 1980 ; Sanchez and Salinas, 1981 ; Wade and Sanchez, 1983, Schomigh and Alakamper, 1984 ; Hulugalle *et al.*, 1986 and Jayashree, 1987).

According to Lawson and Lal (1979) in Alfisol with less favourable soil physical properties, crop growth was enhanced more by surface application of mulch rather than incorporation. The high rate of decay of organic matter which is a character of humid tropics (IITA, 1982 and Maduakor *et al.*, 1984) indicates a need for placement of mulch such that the crop will benefit to the greater extent.

Lal (1978) found higher bulk density in unmulched plots. Kamalam Joseph and Kunju (1981) conducted studies on the effect of mulching on bulk density and found that the mulching decreases the bulk density and found that the mulching decreases the bulk density. Lal (1983) reported that the bulk density of newly cleared tropical Alfisols decreased with increase in mulch. In yam plots mulched with leaves, bulk density was significantly decreased (Hulugalle *et al.*, 1986).

Jayashree (1987) found that sawdust mulched soil showed maximum water holding capacity followed by straw mulch.

The hydraulic conductivity of newly cleared tropical Alfisols was improved by mulching (Lal *et al.*, 1980). Mathan *et al.* (1984) observed that the hydraulic conductivity was influenced by mulching. Among the mulches there were no significant differences.

The higher percentage of water stable aggregates in leaf mulched plot might be due to the addition of organic matter through leaf mulch (Harris *et al.*, 1966). Higher soil aggregation as a result of addition of organic matter has been reported by Kumar and Ghildyal (1969).

2.3.4 Soil chemical properties

According to Mohankumar *et al.* (1973) the green leaf mulch was found to be efficient in increasing the content of soil nutrients. The increased availability of NPK content for leaf mulch over other mulch materials might be due to the nutrient addition by decomposition of the leaf mulch.

Hulugalle *et al.* (1986) established that N, P, K, Mg, exchangeable Ca and total cation were increased which in the plant row treatment of surface mulching. The plant grown under mulched condition recorded a high content of above nutrients. They also reported that the total acidity was decreased by surface mulching.

The chemical analysis showed that the bhindi plants grown under paddy husk mulch showed high content of N, P and K but Ca and Mg contents were found to be maximum in leaf mulched plots (Jayashree, 1987).

2.3.5 Weed growth

Mulches suppressed the growth of weeds to a greater extent and reduced the weed number and weight as compared to control (Gopalakrishna *et al.*, 1960). The beneficial effects of mulching in suppressing weed growth were established by Donald and Joe (1970) ; Muralidharan (1975) ; Thomas (1975) ; Srivastava *et al.* (1973) and Mishra and Mishra (1986).

2.3.6 Growth characters

Srivastava *et al.* (1969) reported that there was significant effect of using various mulches on height of plants. Jayashree (1987) reported that in bhindi leaf mulch treatment had higher leaf area index that unmulched control.

During the earlier stages of growth mulching had no significant effect on leaf area index, but at later stages of growth leaf mulch had a positive and significant effect on leaf area index (Enyl (1973) in cocoyam ; Aina (1981) in maize and Mohankumar and Sadanandan (1988) in taro).

Jha *et al.* (1972) reported mulch directly influenced by the tiller production.

Hulugalle *et al.* (1986) observed a deeper and more extensive root system under all mulched conditions than control.

2.3.7 Yield

Application of leaf mulch during planting and six weeks later using a total of 20 tonnes of green leaves ha^{-1} resulted in 200 per cent increase in yield over the non mulched crop (Kannan and Nair, 1965).

In ginger, according to Aiyadurai (1966) mulching in ginger crop with 15,000 lb of green leaf per acre was sufficient to get increased yield and mulching the crop thrice with 5000 lb of green leaf once at planting time, again 30 days after planting and for the third time, 60 days after planting was optimum required for obtaining maximum yield.

Randhawa and Nanpuri (1965) reported that the optimum mulching being three applications at the rate of 12.5, 5.0 and 5 tonnes ha^{-1} for first, second and third mulching respectively gave maximum yield.

According to Muralidharan (1973) in ginger heavy mulch could change the physical and chemical environment of the soil resulting in increased availability of P and K.

Aclan and Quisumbing (1976) found increase in plant growth parameters, rhizome yield and starch content in ginger crop under leaf mulched conditions. This was further supported by Mohanty (1977) and Mishra and Mishra (1986).

The study of Valsala *et al.* (1990) indicated that under rainfed cultivation of ginger, daincha can be successfully raised in the interspaces of beds in a row. This practice not only helps to reducing the weed growth but also by way of giving 50 per cent of the green leaves required for second mulching.

Under low shade, 25 per cent of the mulch requirement can be reduced without affecting the final yield (Babu, 1993; Babu and Jayachandran, 1997).

2.4 Response of crops to triazole

Triazole contains a group of chemicals which have been developed for use either as fungicide or plant growth regulators. The plant growth regulating effects of the triazole include increases in leaf thickness, epicuticular wax, chloroplast size, photosynthetic pigments, nucleic acids, proteins and stimulation of rooting. The triazole is reported to protect plants from injury due to various stresses, including low and high temperature, drought and air pollutants such as ozone and sulphur dioxide (Fletcher *et al.*, 1986).

2.4.1 Plant growth regulating activity

In a comparative study with several triazoles, S-3307 and paclobutrazol were found to be the most active plant growth retardant effective on both dicotyledon and monocotyledon species (Fletcher *et al.*, 1986).

Foliar application of 1000 ppm paclobutrazol recorded the highest survival and subsequent growth of mango stone grafts in nursery (Burondkar *et al.*, 1993).

In gooseberry paclobutrazol @ 50 ppm and ethephon @ 400 ppm proved to be the most effective treatments in retarding the vegetative growth and improving the yield (Yadava and Sankar, 1993).

Bist *et al.* (1993) reported that use of 125 or 25 mg $tree^{-1}$ PP 333 by soil line pour at late fall stage or 250 ppm promalin foliar application at 20 and 40 cm at new extension growth stages were found most effective in tree shaping by curtailing excessive upright growth problem and increasing the productivity of the trees.

Wang and Shen (1991) observed that treatment of rice seeds with triazole delayed the accumulation of free proline which became rapid with decrease in water potential.

Babu and Singh (1992) observed an increase of 32 and 35 per cent of chlorophyll 'a' and 'b' in triadimefon treated wheat plants.

2.4.2 Protection from water stress

Triadimefon reduces transpiration in wheat, soyabeans, radishes and peas and increases yield under water stress conditions (Fletcher and Nath, 1984).

Triazoles confer drought tolerance and that the effect is clearly associated with a reduction in leaf area, an increase in diffusion resistance of the leaves, a reduction in transpiration and an increase in shoot water potential (Asare - Boamah *et al.*, 1986).

Several studies have now confirmed the observation that the water potential of triazole treated plants is higher than that of untreated plants and that the treated plants characteristically use less water than untreated plants (Davis *et al.*, 1988).

Triazole (Triademofon) at 30 ppm was found to be effective in cucumber for reducing irrigation frequency (KAU, 1995).

2.5 Pest and disease incidence

The study conducted by Nath (1993) on the effect of shade (produced by a peigeon pea crop) and rhizome treatment with formaldehyde on rhizome rot of ginger, the highest rhizome yield was recorded in rhizome treated plants grown in the shade for 150 d. This increased yield was mainly due to reduction of disease incidence. It is suggested that the temperature around the crop may have been reduced by shading and this could ultimately suppress the growth of the fungus.

Shetty (1995) reported that the cultivars Rio-de-Janeiro, Kunduli local, Wayanad local, Kurapampady, Suravi and Karkal were susceptible to phyllosticta leaf spot disease with a disease index of more than 10 per cent.

The leaf spot incidence in ginger was comparatively low under shade. The reason for this reduced disease incidence was attributed to the lesser number of mature leaves under shaded condition (Premanathan, 1981, Jayachandran and Nizam, 1997)

2.6 Economics

The study conducted by Varughese *et al.* (1978) in ginger intercropped in coconut garden, net return, input : out put ratio and employment generated per year from one hectare of coconut garden was Rs. 5020, 2.06 and 132 respectively.

Gopalasundaram and Nelliat (1979) reported that the additional income and employment opportunities can be generated by growing intercrops in coconut garden.

Singh *et al.* (1986) reported that from a survey of 190 farmers of varying sizes on which arecanuts were intercropped with five species, it was concluded that betel vine(*Piper betle*) was the most profitable intercrop, followed by pineapple, ginger (*Zingiber officinale*), bananas and turmeric (*Curcuma longa*).

Dwiwarni *et al.* (1987) conducted experiments on various planting schemes in 7 year old coconut. The highest income per hectare was obtained with cropping system cocoa + cinnamon + pepper + pineapple followed by kapok + pepper + ginger.

Sreenivasan *et al.* (1987) reported that ginger can be intercropped during the first three years after planting rubber.

Under rainfed conditions, coconut + elephant foot yam combination could fetch the highest return followed by coconut + ginger (Rao, 1991).

Ancy (1992) found that the gross and net return were maximum by growing ginger under low shade. The shade in the decreasing order of benefit : cost ratio were 25, 50, zero and 75 per cent. Among the fertilizer levels tried, 93.75 : 62.5 : 62.5 kg N, P_2O_5 and K_2O ha^{-1} gave maximum benefit : cost ratio under open condition. Also reported that fertilizer use efficiency more under 25 per cent shade.

Fernado (1995) reported that in Sri Lanka the coconut monocrop produced a relatively lower net income per unit area compared to the intercropping system.

The profitability of coconut from holdings of size below 0.5 ha was Rs. 3829 ha^{-1} but it rose to Rs. 9114 when intercrop was practiced. Likewise, in 0.5 - 1 ha holdings, the profitability rose from Rs. 12867 to Rs. 15081 ha^{-1} when intercropping was adopted. These findings suggests that coconut based farming system as a strategy is to be strengthened and popularised to make coconut farming even in small holdings economically viable (Thampan, 1999).

MATERIALS AND METHODS

3. MATERIALS AND METHODS

The investigation envisages to study the production potential of ginger under open and different shade levels and to analyse the mechanism involved in its shade loving nature. It is also aimed to standardise optimum dose of nutrients and mulch for ginger intercropped in coconut garden. The efficacy of triazole in the improvement of yield and other desirable characters have also been evaluated. The procedure adopted are discussed below.

3.1. Experimental site

Field trails and pot culture studies were conducted over a period of two seasons during April-May 1996 to December-January 1997 and April-May 1997 to December-January 1998 at Coconut Research Station, Balaramapuram, Thiruvananthapuram, Kerala.

3.1.1. Location

The Coconut Research Station, Balaramapuram situated at 8^0 29' N latitude and 76^0 57' E longitude and at an altitude of 64 m above mean sea level.

3.1.2. Soil

The soil of the experiment site is red loam belonging to the Vellayani series and texturally classed as sandy loam. The important physical and chemical properties of the soil are summerised in Table 1.

Table 1. Physico-chemical properties of soil at the experimental site

	Parameters	Content in the soil	Methods used
A	Physical composition		
	Sand	78.50 %	Bouyoucos Hydrometer (Bouyoucos, 1962)
	Silt	11.50 %	
	Clay	9.50 %	
	Soil texture	Sandy loam	
B	Chemical composition		
	pH	4.5	pH meter with glass electrode (Jackson, 1973)
	Organic carbon (per cent)	0.45 %	Walkey and Black's rapid titration method (Jackson, 1973)
	Available N	195 kg ha^{-1}	Alkaline potassium permanganate method (Subbiah and Asija, 1956)
	Available P_2O_5	24.30 kg ha^{-1}	Bray's calorimetric method (Jackson, 1973)
	Available K_2O	94.40 kg ha^{-1}	Ammonium acetate method (Jackson, 1973)

3.1.3. Climate

The climate of the experimental site was humid tropical. The mean rain fall during the cropping period are presented below.

Table 2. Average rain fall per month during the cropping period

Months	Rain fall in m.m.	
	April 1996 to January 1997	April 1997 to January 1998
April	26.57	12.00
May	15.60	21.86
June	28.11	47.46
July	21.61	20.36
August	20.85	13.62
September	28.63	46.10
October	51.80	48.36
November	10.70	56.89
December	26.44	22.83
January	Nil	Nil
Total rain fall (mm)	230.31	289.48

3.1.4. Season

The pot culture (Experiment I) and the field experiments (Experiment II and III) were conducted during two seasons of April / May 1996 to December / January 1997 and April / May 1997 to December / January 1998.

3.2. Materials

3.2.1 Variety

Ginger cultivar Rio-de-Janeiro was used for the experiment. Rhizome bits weighing 15 g were treated with Mancozeb 0.3 per cent and Malathion 0.1 per cent for 30 minutes before planting.

3.2.2. Fertilizers

Urea (46 per cent N), mussoriephos (20.1 per cent P_2O_5) and muriate of potash (60 per cent K_2O) were used for the experiment. Farm yard manure containing 0.68 per cent N, 0.38 per cent P_2O_5 and 0.67 per cent K_2O were used.

3.2.3. Triazole

The chemical 1, 2, 4 Triazole (minimum 98 per cent pure) ($C_2 H_3 N_3$) manufactured by Sisco Research Laboratories Pvt. Ltd. Mumbai, India was used for the study.

3.2.4. Shade material

The required shade levels were provided with high density polyethylene threads over pandals and calibrated to the required level using quantum photosensors. The mean PAR during the day of calibration under open, 20, 40, 60 and 80 per cent shade levels were 1461, 1120, 825, 550 and 260 μ mol m^{-2} s^{-1} respectively.

3.3. Methods

3.3.1. Treatments

Treatment details of these experiments are furnished in Table 3.1 - 3.3

Experiment I. Production potential of ginger under open and shade levels (Pot culture).

Table 3.1 Treatment details

Sl. No.	Treatments	Notations
1.	0 per cent shade (open)	S_0
2.	20 per cent shade	S_1
3.	40 per cent shade	S_2
4.	60 per cent shade	S_3
5.	80 per cent shade	S_4
	Total treatments 5	Replications 4

Experiment II. Requirement of NPK for ginger in coconut garden

Table 3.2 Treatment details

Treatments	Details	Notations
Nitrogen levels		
(N)	No nitrogen	n_0
	100 per cent of recommended dose	n_1
	200 per cent of recommended dose	n_2
Phosphorus levels		
(P)	No Phosphorus	p_0
	100 per cent of recommended dose	p_1
	200 per cent of recommended dose	p_2
Potash levels		
(K)	No potash	k_0
	100 per cent of recommended dose	k_1
	200 per cent of recommended dose	k_2
Total treatment combinations 27		Replications 3

Treatment combinations

$n_0\ p_0\ k_0$	$n_1\ p_0\ k_0$	$n_2\ p_0\ k_0$
$n_0\ p_0\ k_1$	$n_1\ p_0\ k_1$	$n_2\ p_0\ k_1$
$n_0\ p_0\ k_2$	$n_1\ p_0\ k_2$	$n_2\ p_0\ k_2$
$n_0\ p_1\ k_0$	$n_1\ p_1\ k_0$	$n_2\ p_1\ k_0$
$n_0\ p_1\ k_1$	$n_1\ p_1\ k_1$	$n_2\ p_1\ k_1$
$n_0\ p_1\ k_2$	$n_1\ p_1\ k_2$	$n_2\ p_1\ k_2$
$n_0\ p_2\ k_0$	$n_1\ p_2\ k_0$	$n_2\ p_2\ k_0$
$n_0\ p_2\ k_1$	$n_1\ p_2\ k_1$	$n_2\ p_2\ k_1$
$n_0\ p_2\ k_2$	$n_1\ p_2\ k_2$	$n_2\ p_2\ k_2$

Experiment III Effect of potassium levels, mulching and triazole

Table 3.3 Treatment details

Treatments	Details	Notations
Potassium levels		
(K)	No potash	k_0
	100 per cent of recommended dose	k_1
	200 per cent of recommended dose	k_2
Mulch levels	50 per cent of recommended dose	m_1
(M)	75 per cent of recommended dose	m_2
	100 per cent of recommended dose	m_3
Triazole levels		
(T)	No triazole	t_0
	25 $\mu g\ ml^{-1}$	t_1
	50 $\mu g\ ml^{-1}$	t_2
Total treatment combinations 27		Replications 4

Treatment combinations

$k_0\ m_1\ t_0$	$k_1\ m_1\ t_0$	$k_2\ m_1\ t_0$
$k_0\ m_1\ t_1$	$k_1\ m_1\ t_1$	$k_2\ m_1\ t_1$
$k_0\ m_1\ t_2$	$k_1\ m_1\ t_2$	$k_2\ m_1\ t_2$
$k_0\ m_2\ t_0$	$k_1\ m_2\ t_0$	$k_2\ m_2\ t_0$
$k_0\ m_2\ t_1$	$k_1\ m_2\ t_1$	$k_2\ m_2\ t_1$
$k_0\ m_2\ t_2$	$k_1\ m_2\ t_2$	$k_2\ m_2\ t_2$
$k_0\ m_3\ t_0$	$k_1\ m_3\ t_0$	$k_2\ m_3\ t_0$
$k_0\ m_3\ t_1$	$k_1\ m_3\ t_1$	$k_2\ m_3\ t_1$
$k_0\ m_3\ t_2$	$k_1\ m_3\ t_2$	$k_2\ m_3\ t_2$

Plate 1 General view of the experimental area

Plate 2 General view of the experiment - I

Plate 1

Plate 2

Plate 3 General view of the experiment - II

Plate 4 General view of the experiment - III

Plate 3

Plate 4

Table 3.4. Details of lay out of the experiments

	Seasons	Design	Replications	Treatment combinations	Pot / plot size	Number of pots / plots
Exp. I	I year May 1996 to January 1997 II year May 1997 to January 1998	Completely randomised design	Four	20	Mud pots of size 30 x 35 cm	50
Exp. II	I year May 1996 to January 1997 II year May 1997 to January 1998	3^3 Factorial experiment in randomised block design	Three	27	1 x 4 m	81
Exp. III	I year May 1996 to January 1997 II year May 1997 to January 1998	Strip - split plot design	Four	27	1 x 4 m	108

3.3.2. Design of the experiments

The field plan of the experiments are presented in Fig. 1, 2 and 3.

3.3.3. Cultivation aspects

3.3.3.1. Land preparation and planting

Experiment I (Pot culture)

Pot culture was done using 30 x 35 cm size mud pots. The required shade levels were provided by high density polyethylene threads over "pandals" and calibrated to the required level using quantum photosensors.

Artificial shading to the required level as per the treatments were provided by using high density poly-ethylene shade materials. LI-COR-LI-188 B Quantum radiometer with a photometric sensor was used for confirming the shading capacity of the high density poly-ethylene shade materials to provide the required shade levels. Pandals of size 6 x 6m were erected separately for each shade level. Three metre spacing was provided in between the pandals to avoid mutual shading. Each pandal was covered on all the sides with shade nets except 50 cm from the ground level. Frequent checks were made throughout the course of the experiment to maintain the shade intensities to the requisite levels.

Experiment II

Beds of 4 x 1 m size and 25 cm height were prepared in the interspace of coconut garden, giving 50 cm spacing between beds. Farm yard manure was applied at the rate of 30 t ha^{-1} by placing in small pits taken at a spacing of 25 x 25 cm and seed rhizomes were planted in the pits at depth of 4-5 cm

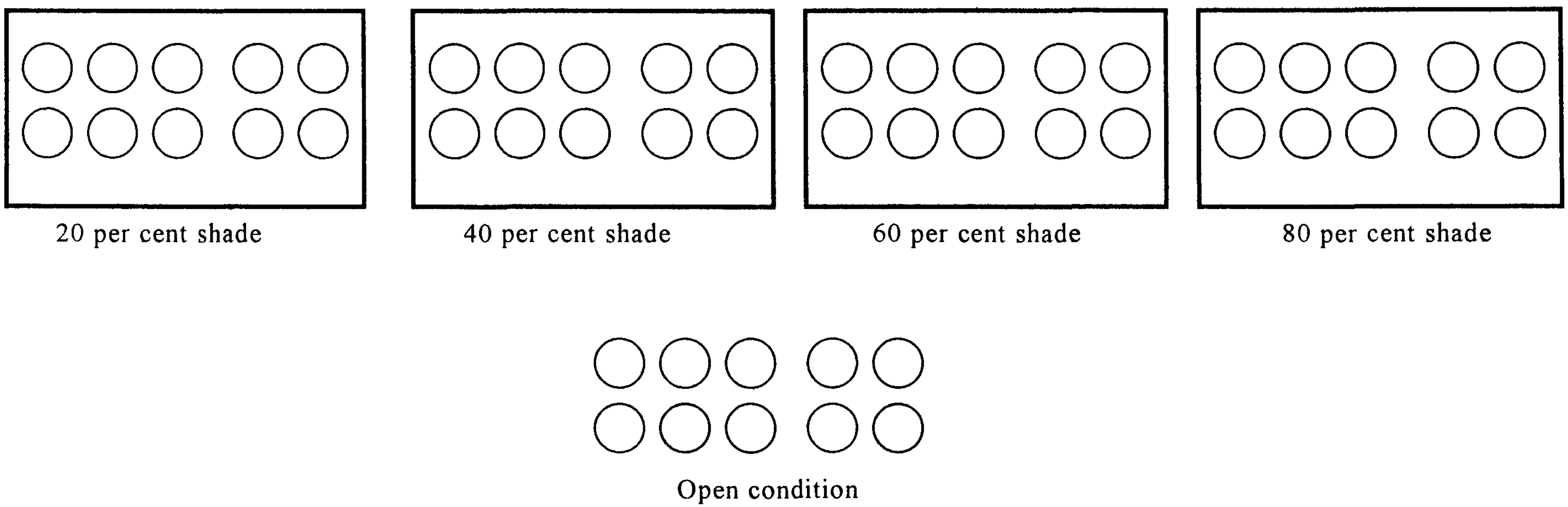


Fig. 1 Layout plan of Experiment - I

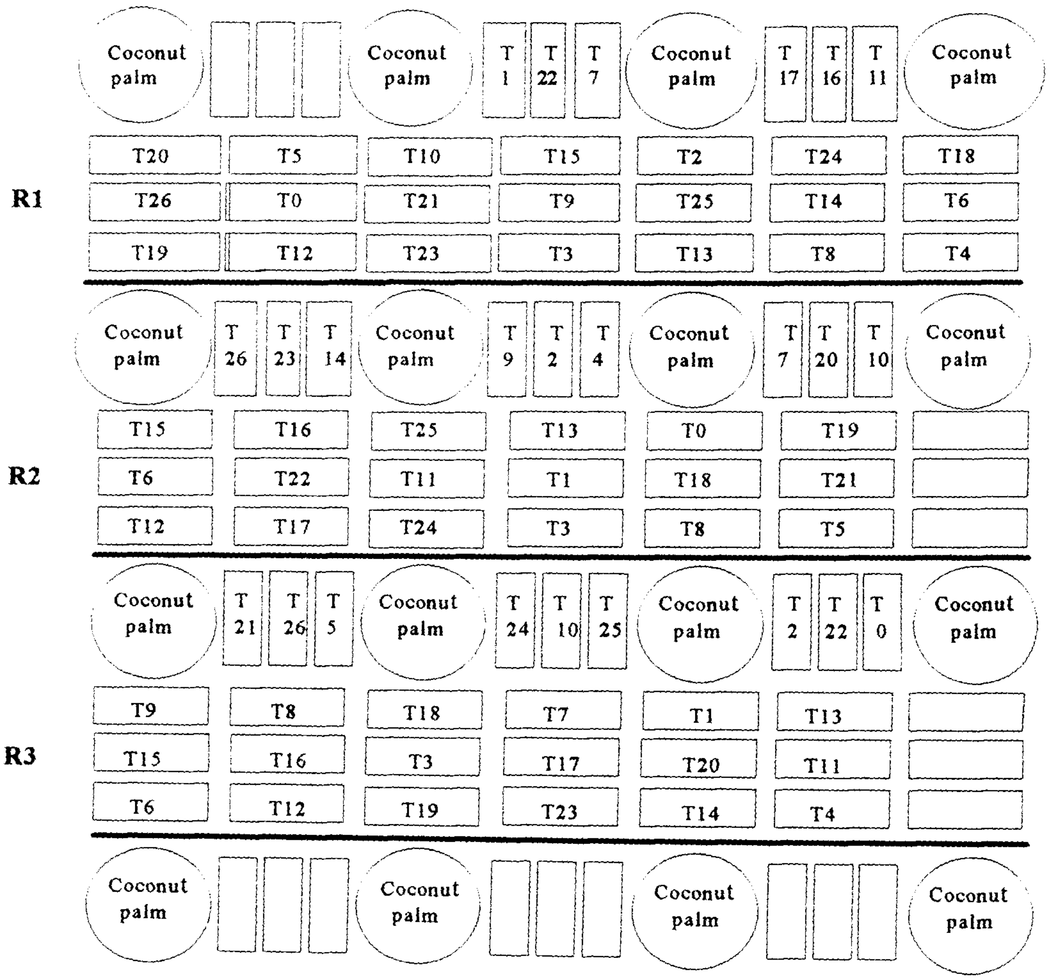


Fig. 2 Layout plan of Experiment - II

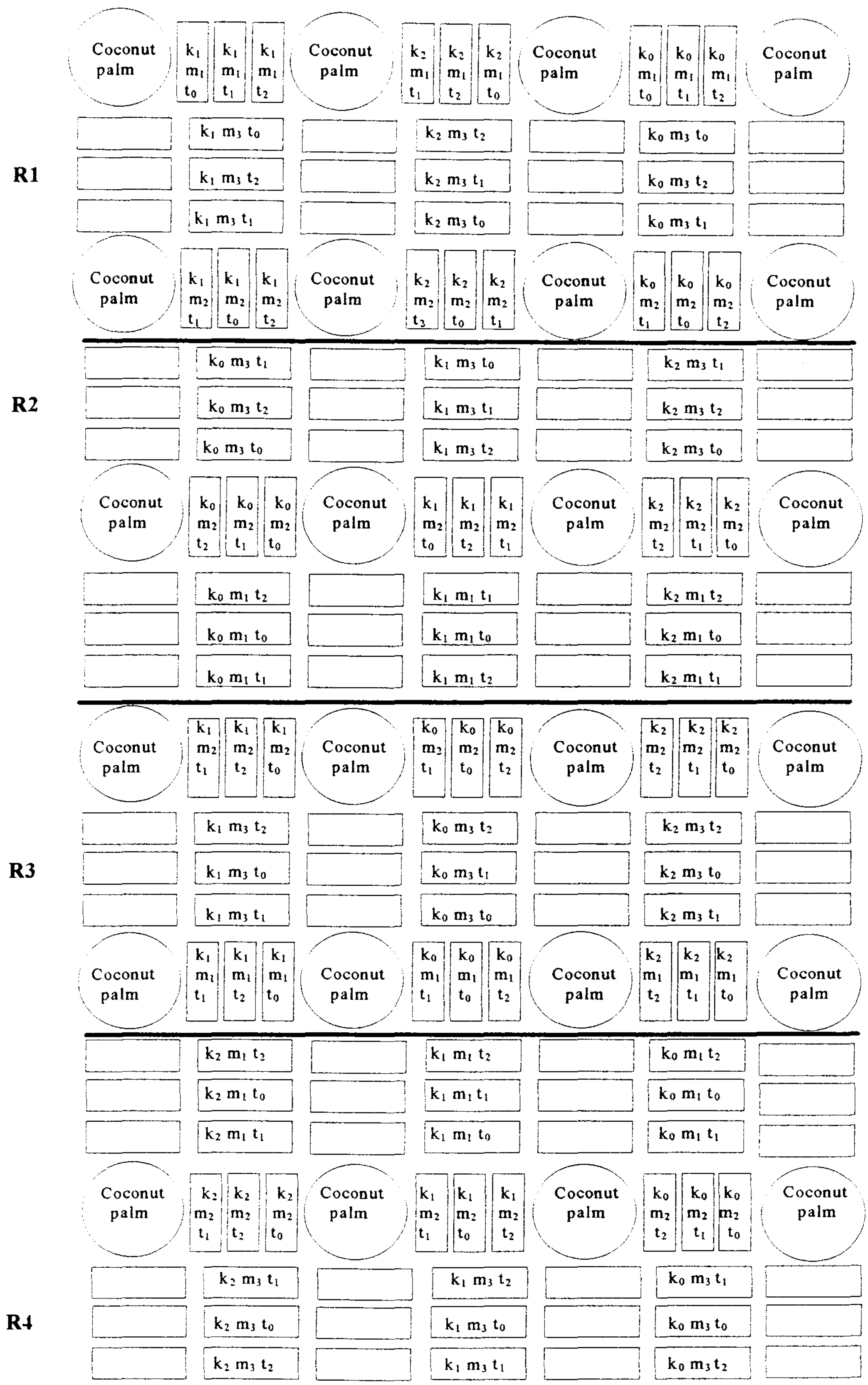


Fig. 3 Layout plan of Experiment - III

and then covered with soil. Except fertilizer applications, all other cultural practices were done as per the package of practices recommendations of the Kerala Agricultural University (KAU, 1996).

Experiment - III

Beds of 4 x 1 m and 25 cm height were prepared in the interspace of coconut garden, giving 50 cm spacing between beds. Farm yard manure was applied at the rate of 30 t ha^{-1} by placing in the small pits taken at a spacing of 25 x 25 cm and seed rhizomes were planted in the pits at a depth of 4-5 cm and then covered with soil. Except application of potash, triazole and mulch, all other cultural practices were done as per the package of practices recommendations of the Kerala Agricultural University (KAU, 1996).

3.3.3.2. Fertilizer application

Experiment I

Fertilizers, viz., urea, mussoriephos and muriate of potash were applied uniformly to all pots as per the package of practices recommendations of the Kerala Agricultural University (KAU, 1996).

Experiment II

The fertilizers, viz., urea, mussoriephos and muriate of potash were applied as per the treatments. Fertilizers were applied in three levels viz., no fertilizers, 75 : 50 : 50 and 150 : 100 : 100 kg N, P_2O_5 and K_2O ha^{-1}. For all treatments, full dose of P_2O_5 and half dose of K_2O were given as basal dressing, half the dose of N at two months after planting and remaining portions of N and K_2O were applied at four months after planting.

Experiment III

The required quantity of fertilizers except potash were applied as per the package of practices recommendations (KAU, 1996). The quantity of potassium was applied as per the treatments. The split applications of the nutrients were similar to experiment II.

3.3.3.3. Mulching

Experiment I

Mulching was done as per the package of practices recommendations of the Kerala Agricultural University (KAU, 1996).

Experiment II

Mulching was done as per the package of practices recommendations of the Kerala Agricultural University (KAU, 1996).

Experiment III

The quantity of green leaves applied as per the treatment levels given in Table-5. Half of the total quantity required was applied as basal. The remaining half was devided into two equal parts and was used for second and third mulching during second and fourth months after planting respectively.

Table 4. Quantity of green leaves used for mulching in experiment III

Time of application	Quantity of mulch t ha^{-1}		
	m_1	m_2	m_3
Basal	7.5	11.25	15
Two months after planting	3.75	5.625	7.5
Four months after planting	3.75	5.625	7.5

3.3.3.4. Triazole application

Experiment III

Aerial spraying with triazole as per the treatments were done during 60, 120, 180 days after planting.

3.3.3.5. After cultivation

Experiment I

Regular watering done during summer seasons.

Experiment II

Hand weeding was done before each mulching and repeated weeding, during the firth and sixth month after planting. Earthing up was also done during the first mulching.

Experiment III

The after cultivation of experiment III was same as in experiment II.

3.3.3.6. Plant protection

Experiment I

The crop was free from pests and diseases.

Experiment II and III

Mild incidence of leaf spot, rhizome rot and attack of stem borer were noticed and it was kept under check by periodic spraying of Dimecron (0.5 per cent) and spraying and drenching with Bordeaux mixture.

3.3.3.7. Harvest

Experiment I

Monthly destructive sampling was conducted from the pots kept for destructive sampling. Final harvest was done from the pots eight months after planting.

Experiment II and III

The harvesting of the crops was carried out eight months after planting. Yield from net plot area were used for calculating per hectare yield.

3.4. Observations

In pot culture study, observations were recorded from individual pots. The observations on various growth parameters were taken at monthly intervals. In field trials, five plants per treatment were randomly selected. The observations on various growth parameters were taken at 60, 120 and 180 days after planting.

3.4.1 Observations on growth characters

The observation on growth characters were taken from five sample plants selected at random from the net plot and monthly intervals for experiment I and bimonthly intervals for experiment II and III.

3.4.1.1 Height of plant

Height of the plant was measured from the base of the plant to the base of young fully opened leaf and expressed in centimeter (cm).

3.4.1.2. Number of tillers

The number of aerial shoots arising around each plant was counted.

3.4.1.3 Number of leaves

Number of leaves produced was recorded by counting fully opened leaves of the tillers from each samples plants.

3.4.1.4 Leaf area

The number of leaves were counted from the sample plants. The length and maximum width of the leaves were measured and the leaf area was calculated based on the length and breadth method (Ancy, 1992).

The relationship $y = 0.6695\ x - 0.7607$ (y is leaf area and x is the product of length and breadth) was utilized for computing the leaf area.

3.4.1.5 Leaf dry weight

The leaf weight was recorded by taking leaves from each plant and dried to a constant weight and expressed in gram (g).

3.4.2 Root studies

The root length, spread, weight, volume and root : shoot ratio were measured as detailed.

3.4.2.1 Root length

After harvest, the root of each plant was removed carefully, washed, maximum length measured and mean length expressed in centimeter (cm).

3.4.2.3 Root spread

Root of each plant after washing was placed as such on a plain paper and maximum width of the root system measured and expressed in centimeter (cm).

3.4.2.4 Root weight

Root removed from each pot was dried and dry weight recorded in g pot^{-1}.

3.4.2.5 Root volume

Volume of roots $plant^{-1}$ was estimated by the displacement method and expressed in cm^3.

3.4.2.6 Root : shoot ratio

Root and shoot weight were recorded separately from each pot and root to shoot ratio worked out.

3.4.3 Rhizome studies

Rhizome spread, rhizome thickness and number of finger rhizomes per plant are studied as detailed.

3.4.3.1 Rhizome spread

Maximum width of the rhizomes harvested from each pot were measured and expressed in cm.

3.4.3.2 Rhizome thickness

Thickness of the rhizomes harvested from each pot was measured at different position and average worked out and expressed in cm.

3.4.3.3 Number of finger rhizome

The number of finger rhizomes were counted and expressed in numbers.

3.4.4. Leaf thickness

The sections were taken from the middle portion of the lamina across the mid-rib. Strips are immediately fixed in FAA (Formalin : acetate : ethanol, formulae of Berlyn and Miksche, 1976), dehydrated in ethanol, immersed in a xylene series and embeded in wax. This lamina cross-section of each strip were cut with a microtome and leaf thickness were measured on different sections of the slide, and in different places within each section, but avoiding the region around the mid-rib and expressed μ m.

3.4.5 Stomatal characters

3.4.5.1 Stomatal index

Stomatal index (SI) is the proportion of the number of stomata to the number of epidermal cells per unit area. As in the case of stomatal frequency, the peel was taken, observed under microscope, the mean counts of stomata and epidermal cells were taken and the ratios worked out using the following formula given by Dhopte and Livera (1989).

$$SI\ (\%) = \frac{S}{S + E} \times 100$$

Where S = number of stomata

E = number of epidermal cells

3.4.5.2 Stomatal frequency

Stomatal frequency refers to the number of stomata per unit area of leaf. Nail polish was smeared on the lower surface of these leaves and allow to dry. It was pealed gently and the peel was observed and counted using a 40 X objective and 10 X eye piece. The field of the microscope was measured using a stage micrometer and stomatal count per unit area, was calculated (Dhopte and Livera, 1989).

3.4.6 Physiological characters

3.4.6.1 Dry matter production

Pseudostems, leaves and rhizomes of the uprooted plants were dried to a constant weight at 70 ^{0}C - 80 ^{0}C in a hot air oven. The sum of the dry weights of component parts gave total dry matter production and expressed as g plant^{-1}.

3.4.6.2 Crop growth rate

Crop growth rate (CGR) was calculated using the formula of Watson (1958) and expressed as g m^{-2} day^{-1}.

$$CGR = NAR \times LAI$$

3.4.6.3 Relative growth rate

Relative growth rate (RGR) is the rate of increase in dry weight per unit dry weight per unit time expressed in g g^{-1} day. It is calculated by the formula suggested by Blackman (1919).

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

W_1 = Dry weight of the plant at time t_1

W_2 = Dry weight of the plant at time t_2

3.4.6.4 Net assimilation rate

Net assimilation rate (NAR) refers to the change in dry weight of the plant per unit leaf area per unit time. The procedure given by Watson (1958) was modified by Buttery (1970) was used for calculating NAR and expressed in g m^{-2} day^{-1}.

$$NAR = \frac{W_2 - W_1}{(t_2 - t_1)\left(\frac{A_1 + A_2}{2}\right)}$$

Where W_1 and W_2 are the total dry weight of plant (g) at time t_1 and t_2 respectively. A_1 and A_2 are leaf area indices at time intervals (days) t_1 and t_2 respectively.

3.4.6.5 Leaf area duration

Leaf area duration (LAD) was calculated using the formula given by Power *et al.* (1967).

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

Where, Li = LAI at stage 1^{st}, Li + 1 = LAI at stage 2^{nd} and $t_2 - t_1$ = time interval between these stages.

3.4.6.6 Leaf area index

Leaf area index (LAI) was computed using the following relationship (Williams, 1946).

$$LAI = \frac{\text{Leaf area of the plant } (cm^2)}{\text{Area of land covered by the plant } (cm^2)}$$

3.4.6.7 Specific leaf weight

Specific leaf weight (SLW) was calculated using the formula and expressed as g cm^2

$$SLW = \frac{\text{Leaf dry weight}}{\text{Leaf area}}$$

3.4.6.8 Relative water content

Relative water content (RWC) was calculated using the formula and expressed as percentage (Weatherley, 1950).

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

3.4.6.9 Root : shoot ratio

Root and shoot dry weights were recorded from each plant and the root : shoot ratios were worked out.

3.4.6.10 Photosynthetically active radiation on leaf surface

Photosynthetically active radiation on leaf surface was measured using the portable photosynthesis system (LCA - 4) and expressed as μ mol m^{-2} s^{-1}.

3.4.6.11 Stomatal conductance

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

3.4.6.12 Stomatal resistance

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

3.4.6.13 Photosynthetic rate

Photosynthetic rate was measured using the portable photosynthesis system (LCA - 4) and expressed as μ mol m^{-2} s^{-1}.

3.4.6.14 Transpiration

Transpiration rate was measured using the portable photosynthesis system (LCA - 4) and expressed as mol m^{-2} s^{-1}.

3.4.7 Biochemical analysis

Chlorophyll and proline content were analysed as detailed.

3.4.7.1 Chlorophyll content

The chlorophyll content was estimated by following method prescribed by Starnes and Hadley (1965). A representative sample of 25 mg was weighed and the leaf tissues were then ground with 10 ml of 80 per cent acetone using a pestle and mortar. The homogenate was centrifuged at 3,000 rpm for 10 minutes. The supernatant was collected and was made up to 25 ml with 80 per cent acetone. The OD value of the extract was measured at 663, 665 and 480 nm using 80 per cent acetone as the blank in the spectrophotmeter.

The amount of pigments was calculated using the formulae and expressed in mg of pigments g^{-1} of fresh leaf.

Formulae

Total chlorophyll content = (20.2 (OD at 645) + 8.01 (OD at 663) x v/ (w x 1000) mg g^{-1}

Chlorophyll a : (12.7 (OD at 663) - 2.69 (OD at 645) x v / (w x 1000) mg g^{-1}

Chlorophyll b : (22.9 (OD at 645) - 4.68 (OD at 663) x v / (w x 1000) mg g^{-1}

3.4.7.2 Proline content

Proline content was estimated from the fully opened leaves by the technique suggested by Bates *et al.* (1973) and expressed in μ g g^{-1} fresh weight.

3.4.8 Yield and yield parameters

3.4.8.1 Shoot dry weight

Experiment I, the shoot dry weight (pseudostems, leaves and inflorescence if any) the each plant per pot was recorded and expressed in g $plant^{-1}$ on dry weight basis.

Experiment II and III, the shoot dry weight (pseudostems, leaves and inflorescence if any) was recorded from the net area and expressed in kg ha^{-1} on dry weight basis.

3.4.8.2 Fresh rhizome yield

In experiment I, the yield of fresh rhizome from each pot were recorded and expressed as g $plant^{-1}$. In experiment II and III the yield of fresh rhizome from each treatment was recorded from the net area and expressed as kg ha^{-1}.

3.4.8.3 Dry ginger yield

Experiment I : the fresh rhizomes after sun drying to a moisture level of 10 per cent from each pot and expressed as g plant^{-1}.

Experiment II and III : the yield of rhizome after drying from each treatment were recorded from the net area and expressed as kg ha^{-1}.

3.4.8.4 Bulking rate

The bulking rate (BR) of rhizome worked out on the basis of increase in the dry weight of rhizome (g) plant^{-1} day^{-1} and expressed as g day^{-1}.

$$BR = \frac{W_2 - W_1}{t_2 - t_1}$$

Where W_1 and W_2 were dry weight of rhizome at two time units t_1 and t_2.

3.4.8.5 Harvest index

Harvest index (HI) was calculated as follows,

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

Where, y econ. and y biol. were dry weight of rhizome and total dry weight of plant, respectively.

3.4.9 Quality analysis

Under quality analysis volatile oil, non-volatile ether extract, starch, fibre content were analysed as detailed.

3.4.9.1 Volatile oil

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

3.4.9.2 Non-volatile ether extract

Non-volatile ether extract (NVEE) was estimated by soxhlet distillation method (AOAC., 1975) and expressed as percentage on dry weight basis.

3.4.9.3 Starch

Starch content was analysed using copper reduction method suggested by A.O.A.C. (1975) and expressed as percentage on dry weight basis.

3.4.9.4 Crude fibre content

The crude fibre was estimated by AOAC method (1975) and expressed as percentage on dry weight basis.

3.4.10 Plant analysis

Sample plants collected from each plot at harvest were initially sun dried, then oven dried to a constant weight. The samples were finally ground in a Willey Mill for the various chemical analysis. The nitrogen content (modified microkjeldahl method), phosphorus content (Vanado-molybdo-phosphoric yellow colour method) and potassium content (Flame photometirc method) were estimated (Jackson, 1973).

Uptake of N, P and K was calculated by multiplying the nutrient contents of the plant with the total dry matter production and expressed in kg ha^{-1}.

3.4.11 Soil analysis

The soil analysis was done to find out the content of organic carbon, available nitrogen, phosphorous and potassium before and after the experiment. Composite soil samples were used for estimating available nutrient present in the soil at the time of laying out of the experiments. Soil samples were collected from individual plots of experiment II and experiment III, after the harvest of the crop, dried in shade, sieved through 2 mm sieve and analyzed. Available N was estimated by alkaline permanganate method (Subbiah and Asija, (1956), available phosphorus by Bray method (Jackson, 1973) and available potassium by neutral normal ammonium acetate method (Jackson, 1973).

3.4.12 Statistical analysis

The data of the pot culture study were analysed by the analysis of variance for completely randomized design and experiment II was analysed employing the technique of analysis of variance for factorial experiment in randomized block design and that of experiment III was analysed employing the technique of analysis of variance for strip-split plot design (Gomez and Gomez, 1984). Critical difference (CD) values at 5 per cent level of significance were provided wherever the effects were found to be significant.

3.4.13 Economic analysis

Economics of cultivation was worked out for both field experiments after taking into account the cost of cultivation of ginger and prevailing market price of ginger rhizomes. In computing the cost involved, different variable cost items like planting materials, manure, fertilizers, plant protection chemicals, irrigation, labour charges etc. were considered at prevailing market rate during 1996-97 and 1997-98.

The net income benefit is to cost ratio were calculated as follows.

Net income (Rs ha^{-1}) = Gross income - total expenditure

Benefit : cost ratio = Net income / total expenditure

RESULTS

4. RESULTS

4.1 EXPERIMENT - I

The results of the experiment on production potential of ginger under open and shade levels are presented below :

4.1.1 Growth characters

4.1.1.1 Plant height

The data presented in Table 5 shows the effect of shade on plant height (cm) during two seasons.

During the first year at all stages of growth, S_3 and S_4 were superior to all other shade levels with respect to plant height. Same trend was observed during the second year also. During later stages of growth i.e. at 180 and 210 DAP, during first year, S_3 recorded maximum plant height and was on par with S_4. But during the second year, S_4 exhibited a maximum plant height followed by S_3. At 240 DAP during the first year, S_4 recorded the maximum plant height (87.25 cm) and was on par with S_3 (84 cm). During second year S_4 recorded the maximum value followed by S_3. In general plants grown under open condition (S_0) registered the lowest plant height in all growth stages.

4.1.1.2 Number of tillers

The mean number of tillers presented in Table 6 show the effect of shade on tiller production during the two seasons.

Table 5. Effect of shade on height of the plants (cm)

Days after planting	Shade (S)									
	S_0 (open)		S_1 (20 per cent)		S_2 (40 per cent)		S_3 (60 per cent)		S_4 (80 per cent)	
	I	II	I	II	I	II	I	II	I	II
30	9.13	9.50	14.25	16.13	15.25	18.00	18.00	21.13	20.50	24.00
60	21.20	25.00	29.00	34.25	31.50	37.15	34.75	53.25	37.50	50.68
90	25.75	33.50	35.50	40.75	42.50	43.75	48.00	61.75	60.75	85.50
120	30.50	40.00	42.75	46.75	45.50	54.25	61.25	66.75	65.75	96.25
150	38.25	46.75	54.00	56.75	55.50	61.00	67.00	71.50	74.00	117.75
180	40.38	54.75	57.00	62.25	58.50	66.00	79.25	77.00	78.25	121.00
210	41.50	57.75	64.25	62.75	64.25	71.25	82.00	80.25	80.75	124.50
240	43.00	62.50	66.75	66.25	69.25	74.50	84.00	85.25	87.25	128.25

	I year		II year	
Effect	SE	**CD(0.01)**	SE	**CD(0.01)**
Shade x period	1.948	**5.482**	4.294	**12.084**

Table 6. Effect of shade on the number of tillers

Days after planting	Shade (S)									
	S_0 (open)		S_1 (20 per cent)		S_2 (40 per cent)		S_3 (60 per cent)		S_4 (80 per cent)	
	I	II	I	II	I	II	I	II	I	II
30	2.00	3.25	2.25	4.50	3.25	5.25	2.25	4.25	3.00	4.75
60	2.75	6.25	4.50	11.75	4.50	9.75	3.75	8.75	4.50	5.50
90	6.75	11.25	10.00	15.25	8.50	15.25	5.75	11.75	6.00	7.25
120	9.00	16.25	16.25	19.25	13.50	18.50	8.00	14.50	7.50	10.00
150	15.00	19.75	24.75	22.75	27.75	23.25	19.00	17.00	16.50	13.00
180	18.00	28.00	27.00	27.00	33.25	29.75	25.00	27.75	18.25	17.50
210	19.50	31.25	37.00	35.00	37.25	34.50	26.25	32.25	18.75	19.75
240	22.50	33.25	39.00	37.50	42.00	38.25	29.75	35.25	20.00	22.00

	I year		II year	
Effect	SE	**CD (0.01)**	SE	**CD (0.01)**
Shade x period	1.503	**4.229**	1.547	**4.352**

Table 7. Effect of shade on number of leaves

Days after Planting	Shade (S)									
	S_0 (open)		S_1 (20 per cent)		S_2 (40 per cent)		S_3 (60 per cent)		S_4 (80 per cent)	
	I	II	I	II	I	II	I	II	I	II
30	10.25	8.75	19.00	19.25	22.00	20.75	13.75	20.00	16.75	18.00
60	12.50	32.50	48.25	76.75	66.75	60.50	37.50	63.50	35.75	43.25
90	39.50	37.25	78.75	91.25	81.00	78.00	50.50	59.00	50.00	59.00
120	71.25	70.00	106.75	153.75	153.50	143.50	97.50	128.00	69.25	86.75
150	134.25	166.25	313.00	228.75	265.00	228.25	158.75	164.25	165.00	117.75
180	197.50	319.00	359.00	275.50	299.50	323.25	223.00	202.25	170.75	163.50
210	235.00	334.25	378.75	347.50	338.75	367.50	229.25	225.00	182.50	188.75
240	257.25	350.75	396.25	417.50	380.00	408.75	262.75	265.50	224.00	221.25

	I year		II year	
Effect	SE	**CD(0.01)**	SE	**CD(0.01)**
Shade x period	15.374	**43.266**	18.053	**50.807**

Table 8. Effect of shade on leaf area (cm^2)

Days after Planting	Shade (S)									
	S_0 (open)		S_1 (20 per cent)		S_2 (40 per cent)		S_3 (60 per cent)		S_4 (80 per cent)	
	I	II	I	II	I	II	I	II	I	II
30	153.75	133.00	285.00	231.50	378.75	309.75	192.50	240.00	217.75	285.50
60	337.50	437.50	1302.75	1180.00	1802.25	1097.75	1013.00	1102.75	781.75	761.50
90	987.50	635.00	2126.25	1570.00	2187.00	1585.00	1363.50	1181.00	1000.00	1139.50
120	1923.75	1400.00	2882.25	2382.50	4144.50	2711.00	2282.50	2523.25	1385.00	1473.00
150	3356.25	3212.50	7825.00	4622.00	6625.00	5699.25	3175.00	3656.25	2885.00	2517.50
180	6912.50	7450.00	12565.00	8358.75	10482.50	9697.50	6102.50	5573.75	3756.50	3620.00
210	9400.00	11387.50	13900.00	13900.00	12800.00	14700.00	6877.50	9000.00	4562.00	5943.75
240	10290.00	14330.00	14850.00	15900.00	14450.00	15212.50	7882.50	9207.50	5488.75	6637.50

	I year		II year	
Effect	SE	**CD (0.01)**	SE	**CD (0.01)**
Shade x period	466.299	**1312.299**	648.424	**1824.849**

During 30 and 60 DAP there was no significant difference in tiller production in different shade levels. From 90 DAP on wards S_1 and S_2 recorded higher tiller number in almost all growth stages. At 240 DAP S_2 recorded the highest tiller count of 42 which was on par with S_1(39) during first season. But during second year S_2 recorded highest tiller number of 38.25 which was on par with tiller count under S_1 (37.50) and S_3 (35.25). In general S_4 registered a lowest tiller number followed by S_0.

4.1.1.3 Number of leaves

The Table 7 shows- the effect of shade on the leaf production during the two seasons.

During early growth stages there was not much variations in the number of leaves per plant under the different intensities of shade over periods. From 120 DAP, S_1 and S_2 recorded higher number of leaves in all growth stages. Towards the later stages of growth i.e., at 210 and 240 DAP, S_4 was found to record the lowest number of leaves. At 240 DAP, S_1 recorded 396 and 418 leaves during first and second year respectively and was on par with S_2 during both the periods.

4.1.1.4 Leaf area

The values presented in Table 8 show the effect of shade on mean leaf area during two seasons.

Leaf area varied significantly among the different shade levels at different growth stages. Up to 150 DAP, not much variations in leaf area was observed due to the shading. At 180 DAP, during the first year S_1 recorded maximum leaf area of 12565 cm^2 followed by S_2 (10482.5 cm^2). The S_0 with a value of 6912 cm^2 was on par with S_3 (6102.5 cm^2). The lowest value was resulted by S_4 (3756.5 cm^2). The same trend was observed during second year also, but the maximum leaf area was recorded by S_2 (9697.5 cm^2). At 210 DAP, during first year S_1 with a value of 13900 cm^2 recorded the maximum leaf area and was on par with S_2 (12800 cm^2). The lowest leaf area was recorded by S_4. During second year, S_2 recorded the maximum leaf area and was on par with S_1. In all other shade levels the same trend was recorded. At 240 DAP, S_1 registered the maximum leaf area (14580 cm^2) and was on par with S_2 (14450 cm^2). The lowest leaf area was registered by shade level S_4. The same trend was observed during the second year.

4.1.1.5 Leaf dry weight

The Table 9 shows the effect of shade on leaf dry weight per plant during the two seasons.

Up to 120 DAP, not much variations in leaf dry weight was observed due to shade over different periods. At 150 DAP, S_1 registered a maximum leaf dry weight followed by S_2 and was on par with S_0, S_3 and S_4. During the second year S_2 recorded the maximum leaf dry weight and was on par with S_1. The lowest leaf dry weight was recorded by the S_4 and was on par with S_0. The shade level S_0 was also on par with S_3 with respect to leaf dry weight. At 180 DAP, S_1 recorded the maximum value followed by S_2 and was on par with S_0 and S_3. The lowest leaf dry weight was recorded by S_4 and

Table 9. Effect of shade on leaf dry weight (g)

Days after Planting	Shade (S)									
	S_0 (open)		S_1 (20 per cent)		S_2 (40 per cent)		S_3 (60 per cent)		S_4 (80 per cent)	
	I	II	I	II	I	II	I	II	I	II
30	1.40	1.53	2.32	1.65	2.28	2.50	1.40	2.13	1.38	1.48
60	2.33	2.23	6.25	3.50	6.52	5.80	3.66	2.85	4.44	1.66
90	6.75	3.65	9.12	3.63	8.00	4.58	5.26	3.98	4.69	2.63
120	9.56	6.60	13.87	6.95	15.32	7.73	9.33	6.13	7.92	3.68
150	21.65	9.93	33.72	21.73	22.25	26.25	20.72	15.83	15.94	7.73
180	25.50	18.58	36.51	30.75	27.17	37.98	22.10	19.10	18.57	13.63
210	30.94	27.13	40.14	41.00	31.35	34.23	23.98	19.88	22.12	18.38
240	33.72	32.98	40.24	41.78	35.64	45.58	24.97	23.23	13.91	14.35

	I year		II year	
Effect	SE	CD(0.01)	SE	CD(0.01)
Shade x period	2.561	7.206	2.314	6.511

Table 10. Effect of shade on root length (cm)

Days after Planting	Shade (S)									
	S_0 (open)		S_1 (20 per cent)		S_2 (40 per cent)		S_3 (60 per cent)		S_4 (80 per cent)	
	I	II	I	II	I	II	I	II	I	II
30	13.75	10.50	13.75	10.50	14.75	12.75	13.25	10.38	10.50	12.25
60	19.25	15.75	36.75	13.75	36.75	16.50	20.00	14.00	17.00	14.25
90	22.50	15.50	44.00	14.50	42.75	17.25	25.00	14.75	21.50	13.25
120	24.50	18.50	42.50	19.50	46.50	19.50	27.00	18.00	21.50	14.50
150	41.25	23.00	62.25	22.75	52.75	23.00	42.25	19.00	32.00	15.00
180	35.75	26.75	63.25	25.25	48.75	25.25	39.50	21.25	30.25	16.25
210	25.25	28.00	26.00	27.00	29.75	27.75	29.00	25.25	13.25	16.50
240	27.50	30.25	25.75	27.00	30.50	28.00	28.00	31.00	14.25	18.50

	I year		II year	
Effect	SE	**CD(0.01)**	SE	**CD(0.01)**
Shade x period	1.468	**4.132**	1.018	**2.865**

was on par with S_3 and S_0. During the second year, S_2 registered a higher leaf dry weight followed by S_1. The lowest leaf dry weight recorded by S_4 was on par with S_0 and S_3. At 210 DAP, S_1 registered the maximum value followed by S_2 and S_0. The lowest value registered by S_4 and was on par with S_3. Almost same trend was recorded during the second year also. At 240 DAP, S_1 registered the highest leaf dry weight of 40.24 g and was on par with S_2(35.64 g)and S_0(33.72g) followed by S_3 (24.97 g) and S_4.(13.91 g). During second year, S_2 recorded maximum leaf dry weight of 45.58 g and was on par with S_1 (41.78 g), followed by S_0 (32.98 g), S_3 (23.23 g) and S_4 (14.35 g).

4.1.2 Root characters

4.1.2.1 Root length

The mean values presented in Table 10 show the effect of shade on root length during the two seasons.

Not much variation in root length was observed due to shade over periods up to 120 DAP. At 150 DAP, S_1 registered maximum root length followed by S_2. The shade level S_3 was on par with S_0. The lowest value was registered by S_4. During second year, S_2 recorded maximum value which was on par with S_0 and S_1 followed by S_3 and S_4. At 150 DAP, S_1 registered maximum root length followed by S_2. But during second year, S_0 registered maximum root length, which was on par with S_1 and S_2. In both the periods, the lowest values were recorded by S_4. At 210 and 240 DAP, in general S_0, S_1, S_2 and S_3 registered the maximum root length with not much variations. The lowest root length was registered by S_4 at all stages of growth.

Plate 5 Root pattern of ginger under different shade levels and open condition

Plate 5

4.1.2.2 Root spread

The Table 11 shows the effect of shade on root spread during the two seasons.

In general, up to 210 DAP, the root spread due to shade over periods, at S_0, S_1 and S_2 were on par and superior to S_3 and S_4 . At 240 DAP, during first season, S_2 recorded maximum root spread of 18 cm which was on par with S_1 (16 cm). The root spread S_1 (16 cm) and S_o were on par with S_2 (22.75 cm).The root spread S_2 (22.75 cm) was on par with S_1 (21.75 cm). The lowest root spread was recorded by S_4 and S_3. The same trend was observed during the second season.

4.1.2.3 Root dry weight

The Table 12 shows the effect of shade on root dry weight during the two seasons.

Not much variations in root dry weight per plant was observed due to shade over periods up to 90 DAP. At 120 DAP, during both the years, S_2 recorded maximum root dry weight followed by S_1, S_0 and S_3. At 150 and 180 DAP, maximum root dry weight was recorded by S_1 which was on par with S_2. At 210 DAP, during first year, S_0 registered maximum root dry weight which was on par with S_1. But during second year, S_2 recorded maximum root dry weight which was on par with S_1 and S_0. At 240 DAP, during first year, S_1 recorded maximum root dry weight of 1.41 g which was on par with S_0.(1.69 g). But during second year maximum root dry weight of 1.50 g was recorded at S_0 which was on par with S_1 (1.35 g). The root dry

Table 11. Effect of shade on root spread (cm)

Days after Planting	Shade (S)									
	S_0 (open)		S_1 (20 per cent)		S_2 (40 per cent)		S_3 (60 per cent)		S_4 (80 per cent)	
	I	II	I	II	I	II	I	II	I	II
30	7.75	8.10	7.00	7.60	7.25	7.50	5.00	4.80	5.00	4.63
60	12.25	9.38	18.75	9.10	15.75	7.60	8.25	5.63	8.75	5.00
90	14.75	12.50	19.38	12.50	18.25	13.25	9.50	6.75	10.25	5.25
120	15.75	14.25	20.75	14.50	21.50	15.25	11.25	13.25	12.75	7.00
150	25.50	15.75	32.25	16.25	33.00	17.00	32.50	13.50	15.25	8.25
180	22.75	16.25	28.25	17.25	30.25	17.25	29.25	14.00	14.00	8.25
210	14.00	19.50	17.25	18.00	19.25	19.50	7.50	15.25	6.00	8.25
240	13.25	25.00	16.00	21.75	18.00	22.75	8.00	16.75	4.00	10.50

	I year		II year	
Effect	SE	**CD(0.01)**	SE	**CD(0.01)**
Shade x period	1.074	**3.022**	0.810	**2.279**

Table 12. Effect of shade on root dry weight (g)

Days after Planting	Shade (S)									
	S_0 (open)		S_1 (20 per cent)		S_2 (40 per cent)		S_3 (60 per cent)		S_4 (80 per cent)	
	I	II	I	II	I	II	I	II	I	II
30	0.12	0.12	0.13	0.13	0.24	0.23	0.16	0.16	0.08	0.11
60	0.23	0.25	0.46	0.51	0.65	0.65	0.28	0.27	0.20	0.19
90	0.42	0.46	0.59	0.60	0.65	0.68	0.31	0.31	0.20	0.21
120	0.46	0.46	0.46	0.46	0.75	0.74	0.33	0.32	0.25	0.25
150	0.68	0.64	1.20	1.19	1.12	1.13	0.51	0.82	0.31	0.26
180	0.74	0.71	1.20	1.19	1.08	1.16	0.56	0.87	0.29	0.29
210	1.29	1.26	1.25	1.31	0.95	1.34	0.29	0.32	0.67	0.21
240	1.16	1.50	1.41	1.35	0.98	1.28	0.36	0.39	0.43	0.25

	I year		II year	
Effect	SE	**CD(0.01)**	SE	**CD(0.01)**
Shade x period	0.080	**0.224**	0.051	**0.143**

weight recorded by S_2 (1.28 g) was on par with S_1 (1.35 g). In general, from 120 DAP, the lowest root dry weight was registered by the shade levels S_3 and S_4.

4.1.2.4 Root volume

The content of the Table 13 reveals the effect of shade on root volume during the two seasons.

Not much variations in root volume per plant was observed due to shade over periods during early crop growth stages up to 120 DAP. At 150 DAP, during both the seasons, S_2 registered a maximum value and was on par with S_1. This was followed by S_0 and was on par with S_3. The lowest value was registered by S_4. At 180 DAP, S_3 recorded the maximum value which was on par with S_2 and S_1. The shade level S_4 followed by S_0 registered the lowest volume. The same trend was observed during the second season. At 210 DAP, during both the years S_1 recorded maximum value and was on par with S_0. This was followed by S_2 which was on par with S_3. The lowest value was recorded by S_4. At 240 DAP, S_1 registered maximum root volume of 161.25 cm^3 followed by S_2 (152.50 cm^3) which was on par with S_0 (151.25 cm^3). The shade level S_3 (112.50 cm^3) followed by S_4 (57.50 cm^3) recorded the lowest values. During second season, S_1 registered maximum root volume of 157.50 cm^3 which was on par with S_0 (150 cm^3) followed by S_2 (137.50 cm^3), S_3 (120 cm^3)and S_4(58.75 cm^3).

Table 13. Effect of shade on root volume (cm^3)

Days after planting	Shade (S)									
	S_0 (open)		S_1 (20 per cent)		S_2 (40 per cent)		S_3 (60 per cent)		S_4 (80 per cent)	
	I	II	I	II	I	II	I	II	I	II
30	8.75	8.25	6.75	6.88	8.50	9.25	7.50	6.75	8.75	9.25
60	9.00	10.00	8.50	9.00	12.75	13.50	8.25	7.25	10.25	9.75
90	22.00	23.75	25.00	23.25	26.50	23.50	16.25	16.75	17.00	16.25
120	29.25	30.00	30.50	30.00	29.75	31.25	21.25	20.75	21.25	22.00
150	39.75	38.00	48.75	51.00	49.50	51.00	35.25	35.00	25.25	26.25
180	74.50	75.00	88.75	91.25	95.00	93.75	99.75	98.50	43.50	40.00
210	130.00	130.00	136.00	136.25	112.50	115.00	108.75	108.75	42.00	41.25
240	151.25	150.00	161.25	157.50	152.50	137.50	112.50	120.00	57.50	58.75

	I year		II year	
Effect	SE	CD(0.01)	SE	CD(0.01)
Shade x period	6.536	**18.393**	6.572	**18.497**

Table 14. Effect of shade on rhizome spread (cm)

Days after planting	Shade (S)									
	S_0 (open)		S_1 (20 per cent)		S_2 (40 per cent)		S_3 (60 per cent)		S_4 (80 per cent)	
	I	II	I	II	I	II	I	II	I	II
90	9.75	9.75	13.00	10.75	14.50	14.00	6.75	7.75	7.00	7.00
120	10.75	9.23	12.75	12.75	13.75	15.50	7.50	8.38	8.50	8.25
150	12.75	9.68	23.50	13.25	20.75	16.50	15.50	16.25	15.75	9.00
180	14.00	15.63	24.00	19.00	23.25	17.25	12.00	16.75	10.75	9.75
210	16.25	20.00	25.00	22.25	24.00	22.25	12.50	18.50	12.75	10.50
240	17.00	23.75	25.75	23.75	25.75	24.50	14.75	20.25	14.75	12.75

	I year		II year	
Effect	SE	CD(0.01)	SE	CD(0.01)
Shade x period	1.293	**3.658**	0.817	**2.310**

Table 15. Effect of shade on the rhizome thickness (cm)

Days after planting	Shade (S)									
	S_0 (open)		S_1 (20 per cent)		S_2 (40 per cent)		S_3 (60 per cent)		S_4 (80 per cent)	
	I	II	I	II	I	II	I	II	I	II
90	0.58	0.45	0.85	0.65	0.83	0.85	0.50	0.45	0.28	0.30
120	1.33	0.65	1.68	0.90	1.33	0.90	1.13	0.60	0.95	0.55
150	2.10	1.08	2.40	1.20	2.53	1.18	1.23	0.90	1.24	0.85
180	2.05	1.43	2.03	1.40	1.78	1.35	1.28	1.08	1.45	1.03
210	2.24	1.58	2.03	1.58	2.05	1.55	1.58	1.15	1.50	1.10
240	2.23	1.85	2.15	1.80	2.13	1.73	1.73	1.38	1.70	1.23

	I year		II year	
Effect	SE	**CD(0.01)**	SE	**CD(0.01)**
Shade x period	0.129	**0.364**	0.064	**0.181**

Table 16. Effect of shade on number of finger rhizomes

Days after planting	Shade (S)									
	S_0 (open)		S_1 (20 per cent)		S_2 (40 per cent)		S_3 (60 per cent)		S_4 (80 per cent)	
	I	II	I	II	I	II	I	II	I	II
90	9.25	10.75	15.00	15.00	16.75	14.25	9.00	8.75	5.75	6.25
120	13.75	13.75	17.25	17.25	15.50	16.25	9.50	8.75	6.75	6.75
150	14.75	13.75	32.75	17.75	20.00	16.75	14.25	9.50	13.75	7.00
180	15.25	14.50	23.25	19.00	21.75	17.50	11.50	10.25	9.25	7.00
210	14.25	15.00	24.00	19.75	27.00	18.00	11.50	11.25	7.00	7.25
240	15.25	14.50	27.75	20.25	27.00	19.75	13.00	12.25	7.50	7.00

	I year		II year	
Effect	SE	**CD(0.05)**	SE	**CD(0.05)**
Shade x period	2.168	**6.131**	0.739	**2.092**

4.1.3 Rhizome characters

4.1.3.1 Rhizome spread

The content of Table 14 reveals the effect of shade on rhizome spread during the two seasons.

In general S_1 and S_2 recorded the maximum rhizome spread over different periods. At later stages of growth the lowest rhizome spread was recorded by S_4 followed S_3. At 240 DAP, S_1 recorded significantly higher rhizome spread of 25.75 cm which was on par with S_2 (25.75 cm).The shade level S_0 recorded a rhizome spread of 17 cm which was on par with S_3 (14.75 cm)and S_4 (14.75 cm). During second season, S_2 recorded maximum rhizome spread of 24.50 cm which was on par with S_1 (23.75 cm) and S_0 (23.75 cm). The shade level S_3 recorded a rhizome spread of 20.25 cm followed by S_4 (12.75).

4.1.3.2 Rhizome thickness

The results presented in Table 15 show the effect of shade on rhizome thickness during the two seasons.

Not much variations in rhizome thickness was observed during early growth stages up to 150 DAP. At 180 DAP, maximum rhizome thickness was recorded by S_0 which was on par with S_1 and S_2. The lowest value was recorded by S_4 was on par with S_3. The same trend was observed during all stages of growth during both the seasons. In general, from 180 DAP, the rhizome thickness was significantly higher in S_0, S_1 and S_2. At 240 DAP, S_0 recorded highest rhizome thickness of 2.23 cm which was on par with rhizome thickness at S_1(2.15 cm) and S_2 (2.13 cm). The lowest rhizome thickness was observed under S_4 (1.70 cm) which was on par with rhizome thickness at S_3 (1.73 cm). The same trend was observed during second season.

4.1.3.3 Number of finger rhizomes

The results presented in Table 16 show the effect of shade on number of finger rhizomes during the two seasons.

In general, the shade levels S_1 recorded the maximum finger rhizomes per plant which was on par with S_2 during almost all growth stages. The shade level S_0 ranked third in production of finger rhizomes per plant followed by S_3 and S_4. In all growth stages S_4 registered lowest number of finger rhizomes followed by S_3. At 240 DAP, S_1 recorded significantly higher number of finger rhizomes of 27.75 which was on par with S_2 (27.00). The number of finger rhizomes per plant at S_o (15.25) and S_3 were on par and the lowest value recorded at S_4 (7.50). During second season, number of finger rhizomes per plant at S_1 (20.25) and S_2 (19.75) were on par and significantly superior to all shade levels, which was followed by S_0 (14.50), S_3(12.25) and S_4 (7.00).

4.1.4 Leaf thickness

The effect of shade on leaf thickness during the two seasons are presented in the Table 17.

Among the different shade levels, S_2 recorded the maximum leaf thickness of 209.70 μ m which was on par with S_1 (188.74 μ m) and S_0 (181.76 μ m). The shade level S_4 recorded the lowest leaf thickness of 118.83 μ m which was on par with S_3 (146.74 μ m). Almost the same trend in leaf thickness was observed during the second year.

4.1.5 Stomatal characters

4.1.5.1 Stomatal index

The effect of shade on stomatal index during the two seasons are presented in Table 17.

Among different shade levels, S_1 recorded a maximum stomatal index of 10.55 per cent which was on par with S_0 (10.45 per cent). This was followed by shade levels S_2 (9.45 per cent), S_3 (7.45 per cent) and S_4 (5.88 per cent). Same trend on stomatal index was observed during the second year.

4.1.5.2 Stomatal frequency

Table 17 also reveals the effect of shade on stomatal frequency during the two seasons.

Among the different shade levels, S_0 registered a maximum stomatal frequency of 3.50 which was on par with S_1 (3.25) and S_2 (3.00). The lowest stomatal frequency was observed at shade level S_4 (2.00) which was on par with S_3 (2.50). Same trend in stomatal frequency was observed during the second year.

4.1.6 Physiological aspects

4.1.6.1 Dry matter production

Table 18 shows the effect of shade on dry matter production (DMP) during the two seasons.

During early growth stages, up to 90 DAP there was no significant variation in dry matter production in different shades over periods. At 120

Table 17. Effect of shade on leaf thickness, stomatal index and sotmatal frequency at 180 DAP

Shade levels	Leaf thickness μ m		Stomatal index		Stomatal frequency	
	I	II	I	II	I	II
S_0 (open)	181.76	183.50	10.45	10.83	3.50	3.75
S_1 (20 per cent)	188.74	181.76	10.55	11.45	3.25	3.50
S_2 (40 per cent)	209.70	209.72	9.45	9.20	3.00	3.25
S_3 (60 per cent)	146.74	146.74	7.46	7.08	2.50	2.50
S_4 (80 per cent)	118.83	111.84	5.88	5.85	2.00	2.00
F	6.162**	9.779**	19.052**	41.263**	7.909**	9.107**
SE	14.554	12.143	0.466	0.373	0.214	0.242
CD	**43.861**	**36.596**	**1.404**	**1.123**	**0.645**	**0.728**

** Significant at 1 percent level

Table 18. Effect of shade on the dry matter production (g)

Days after planting	Shade (S)									
	S_0 (open)		S_1 (20 per cent)		S_2 (40 per cent)		S_3 (60 per cent)		S_4 (80 per cent)	
	I	II	I	II	I	II	I	II	I	II
30	2.29	2.18	3.35	2.50	3.66	3.83	2.73	2.83	2.13	2.23
60	2.66	3.25	7.25	4.83	8.99	7.71	5.41	3.88	5.14	2.50
90	8.58	13.43	22.94	20.49	17.90	22.59	14.04	15.96	7.71	14.26
120	13.62	23.50	33.14	47.10	34.47	53.34	23.10	34.07	11.41	24.47
150	25.83	37.53	79.21	76.51	56.08	74.28	47.33	56.71	29.90	35.86
180	39.64	66.90	87.80	101.44	72.25	104.39	54.05	72.94	37.19	43.80
210	78.64	86.48	122.34	131.25	104.76	141.35	61.58	87.28	48.66	53.35
240	98.69	130.83	142.12	152.08	130.87	161.50	63.27	104.63	55.00	62.00

	I year		II year	
Effect	SE	CD(0.01)	SE	CD(0.01)
Shade x period	2.865	**8.064**	4.479	**12.606**

DAP, S_2 recorded maximum value which was on par with S_1. The same trend was observed during second year also. At 150 DAP, maximum DMP recorded by S_1 during both the years but during second year, S_1 was on par with S_2. At 180 DAP, S_1 recorded maximum DMP followed by S_2. But during second year S_2 was on par with S_1. At 210 DAP, same trend was observed as at 180 DAP. At harvest, S_1 recorded maximum DMP of 142.12 g followed by S_2 (130.87 g). But during second year, S_2 (161.50 g) and S_1 (152.08 g) were on par. In later stages of growth, S_4 recorded lowest DMP followed by S_3 and S_0. In general, maximum DMP was observed during the two seasons in S_1 and S_2, followed S_0. The lowest DMP was observed in plants grown under heavy shade (S_4).

4.1.6.2 Crop growth rate

The values presented in the Tables 19 a and 19 b show the effect of shade on CGR during the two seasons.

Between 30 and 60 DAP, S_2 recorded the maximum crop growth rate of 0.2707 g m^{-2} day^{-1} followed by S_1 (0.1944 g m^{-2} day^{-1}) which was on par with S_4 (0.1404 g m^{-2} day^{-1}) and S_3 (0.1381 g m^{-2} day^{-1}) (Table 20 a). During second year also S_2 recorded the maximum CGR of 0.1979 g m^{-2} day^{-1} which was on par with S_1 (0.1260 g m^{-2} day^{-1}).

Between 60 and 90 DAP, S_1 recorded the highest CGR of 0.6371 g m^{-2} day^{-1} followed by S_3 which was on par with S_2 and S_0. No significant difference in CGR was noticed among different shade levels during second year.

Table 19 (a) Effect of shade on crop growth rate (CGR) (g m^{-2} day^{-1})

Shade levels	Between 30 – 60 DAP		Between 60 – 90 DAP		Between 90-120 DAP		Between 120-150	
	I	II	I	II	I	II	I	II
S_0 (open)	0.0165	0.0500	0.3007	0.3882	0.1946	0.4064	0.5234	0.5597
S_1 (20 per cent)	0.1944	0.1260	0.6371	0.5043	0.3356	0.9565	2.2291	1.1565
S_2 (40 per cent)	0.2707	0.1979	0.3294	0.5055	0.6460	1.1614	0.9193	0.8636
S_3 (60 per cent)	0.1381	0.0509	0.3317	0.3671	0.3317	0.7143	0.8941	0.8206
S_4 (80 per cent)	0.1404	0.0121	0.1025	0.4023	0.1210	0.3716	0.7411	0.4282
F	24.4600**	8.2750**	9.3670	2.2404	6.8858	17.8578**	7.0623**	4.5541*
SE	0.0188	0.02583	0.0625	0.0444	0.0766	0.0812	0.2527	0.1329
CD	**0.0566**	**0.0778**	**0.1884**	-	**0.2310**	**0.2446**	**0.7615**	**0.4005**

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

Table 19 (b) Effect of shade on crop growth rate (CGR) (g m^{-2} day^{-1})

Shade levels	Between 150-180 DAP		Between 180-210 DAP		Between 210-240 DAP	
	I	II	I	II	I	II
S_0 (open)	0.4370	1.2972	1.3024	0.5888	0.7460	1.6711
S_1 (20 per cent)	0.1700	0.9680	1.2070	0.9975	0.6759	0.7424
S_2 (40 per cent)	0.3094	1.1786	1.2133	1.1664	0.9247	0.6422
S_3 (60 per cent)	0.1941	0.5803	0.2677	0.5030	0.0567	0.6050
S_4 (80 per cent)	0.1570	0.3019	0.4191	0.3179	0.2304	0.2972
F	1.9141	4.9176	11.7336**	1.4331	3.2989*	2.8723
SE	0.0860	0.1878	0.1448	0.2960	0.2018	0.3062
CD	-	-	**0.4363**	-	**0.6082**	-

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

Between 90 and 120 DAP, S_2 recorded maximum CGR of 0.6460 g m^{-2} day^{-1} followed by S_1 which was on par with S_1, S_3, S_0 and S_4. Almost same trend was observed during the second year also.

Between 120 and 150 DAP, S_1 recorded the highest CGR of 2.2291 g m^{-2} day^{-1} followed by S_2 (0.9193 g m^{-2} day^{-1}) which was on par with all other shade levels. The same trend was observed in the second year also.

Between 150 and 180 DAP, there was no significant difference in CGR during both the seasons (Table 20 b).

Between 180 and 210 DAP, S_0 recorded the highest CGR of 1.3024 g m^{-2} day^{-1} which was on par with S_2 (1.2133 g m^{-2} day^{-1}) and S_1 (1.2070 g m^{-2} day^{-1}) during first year. No significant difference in CGR was noticed among different shade levels during second year.

Between 210 and 240 DAP, the shade level S_2 recorded maximum CGR of 0.9247 g m^{-2} day^{-1} which was on par with S_0 (0.7460 g m^{-2} day^{-1}) and S_1 (0.6759 g m^{-2} day^{-1}). No significant difference in CGR was noticed among different shade levels during second year.

4.1.6.3 Relative growth rate

Tables 20a and 20 b depict the effect of shade on relative growth rate (RGR) during the two seasons.

The relative growth rate did not vary significantly among the different shade levels over periods. Between 30 and 60 DAP, S_2 recorded a maximum RGR of 0.300 g g^{-1}day, this was on par with S_3 S_4 and S_1. The lowest relative growth rate was

Table 20 (a) Effect of shade on relative growth rate (RGR) (g g^{-1} day)

Shade level	Between 30 – 60 DAP		Between 60 - 90 DAP		Between 90-120 DAP		Between 120-150	
	I	II	I	II	I	II	I	II
S_0 (open)	0.0043	0.0135	0.0400	0.0473	0.0153	0.0185	0.0214	0.0157
S_1 (20 per cent)	0.0258	0.0216	0.0383	0.0487	0.0123	0.0276	0.0289	0.0161
S_2 (40 per cent)	0.0300	0.0255	0.0226	0.0358	0.0221	0.0284	0.0159	0.0111
S_3 (60 per cent)	0.0229	0.0102	0.0312	0.0477	0.0172	0.0253	0.0233	0.0169
S_4 (80 per cent)	0.0289	0.0037	0.0140	0.0585	0.0131	0.0182	0.0321	0.0122
F	20.2234**	2.7279	10.4088**	8.4340**	1.4969	4.7166*	4.2626*	1.3764
SE	0.0023	0.0053	0.0034	0.0028	0.0032	0.0023	0.0031	0.0022
CD	**0.0070**	-	**0.0102**	**0.0083**	-	**0.0069**	**0.0093**	-

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

Table 20 (b) Effect of shade on relative growth rate (RGR) (g g^{-1} day)

Shade level	Between 150-180 DAP		Between 180-210 DAP		Between 210-240 DAP	
	I	II	I	II	I	II
S_0 (open)	0.0143	0.0193	0.0228	0.0086	0.0074	0.0138
S_1 (20 per cent)	0.0035	0.0096	0.0111	0.0085	0.0049	0.0047
S_2 (40 per cent)	0.0088	0.0113	0.0124	0.0097	0.0073	0.0048
S_3 (60 per cent)	0.0050	0.0085	0.0043	0.0056	0.0011	0.0065
S_4 (80 per cent)	0.0073	0.0068	0.0089	0.0071	0.0038	0.0049
F	4.1572*	4.1022*	30.2401**	0.3846	1.6852	2.6438
SE	0.0020	0.0024	0.0012	0.0026	0.0020	0.0024
CD	**0.0062**	**0.0072**	**0.0038**	-	-	-

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

recorded by S_0 (0.0043 g g^{-1}day). During the second year, no significant variation was observed among the different shade levels with regard to RGR.

Between 60 and 90 DAP, S_0 registered a maximum RGR of 0.0400 g g^{-1}day. It was on par with S_1 and S_3. But during second year, S_4 recorded highest RGR. This was followed by S_1, which was on par with S_3 and S_0. The S_4 and S_2 recorded the lowest RGR during first and second years respectively.

The different shade levels did not show appreciable difference in RGR between 90 and 120 and 120 and 150 DAP.

Between 150 and 180 DAP, S_0 recorded the highest RGR and it was on par with S_2 (Table 21 b). During second year also S_0 recorded maximum RGR followed by S_2. All other shade levels, which were on par with S_2.

Between 180 and 210 DAP, S_0 recorded the maximum RGR followed by S_2 which was par with all other shade levels (Table 21 b). No significant difference in RGR was observed during second year.

Between 210 and 240 DAP, no significant difference in RGR among different shade levels were observed during both the seasons (Table 21 b).

4.1.6.4 Net assimilation rate

The effect of shade on net assimilation rate (NAR) during the two seasons are presented in the Tables 21 a and 21 b.

Among different shade levels, the period between 30 and 60 DAP, S_4 recorded the highest NAR of 0.1107 g m^{-2} day^{-1} which was on par with S_2, S_1 and S_3 (Table 22 a). But during the second year S_2 with a NAR of 0.1700 g m^{-1} day^{-1} was on par with S_0 and S_1.

Table 21 (a) Effect of shade on net assimilation rate (NAR) (g m^{-2} day^{-1})

Shade levels	Between 30 – 60 DAP		Between 60 - 90 DAP		Between 90-120 DAP		Between 120-150	
	I	II	I	II	I	II	I	II
S_0 (open)	0.0205	0.0988	0.1888	0.6174	0.0896	0.3985	0.1382	0.3587
S_1 (20 per cent)	0.0933	0.0922	0.1963	0.3872	0.1047	0.6226	0.2624	0.5040
S_2 (40 per cent)	0.0933	0.1700	0.0915	0.4089	0.1400	0.7020	0.1134	0.3235
S_3 (60 per cent)	0.0857	0.0542	0.1500	0.3540	0.1427	0.4889	0.2781	0.4297
S_4 (80 per cent)	0.1107	0.0246	0.0632	0.4327	0.0801	0.3428	0.3172	0.2895
F	13.883**	3.806*	10.309**	4.007*	1.179	4.231*	18.058**	2.435
SE	0.0094	0.0281	0.0183	0.0516	0.0264	7.308	0.0213	0.0552
CD	**0.0282**	**0.0847**	**0.0553**	**0.1555**	-	**0.2202**	**0.0641**	-

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

Table 21 (b) Effect of shade on net assimilation rate (NAR) (g m^{-2} day^{-1})

Shade levels	Between 150-180 DAP		Between 180-210 DAP		Between 210-240 DAP	
	I	II	I	II	I	II
S_0 (open)	0.1300	0.4344	0.3821	0.2288	0.1770	0.5016
S_1 (20 per cent)	0.0549	0.3206	0.3085	0.3237	0.1685	0.2341
S_2 (40 per cent)	0.1219	0.3158	0.3463	0.3547	0.2227	0.2018
S_3 (60 per cent)	0.1189	0.2707	0.1402	0.2095	0.0345	0.2705
S_4 (80 per cent)	0.1516	0.2182	0.3279	0.2367	0.1597	0.1925
F	0.799	0.800	4.902**	0.400	1.0700	1.435
SE	0.0405	0.0894	0.0424	0.1016	0.0680	0.1065
CD	-	-	**0.1278**	-	**0.2048**	**0.3209**

** Significant at 1 per cent level

Between 60 and 90 DAP, S_1 recorded highest NAR of 0.1963 g m^{-2} day^{-1} which was on par with S_0 and S_3. Whereas during the second year S_0 (0.6174 g m^{-2} day^{-1}) recorded highest NAR which was followed by S_4 which was on par with all other shade levels.

Between 90 and 120 DAP, the NAR did not vary significantly among the different shade levels. In general, maximum NAR was recorded by shade levels S_1, S_2 and S_3.

Between 120 and 150 DAP, S_4 registered highest NAR of 0.3172 g m^{-2} day^{-1} which was on par with S_3 and S_1 during first year. No significant difference in NAR was noticed among different shade levels during second year.

Between 150 and 180 DAP, no significant difference in CGR was noticed among different shade levels during both the seasons.

Between 180 and 210 DAP, S_0 recorded maximum NAR of 0.3821 g m^{-2} day^{-1} which was on par with S_2, S_4 and S_1 during first year. No significant difference in NAR was noticed among different shade levels during second year.

Between 210 and 240 DAP, no significant difference in NAR was noticed among different shade levels during both the seasons.

4.1.6.5 Leaf area duration

The effect of shade on leaf area duration (LAD) during the two seasons are presented in Tables 22 a and 22 b.

Between 30 and 60 DAP, during first year S_2 recorded the maximum LAD of 57.46 which was followed by S_1 (41.94). During second year S_1 with a LAD of 25.95 was on par with S_2, S_3 and S_4.

Table 22 (a) Effect of shade on leaf area duration (LAD)

Shade levels	Between 30 – 60 DAP		Between 60 - 90 DAP		Between 90-120 DAP		Between 120-150	
	I	II	I	II	I	II	I	II
S_0 (open)	13.87	10.49	31.81	16.99	55.76	25.90	87.99	40.00
S_1 (20 per cent)	41.94	25.95	82.28	41.37	99.06	43.63	178.44	57.86
S_2 (40 per cent)	57.46	23.78	86.91	37.71	121.56	44.83	179.49	67.62
S_3 (60 per cent)	31.53	23.63	57.04	34.65	70.77	39.93	84.05	52.47
S_4 (80 per cent)	26.95	20.70	42.51	27.73	47.09	29.74	59.96	35.96
F	52.301**	7.829**	17.881	10.799**	22.678**	3.419*	14.278**	5.181**
SE	2.265	2.187	5.701	2.928	6.507	4.601	15.003	5.697
CD	**6.827**	**6.591**	**17.201**	**8.826**	**19.609**	**13.866**	**45.215**	**17.169**

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

Table 22 (b) Effect of shade on leaf area duration (LAD)

Shade levels	Between 150-180 DAP		Between 180-210 DAP		Between 210-240 DAP	
	I	II	I	II	I	II
S_0 (open)	106.52	71.27	104.08	87.02	115.23	90.41
S_1 (20 per cent)	182.76	84.39	110.27	99.49	119.79	102.65
S_2 (40 per cent)	154.09	100.39	97.01	110.37	113.45	106.19
S_3 (60 per cent)	71.43	62.15	53.99	66.70	61.41	66.02
S_4 (80 per cent)	52.53	41.82	34.66	42.26	41.87	41.15
F	8.773**	9.124**	31.745**	10.278**	70.876**	10.501**
SE	18.477	7.343	5.965	8.465	4.287	8.456
CD	**55.685**	**22.128**	**17.976**	**25.511**	**12.921**	**25.484**

** Significant at 1 per cent level

Between 60 and 90 DAP, S_2 with a LAD of 86.91 was on par with S_1 (82.28). During second year maximum LAD was recorded by S_1 (41.37) which was on par with S_2 (37.71) and S_3 (34.65).

Between 90 and 120 DAP, S_2 recorded significantly higher LAD of 121.56 which was followed by S_1 (99.06). During second year S_2 with a LAD of 44.83 which was on par with S_1 (43.63) and S_3 (39.93).

Between 120 and 150 DAP, highest LAD was recorded by S_2 (179.49) which was on par with S_1 (178.44). During second year S_2 recorded maximum LAD of 67.62 which was on par with S_1 (57.86) and S3 (52.47).

Between 150 and 180 DAP, S_1 (182.76) recorded maximum LAD which was on par with S_2 (154.09). But during the second year S_2 recorded maximum LAD of 100.390 which was on par with S_1 (84.39) (Table 23 b).

Between 180 and 210 DAP, S_1 recorded the highest LAD of 110.27 which was on par with S_0 (104.08) and S_2 (97.01). During second year, S_2 registered maximum LAD of 110.37 which was on par with S_1 (99.49) and S_0 (87.02). Between 210 and 240 DAP, the same trend was observed as above.

4.1.6.6 Leaf Area Index

Table 23 reveals the effect of shade on leaf area index (LAI) during the two seasons.

Up to 180 DAP, an appreciable difference in LAI was not observed among the treatments over periods. In general, S_1 and S_2 recorded the maximum leaf area index. At 210 DAP, S_1 registered maximum LAI which was on par with S_0 and S_2. The lowest LAI was recorded by S_4 which was on par

Table 23 Effect of shade on leaf area index (LAI)

Days after planting	Shade (S)									
	S_0 (open)		S_1 (20 per cent)		S_2 (40 per cent)		S_3 (60 per cent)		S_4 (80 per cent)	
	I	II	I	II	I	II	I	II	I	II
30	0.38	0.21	0.71	0.31	0.95	0.37	0.48	0.35	0.54	0.46
60	0.54	0.49	2.08	1.42	2.88	1.22	1.62	1.23	1.25	0.92
90	1.58	0.65	3.40	1.33	3.50	1.29	2.18	1.09	1.60	0.93
120	2.14	1.08	3.20	1.58	4.61	1.69	2.54	1.58	1.54	1.06
150	3.73	1.59	8.69	2.28	7.36	2.81	3.07	1.92	2.46	1.34
180	3.37	3.17	3.49	3.34	2.91	3.88	1.70	2.22	1.04	1.45
210	3.57	2.64	3.86	3.29	3.56	3.48	1.90	2.22	1.27	1.37
240	4.12	3.39	4.13	3.55	4.01	3.60	2.19	2.18	1.52	1.37

	I year		II year	
Effect	SE	**CD(0.01)**	SE	**CD(0.01)**
Shade x period	0.374	**1.052**	0.203	**0.571**

Table 24 Effect of shade on specific leaf weight (SLW) (g m^{-2})

Days after planting	Specific leaf weight									
	S_0 (open)		S_1 (20 per cent)		S_2 (40 per cent)		S_3 (60 per cent)		S_4 (80 per cent)	
	I	II	I	II	I	II	I	II	I	II
30	0.0076	0.0119	0.0041	0.0028	0.0044	0.0031	0.0047	0.0034	0.0029	0.0029
60	0.0078	0.0072	0.0052	0.0024	0.0041	0.0030	0.0029	0.0025	0.0037	0.0023
90	0.0070	0.0093	0.0046	0.0062	0.0047	0.0028	0.0029	0.0038	0.0039	0.0027
120	0.0083	0.0094	0.0044	0.0024	0.0041	0.0025	0.0031	0.0042	0.0028	0.0022
150	0.0048	0.0060	0.0045	0.0031	0.0042	0.0033	0.0041	0.0035	0.0030	0.0028
180	0.0042	0.0054	0.0041	0.0040	0.0045	0.0048	0.0036	0.0030	0.0027	0.0034
210	0.0044	0.0031	0.0040	0.0024	0.0044	0.0051	0.0028	0.0020	0.0033	0.0027
240	0.0041	0.0054	0.0042	0.0048	0.0064	0.0045	0.0030	0.0031	0.0035	0.0029

	I year		II year	
Effect	SE	CD	SE	CD
Shade x period	0.00028	0.00078	0.00077	0.00217

with S_3. During second year S_2 recorded maximum LAI which was on par with S_1. The S_1 was followed S_0 which was on par with S_3. The lowest LAI registered was by S_4. At harvest, S_1 registered highest LAI of 4.13 which was on par with S_0 (4.12) and S_2(4.01). The lowest LAI observed in S_4 (2.19) was on par with S_3 (2.19). Second year S_2 recorded highest LAI which was on par with S_1 and S_0. This was followed S_3 and S_4.

4.1.6.7 Specific leaf weight

The effect of shade on specific leaf weight (SCW) during the two seasons are presented in Table 24 .

Up to 150 DAP, maximum specific leaf weight was recorded by S_0. In all other shade levels not much variations was observed. At 180 DAP significantly higher SLW of 0.0045 g m^{-2} was recorded at S_2 which was on par with S_0 (0.0042 g m^{-2}) and S_1(0.0041 g m^{-2}). During the second season, S_0 recorded maximum SLW of 0.0054 g m^2 which was on par with S_2 (0.0048 g m^{-2}), S_1 (0.0040 g m^2) and S_4 (0.0034 g m^{-2}). At 210 DAP, maximum SLW was recorded at S_0 (0.0044 g m^2)which was on par with S_2 (0.0044 g m^{-2}) and S_1 (0.0040 g m^{-2}). During the second season, significantly higher SLW of 0.0051 g m^{-2} recorded at S_2 which was on par with S_0 (0.0031 g m^{-2}). At harvest , significantly higher SLW of 0.0064 g m^2 was recorded at S_2 which was followed by S_1 (0.0042 g m^{-2}), S_0 (0.0041 g m^{-2}) and S_4 (0.0035 g m^{-2}). During the second season, S_0 recorded maximum SLW of 0.0054 g m^{-2} which was on par with S_1 (0.0048 g m^{-2}) and S_2 (0.0045 g m^{-2}). In general , the lowest SLW was recorded under shade level S_3 and S_4.

4.1.6.8 Relative water content

The effect of shade on relative water content during the two seasons are presented in Table 25.

Among different shade levels, S_4 recorded maximum relative water content of 90.01 per cent followed by S_2 (86.94 %). The shade levels S_2 (86.94 per cent) and S_3 (86.66 per cent) were on par, which was followed by S_0 (84.50 per cent) and the lowest value recorded by S_1 (81.76 per cent). During the second year also same trend was noticed but S_1 recorded a lowest value of 82.91 per cent which was on par with S_0 (84.04 per cent).

During all growth stages, S_4 recorded the maximum relative water content which was superior to all other shade levels. The lowest relative water content was recorded by S_1 over different periods. In general, there was not much variations among S_3, S_2 and S_0 with respect to the relative water content.

4.1.6.9 Root : shoot ratio

The effect of shade on root : shoot ratios during the two seasons are presented in Table 26.

Among different shade levels, S_0 recorded the maximum root : shoot ratio during both the seasons. In all other shade levels there was not much variations in root : shoot ratio. But during the second year the maximum root : shoot ratio was recorded by S_0 which was on par with S_3 and S_4.

In general, the root : shoot ratio was consistent over different shade levels with respect to various days after planting. The effect of shade did not

Table 25 Effect of shade on relative water content (%)

Days after planting	Shade (S)									
	S_0 (open)		S_1 (20 per cent)		S_2 (40 per cent)		S_3 (60 per cent)		S_4 (80 per cent)	
	I	II	I	II	I	II	I	II	I	II
120	82.63	81.60	82.03	82.50	85.70	84.55	86.45	84.23	89.09	89.28
150	84.27	83.95	81.82	84.45	87.13	86.56	85.51	86.84	89.83	89.43
180	84.45	83.98	81.47	81.98	87.14	87.00	86.56	88.30	90.58	91.75
210	85.36	85.52	81.59	82.56	87.64	87.55	87.37	87.23	89.53	91.03
240	85.79	85.13	81.91	83.05	87.08	86.23	87.43	87.13	91.01	91.88
Mean	84.50	84.04	81.76	82.91	86.94	86.38	86.66	86.74	90.01	90.67

	I year		II year	
Effect	SE	CD(0.05)	SE	CD(0.05)
Shade	0.347	**1.045**	0.546	**1.645**
Shade x period	0.569	-	0.780	-

Table 26 Effect of shade on root : shoot ratio

Days after planting	Shade (S)									
	S_0 (open)		S_1 (20 per cent)		S_2 (40 per cent)		S_3 (60 per cent)		S_4 (80 per cent)	
	I	II	I	II	I	II	I	II	I	II
30	0.110	0.042	0.058	0.032	0.098	0.024	0.100	0.026	0.077	0.044
60	0.181	0.233	0.079	0.062	0.089	0.134	0.228	0.019	0.054	0.131
90	0.091	0.475	0.071	0.165	0.068	0.141	0.060	0.175	0.050	0.211
120	0.056	0.153	0.036	0.064	0.044	0.060	0.031	0.086	0.044	0.106
150	0.049	0.112	0.035	0.105	0.041	0.099	0.042	0.097	0.024	0.122
180	0.038	0.320	0.033	0.194	0.035	0.154	0.035	0.328	0.021	0.204
210	0.052	0.369	0.031	0.240	0.025	0.177	0.011	0.353	0.009	0.169
240	0.043	0.367	0.033	0.267	0.024	0.203	0.013	0.321	0.007	0.248
Mean	0.077	0.259	0.047	0.141	0.053	0.124	0.065	0.175	0.036	0.154

	I year		II year	
Effect	SE	CD(0.01)	SE	CD(0.01)
Shade	0.008	**0.025**	0.021	**0.064**
Shade x period	0.027	-	0.038	**0.108**

influence the root : shoot ratio in almost all growth stages. However, S_0 recorded the maximum root : shoot ratio in almost all growth stages.

4.1.7 Photosynthetic rate and related parameters of ginger at 180 DAP measured using leaf chamber analyser

4.1.7.1 Photosynthetically active radiation (PAR) on leaf surface

Photosynthetically active radiation (PAR) on leaf surface at 180 DAP varied significantly among different shade levels (Table 27 a).

The shade level S_0 recorded the highest PAR of 880 μ mol m^{-2} s^{-1} on leaf surface which was followed by S_1 (591.5 μ mol m^{-2} s^{-1}) and S_2 (397.75μ mol m^{-2} s^{-1}). No significant difference in PAR on leaf surface was observed between shade levels S_3 and S_4. Almost the same trend was observed during the second year but no significant difference in PAR on leaf surface was observed between S_1 and S_2.

4.1.7.2 Stomatal conductance

The stomatal conductance varied significantly among different shade levels at 180 DAP (Table 27 a).

The shade level S_0 recorded the maximum stomatal conductance of 0.04 μ mol m^{-2} s^{-1} followed by the shade levels S_1 and S_2 with same value of 0.02 μ mol m^{-2} s^{-1}. The lowest stomatal conductance of 0.01μ mol m^{-2} s^{-1} was observed at the shade levels S_3 and S_4.

During the second year, shade level S_0 registered significantly higher stomatal conductance of 0.07 μ mol m^{-2} s^{-1} which was followed by S_1 (0.05 μ

Table 27 (a) Photosynthetic rate and related parameters of ginger at 180 DAP measured using leaf chamber analyser

Shade	P.A.R. on leaf surface μ mol m^{-2} s^{-1}		Stomatal conductance μ mol m^{-2} s^{-1}		Stomatal resistance μ mol m^{-2} s^{-1}		Photosynthetic rate μ mol m^{-2} s^{-1}	
	I	II	I	II	I	II	I	II
S_0 (open)	880.75	1461.25	0.04	0.07	24.12	14.13	7.54	6.32
S_1 (20per cent)	591.5	452.00	0.02	0.05	57.46	21.35	2.51	5.61
S_2 (40per cent)	397.75	322.50	0.02	0.04	71.10	25.46	1.80	3.36
S_3 (60per cent)	76.26	76.50	0.01	0.04	74.57	25.72	1.16	2.45
S_4 (80per cent)	33	45.25	0.01	0.03	155.19	44.94	0.72	1.86
F	403.634**	126.296**	23.659**	15.900**	10.932**	27.596**	139.275**	25.043**
SE	17.724	51.500	0.003	0.004	14.608	2.173	0.234	0.392
CD	**53.415**	**155.207**	**0.009**	**0.013**	**44.023**	**6.548**	**0.706**	**1.180**

** Significant at 1 per cent level

Table 27 (b) Photosynthetic rate and related parameters of ginger at 180 DAP measured using leaf chamber analyser

Shade	Transpiration rate (mol m^{-2} s^{-1})	
	I	II
S_0 (open)	1.43	1.73
S_1 (20 percent)	0.61	1.29
S_2 (40per cent)	0.59	1.10
S_3 (60per cent)	0.50	0.76
S_4 (80per cent)	0.25	0.53
F	35.113**	11.707**
SE	0.075	0.136
CD	**0.227**	**0.410**

** Significant at 1 per cent level

mol m^{-2} s^{-1}), S_2 (0.04 μ mol m^{-2} s^{-1}) and S_3 0.04 μ mol m^{-2} s^{-1}). The lowest stomatal conductance was registered at shade level S_4 (0.03 μ mol m^{-2} s^{-1}) which was on par with S_2 and S_3.

4.1.7.3 Stomatal resistance

The shade levels did not show appreciable variations in stomatal resistance at 180 DAP (Table 27 a).

The shade level S_4 recorded maximum stomatal resistance of 155.19 μ mol m^{-2} s^{-1} and was followed by S_3 (74.57 μ mol m^{-2} s^{-1}) which was on par with S_2 (71.10 μ mol m^{-2} s^{-1}) and S_1 (57.46 μ mol m^{-2} s^{-1}). The lowest stomatal resistance was recorded by S_0 (24.12 μ mol m^{-2} s^{-1}) which was on par with S_1 (57.46 μ mol m^{-2} s^{-1}).

During the second year, S_4 recorded a maximum stomatal resistance of 44.94 μ mol m^{-2} s^{-1}. The shade level S_3 recorded a stomatal resistance of 25.72 μ mol m^{-2} s^{-1} which was on par with S_1 (21.35 μ mol m^{-2} s^{-1}) and S_2 (25.45 μ mol m^{-2} s^{-1}). The lowest stomatal resistance was recorded at the shade level S_0 (14.13 μ mol m^{-2} s^{-1}).

4.1.7.4 Photosynthetic rate

The different shade levels recorded an appreciable variation in photosynthetic rate at 180 DAP (Table 27 a).

The shade level S_0 recorded the maximum photosynthetic rate of 7.54 μ mol m^{-2} s^{-1} . The next highest level of photosynthetic rate was recorded by S_1 (2.51 μ mol m^{-2} s^{-1}) which was on par with S_2 (1.80 μ mol m^{-2} s^{-1}).

The photosynthetic rate at the shade level S_2 (1.80 μ mol m^{-2} s^{-1}) which was on par with S_3 (1.16 μ mol m^{-2} s^{-1}). The lowest photosynthetic rate was registered by S_4 (0.72 μ mol m^{-2} s^{-1}) which was on par with S_3 (1.16 μ mol m^{-2} s^{-1}).

During the second year, the highest photosynthetic rate of 6.32 μ mol m^{-2} s^{-1} was recorded by S_0 which was on par with S_1 (5.61 μ mol m^{-2} s^{-1}). The photosynthetic rate of 3.36 μ mol m^{-2} s^{-1} was recorded by S_2 which was on par with S_3 (2.45 μ mol m^{-2} s^{-1}). The lowest photosynthetic rate was recorded by S_0 (14.13 μ mol m^{-2} s^{-1}).

4.1.7.5 Transpiration rate

Appreciable difference in transpiration rate at 180 DAP was observed (Table 27 b).

Under open condition (S_0) the maximum transpiration rate of 1.43 mol m^{-2} s^{-1} was recorded, which was followed by S_1 (0.61 mol m^{-2} s^{-1}). The transpiration rate at shade levels S_1 (0.61 mol m^{-2} s^{-1}), S_2 (0.59 mol m^{-2} s^{-1}) and S_3 (0.50 mol m^{-2} s^{-1}) were on par and the lowest rate was recorded at S_4 (0.25 mol m^{-2} s^{-1}).

During the second year, S_0 registered maximum transpiration rate of 1.73 mol m^{-2} s^{-1} which was followed by S_1 (1.29 mol m^{-2} s^{-1}). The transpiration rate at shade levels S_1 (1.29 mol m^{-2} s^{-1}) and S_2 (1.10 mol m^{-2} s^{-1}) were on par with and S_2 was also on par with S_3 (0.76 mol m^{-2} s^{-1}). The lowest transpiration rate of 0.03 mol m^{-2} s^{-1} was recorded by S_4 which was on par with S_3 (0.76 mol m^{-2} s^{-1}).

4.1.8 Biochemical aspects

4.1.8.1 Chlorophyll content

The effect of shade on chlorophyll content for both the seasons are presented in the Table 28.

The chlorophyll 'a' content in the plant varied significantly among different shade levels. The highest chlorophyll 'a' content was recorded at S_4 (1.42 mg g^{-1}) which was followed S_3 (0.99 mg g^{-1}), S_2 (0.72 mg g^{-1}), S_0 (0.62 mg g^{-1}) and S_1 (0.54 mg g^{-1}). The same trend in chlorophyll 'a' content was observed during the second year.

The chlorophyll 'b' content in the plant varied significantly among the different shade levels. The highest chlorophyll was recorded at S_4 (1.38 mg g^{-1}) which was followed by S_3 (1.08 mg g^{-1}). The shade level S_2 registered a chlorophyll 'b' content of 0.76 mg g^{-1} which was on par with the chlorophyll 'b' content at S_1 (0.66 mg g^{-1}) and S_0 (0.72 mg g^{-1}). The same trend in chlorophyll 'b' content was observed during the second season.

The total chlorophyll content varied significantly among different shade levels. The highest chlorophyll (total) content was recorded by S_3 (2.06 mg g^{-1}), followed by S_2 (1.48 mg g^{-1}), S_0 (1.35 mg g^{-1}) and S_1 (1.20 mg g^{-1}). The same trend in chlorophyll (total) content was observed during second year.

4.1.8.2 Proline content

The data on effect of treatments on proline content for both the seasons are presented in the Table 28.

Table 28 Effect of shade on chlorophyll content (mg g^{-1}) and proline content (μ g g^{-1}) on fresh weight basis at 180 DAP

Shade level	Chorophyll 'a'		Chorophyll 'b'		Chorophyll (total)		Proline content	
	I	II	I	II	I	II	I	II
S_0 (open)	0.62	0.64	0.72	0.73	1.35	1.37	1.37	1.10
S_1 (20 %)	0.54	0.56	0.66	0.67	1.20	1.22	1.28	1.00
S_2 (40 %)	0.72	0.70	0.76	0.75	1.48	1.48	0.78	0.82
S_3 (60 %)	0.99	0.98	1.08	1.07	2.06	2.04	0.74	0.78
S_4 (80 %)	1.42	1.32	1.38	1.39	2.80	2.71	0.56	0.51
F	378.653*	421.702*	180.588*	736.830*	388.955*	599.925*	18.508*	26.019*
SE	0.018	0.015	0.023	0.011	0.033	0.025	0.083	0.044
CD	**0.055**	**0.046**	**0.068**	**0.034**	**0.101**	**0.075**	**0.249**	**0.133**

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

Table 29 Effect of shade on shoot dry weight (g $plant^{-1}$)

Days after planting	Shoot dry weight									
	S_0 (open)		S_1 (20 per cent)		S_2 (40 per cent)		S_3 (60 per cent)		S_4 (80 per cent)	
	I	II	I	II	I	II	I	II	I	II
30	1.500	1.958	2.450	1.900	5.675	3.425	2.575	2.543	2.550	2.113
60	1.975	2.600	6.150	4.475	10.950	6.860	4.125	3.680	3.975	2.208
90	4.875	3.850	14.450	10.700	13.375	12.520	9.625	7.253	6.425	4.895
120	7.925	12.505	22.250	27.500	21.550	30.750	19.000	18.250	7.750	10.750
150	14.300	18.905	37.625	36.250	41.750	42.000	20.125	20.250	13.750	14.250
180	21.250	22.913	40.500	39.000	45.975	48.750	24.250	25.250	15.225	16.250
210	38.200	28.250	48.750	44.250	48.150	53.750	27.225	27.500	19.750	22.500
240	44.125	36.250	50.250	47.500	50.000	57.250	26.450	32.500	21.700	27.500

	I year		II year	
Effect	SE	**CD(0.01)**	SE	**CD(0.01)**
Shade x period	1.455	**4.094**	2.012	**5.662**

The proline content in the plant varied significantly among different shade levels at 180 DAP. During first year, the shade level S_0 recorded the highest proline content of 1.37 μ g g^{-1} which was on par with S_1 (1.28 μ g g^{-1}). The shade level S_2 registered proline content of 0.78 μ g g^{-1} which was on par with proline content recorded at S_3 (0.74 μ g g^{-1}) and S_4 (0.56 μ g g^{-1}).

During the second year, the shade level S_0 recorded highest proline content 1.10 μ g g^{-1} which was on par with S_1 (1.00 μ g g^{-1}). The shade level S_2 recorded a proline content of 0.82 μ g g^{-1} which was on par with S_3 (0.78 μ g g^{-1}). The lowest proline content of 0.51 μ g g^{-1} was recorded at the shade level S_4.

4.1.9 Yield and yield components

4.1.9.1 Shoot dry weight

The data presented in Table 29 show the effect of shade on shoot dry weight per plant during the two seasons.

Up to 90 DAP, there was not much variations in shoot dry weight due to the different intensities of shade over periods. From 120 DAP, S_1 and S_2 recorded the maximum shoot dry weight per plant in all growth stages. In later stages of growth, S_0 and S_3 were on par and S_4 recorded the lowest shoot dry weight per plant. At 240 DAP, during first season, S_1 recorded significantly higher shoot dry weight of 50.25 g which was on par with the shoot dry weight recorded under S_2 (50.00 g).The shade level S0 recorded a shoot dry weight of 44.125 g which was followed by S_3 (26.45 g) and S_4 (21.70). During second season, S_2 recorded significantly higher shoot dry weight of 57.25 g which was followed by S_1 (47.50 g). The shade level

S_0 recorded a shoot dry weight of 36.25 g which was on par S_3 (32.50 g).The lowest shoot dry weight was recorded under S_4 (27.50 g) which was on par with S_3 (32.50 g).

4.1.9.2 Fresh ginger yield

The figures presented in Table 30 show the effect of shade on fresh ginger per plant during the two seasons.

Among different shade levels, S_1 recorded the maximum fresh ginger yield of 278.13 g followed by S_2 (215.72 g). Negative effect was observed on fresh ginger yield with an increase in shade intensity from S_3 to S_4. However the fresh ginger yield of open and 60 per cent shade level was on par. The same trend was observed in second year. During both the years maximum fresh ginger yield was recorded by 20 per cent shade.

The fresh ginger yield was inconsistent over shades with respect to various days after planting. Up to 120 DAP, effect of shade did not influence the fresh ginger yield but at 150 DAP maximum fresh ginger yield was recorded by S_1. The same result was observed during second year up to 150 DAP. At 180 DAP, S_1 recorded higher yield than any other shade levels in the first year and S_4 performed in the same way as S_0. But during the second year fresh ginger yield was more or less same in both S_1 and S_2 and maximum under these shade levels. In this year least ginger yield was recorded with S_4 while S_3 and S_0 were on par. At 210 DAP, maximum yield was recorded with S_1 followed by S_2 in both the years. The lowest ginger yield was observed with S_4. At full maturity, both S_1 and S_2 recorded more or less the same yield i.e., the fresh ginger yield was not significantly different at S_1

Table 30. Effect of shade on fresh ginger yield (g plant^{-1})

Days after planting	Shade (S)									
	S_0 (open)		S_1 (20 per cent)		S_2 (40 per cent)		S_3 (60 per cent)		S_4 (80 per cent)	
	I	II	I	II	I	II	I	II	I	II
90	29.25	44.59	82.50	50.86	47.25	45.79	49.75	47.91	21.75	47.27
120	32.50	50.88	139.50	106.25	110.29	109.29	74.78	76.75	32.64	69.00
150	75.75	87.25	271.25	203.75	157.50	158.75	151.75	155.00	113.50	107.50
180	115.00	188.75	306.75	297.00	227.00	243.75	173.75	190.00	136.75	122.50
210	253.75	251.25	407.50	391.25	311.00	306.25	229.25	203.75	153.50	137.50
240	**365.00**	**341.25**	**461.25**	**438.75**	**441.25**	**351.25**	**245.00**	**220.00**	**185.75**	**172.50**

	I year		II year	
Effect	SE	CD(0.01)	SE	CD(0.01)
Shade x period	13.367	**37.808**	11.022	**31.175**

Table 31. Effect of shade on dry ginger yield (g plant^{-1})

Days after planting	Shade (S)									
	S_0 (open)		S_1 (20 per cent)		S_2 (40 per cent)		S_3 (60 per cent)		S_4 (80 per cent)	
	I	II	I	II	I	II	I	II	I	II
90	3.53	7.88	13.08	8.04	7.34	8.34	8.17	7.74	3.52	8.34
120	5.04	9.12	19.87	18.08	16.84	20.02	12.33	14.24	5.42	12.40
150	11.28	16.60	43.88	39.09	25.61	30.33	25.05	29.01	16.39	19.89
180	19.15	36.73	49.90	54.96	38.23	48.14	28.66	39.44	23.25	24.25
210	51.50	47.98	79.44	76.50	66.54	63.10	36.08	42.78	30.72	26.35
240	**68.76**	**79.08**	**96.64**	**92.38**	**90.33**	**88.00**	**36.83**	**61.88**	**35.84**	**29.13**

	I year		II year	
Effect	SE	CD(0.01)	SE	CD(0.01)
Shade x period	2.778	**7.857**	2.831	**8.006**

and S_2 during both the years. The shade level S_0 was on par with S_3 during first year but during the second year it was on par with S_2. During both the years S_4 recorded the lowest value. In conclusion the shade levels 20 and 40 per cent produced maximum fresh ginger yield and that of 60 and 80 per cent showed yield reduction. Open condition was found to be better than 60 to 80 per cent shade.

4.1.9.3 Dry ginger

The effect of shade on dry ginger per plant during the two seasons are presented in Table 31.

Among different shade levels S_1 recorded a maximum dry ginger yield of (50.47 g) followed by S_2 (40.82 g). The dry ginger yield of 26.54 g of open (S_0) was on par with the dry ginger yield of S_3 (24.52 g). The shade level S_4 could produce only the lowest quantity of dry ginger (19.18 g). The same trend was observed during the second year.

During 90 and 120 DAP, not much variations in dry ginger yield was observed due shade over periods. At 150 DAP, S_1 registered a maximum dry ginger yield followed by S_2 and was on par with S_3. The same trend was observed during the second year. At 180 DAP, S_1 recorded a maximum dry ginger yield followed by S_2 and S_3. During the second year the same trend was noticed but S_1 and S_2 were on par. At 210 DAP, during both the years S_1 registered a maximum dry ginger yield followed by S_2. The lowest yield was recorded by S_4. At full maturity, S_1 gave 96.64 g dry ginger per plant which was on par with S_2 (90.33g) followed by S_0 (68.76 g). The same trend was observed during the second year also. During both the years, the lowest dry ginger yield was recorded by S_4.

4.1.9.4 Bulking rate

The results presented in Table 32 show the effect of shade on bulking rate during the two seasons.

Between 90 and 120 DAP, during both the seasons, S_2 recorded the maximum bulking ratio rate which was on par with S_1. There was not much variation in other shade levels.

Between 120 and 180 DAP, during both the seasons S_1 registered a maximum bulking rate followed by S_3, which was on par with other shade levels.

In all other growth stages there was not much variations in bulking rate due to the different intensities of shade.

4.1.9.5 Harvest index

The results presented in Table 33 show the effect of shade on harvest index of the plant during the two seasons.

During first year, at 90 DAP, the harvest index of S_3 was 0.582. This was on par with S_1 (0.571). In all other shade levels there was no significant difference. But during the second year, S_0 with a harvest index of 0.586 which was on par with S_4 (0.585). In all other shade levels there was no significant difference with respect to harvest index.

At 120 DAP, during first year, S_1 recorded maximum harvest index of

Table 32 Effect of shade on bulking rate (BR) (g day^{-1})

Shade levels	Between 90 - 120 DAP		Between 120 - 150 DAP		Between 150-180 DAP		Between 180-210		Between 210-240	
	I	II	I	II	I	II	I	II	I	II
S_0 (open)	0.054	0.041	0.208	0.250	0.263	0.671	1.078	0.375	0.575	1.037
S_1 (20 %)	0.227	0.334	0.800	0.700	0.201	0.529	0.985	0.718	0.573	0.529
S_2 (40 %)	0.317	0.389	0.292	0.344	0.420	0.594	0.944	0.499	0.793	0.830
S_3 (60 %)	0.139	0.217	0.424	0.492	0.121	0.348	0.247	0.111	0.025	0.637
S_4 (80 %)	0.063	0.135	0.366	0.250	0.229	0.145	0.249	0.070	0.171	0.093
F	3.825*	6.693**	33.424**	3.405*	1.119	2.308	18.583**	2.989	2.494	5.618**
SE	0.0577	0.0550	0.0395	0.1039	0.1044	0.139	0.0965	0.1567	0.2014	0.1498
CD	**0.1738**	**0.1656**	**0.1191**	**0.3129**	-	-	**0.2907**	-	-	**0.4514**

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

Table 33 Effect of shade on harvest index (HI)

Shade levels	90 DAP		120 DAP		150 DAP		180 DAP		210 DAP		210 DAP	
	I	II	I	II	I	II	I	II	I	II	I	II
S_0 (open)	0.412	0.586	0.370	0.386	0.436	0.441	0.485	0.546	0.655	0.555	0.695	0.605
S_1 (20 %)	0.571	0.392	0.598	0.384	0.559	0.513	0.569	0.541	0.651	0.584	0.681	0.611
S_2 (40 %)	0.412	0.368	0.485	0.372	0.465	0.403	0.532	0.455	0.635	0.463	0.688	0.546
S_3 (60 %)	0.582	0.482	0.529	0.419	0.553	0.517	0.530	0.541	0.583	0.500	0.582	0.591
S_4 (80 %)	0.456	0.585	0.474	0.501	0.548	0.556	0.624	0.555	0.632	0.492	0.650	0.471
F	6.084**	11.279**	16.426**	3.964*	1.953	2.221	2.658	2.088	1.314	2.292	5.752	3.861*
SE	0.0340	0.0307	0.0206	0.0264	0.0409	0.0417	0.0319	0.0284	0.0250	0.0326	0.0193	0.0287
CD	**0.1026**	**0.0926**	**0.0622**	**0.0795**	-	-	-	**0.2084**	-	-	-	**0.0866**

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

0.589 but during the second year S_4 registered maximum harvest index of 0.501. There was not much variations in harvest index among different shade levels during both the periods.

At 150, 180 and 210 DAP, there was no significant difference in harvest index due to shade.

At full maturity, during first year, there was no significant difference in harvest index among different shade levels. But during second year the shade levels S_1, S_0 and S_3 were superior to S_4 but S_2 was on par with S_4.

4.1.10 Quality analysis

4.1.10.1 Volatile oil content

The figures presented in the Table 34 show the effect of shade on volatile oil content during the two seasons.

Among different shade levels, S_4 recorded a maximum volatile oil of 2.78 per cent which was on par with S_3 (2.75 per cent) and S_2 (2.64 per cent). The shade level S_1, with a volatile oil content of 2.35 per cent. The lowest volatile oil content was recorded by S_0 (2.06 per cent). The same trend was observed during the second year.

At 120 DAP, there was variation in volatile oil content was observed due to shade over periods. The shade S_4 recorded the maximum volatile oil content of 2.48 per cent which was on par with S_3 and S_2. This was followed by S_1 and S_0. Same trend was observed during the second year. At 150 DAP, almost same trend was observed as above. At 180, 210 and 240 DAP, not much variation in volatile oil content was observed due to shade. In general S_0 recorded the lowest volatile oil content during different growth stages.

Table 34. Effect of shade on volatile oil content of ginger rhizome (v / w %) on dry weight basis

Days after planting	Shade (S)									
	S_0 (open)		S_1 (20 per cent)		S_2 (40 per cent)		S_3 (60 per cent)		S_4 (80 per cent)	
	I	II	I	II	I	II	I	II	I	II
120	1.45	1.53	1.98	1.98	2.48	2.38	2.48	2.43	2.48	2.50
150	2.40	2.23	2.78	2.73	2.38	3.28	3.53	3.68	3.93	3.70
180	2.20	2.20	2.55	2.33	2.58	2.48	2.98	2.63	2.53	2.50
210	2.03	1.75	2.18	1.93	2.23	2.21	2.25	2.08	2.40	1.93
240	2.23	2.18	2.28	2.33	2.55	2.63	2.53	2.50	2.55	2.38
Mean	2.06	1.98	2.35	2.26	2.64	2.59	2.75	2.66	2.78	2.60

	I year		II year	
Effect	SE	**CD(0.01)**	SE	**CD(0.01)**
Shade	0.092	**0.276**	0.065	**0.195**
Shade x period	0.149	**0.420**	0.112	**0.316**

Table 35. Effect of shade on non-volatile ether extract (NVEE) content of ginger rhizome (%) on dry weight basis

Days after planting	Shade (S)									
	S_0 (open)		S_1 (20 per cent)		S_2 (40 per cent)		S_3 (60 per cent)		S_4 (80 per cent)	
	I	II	I	II	I	II	I	II	I	II
120	5.48	5.48	6.10	6.50	6.88	6.95	3.88	3.88	3.68	3.73
150	6.95	7.15	9.63	9.88	8.63	9.25	6.00	5.98	4.40	4.83
180	6.75	7.05	9.75	10.13	8.58	9.15	6.08	6.03	4.38	5.30
210	6.33	6.00	8.40	8.45	8.10	8.33	5.85	5.63	4.90	4.88
240	6.00	6.13	6.88	7.00	8.75	8.90	6.95	5.78	5.35	5.33
Mean	6.30	6.36	8.15	8.39	8.19	8.52	5.75	5.46	4.54	4.81

	I year		II year	
Effect	SE	**CD(0.01)**	SE	**CD(0.01)**
Shade	0.354	**1.068**	0.422	**1.273**
Shade x period	0.374	**1.057**	0.450	**1.272**

4.1.10.2 Non-volatile ether extract

The data presented in Table 35 show the effect of shade on Non-volatile ether extract (NVEE) content during the two seasons.

Among different shade levels S_2 recorded the maximum NVEE of 8.19 per cent which was on par with S_1 (8.15 per cent). The shade level S_0 with a maximum NVEE content of 6.30 per cent which was on par with S_3 (5.75 per cent). The lowest NVEE was recorded by S_4 (4.54 per cent). The same trend was observed during the second year also.

The NVEE content inconsistently varied over shade with respect to various days after planting. At 120 DAP, S_2 registered a maximum NVEE content which was on par with S_1. The shade level, S_0 was on par with S_1. The lowest NVEE content was recorded from S_4 and was on par with S_3. The same trend was observed during second year. In general at 150, 180 and 210 DAP, S_1 recorded a maximum value which was on par with S_2. This was followed S_0, which was on par with S_3. The lowest NVEE content was recorded from S_4. At full maturity, S_2 registered a maximum NVEE which was followed by S_3 which was on par with S_1 and S_0. The lowest NVEE content was recorded by S_4 and was on par with S_0. During the second year also the same trend was observed but the lowest value of S_4 was on par with S_3 and S_0. In general, the lower shade levels (S_1 and S_2) were found to be favorable for more production of NVEE and oleoresin.

4.1.10.3 Starch content

The Table 36 show the effect of shade on starch content during the two seasons.

Among different shade levels, S_1 recorded the maximum starch content of 33.04 per cent. The starch content under the shade level S_0 (31.74 per cent) was on par with S_2 (31.37 per cent). The lowest starch content was recorded by S_4 (27.36 per cent), which was followed by S_3 (29.30 per cent). The same trend was observed during second season.

During 120, 150 and 180 DAP, not much variation in starch content was observed due to shade over periods. At 210 DAP, S_1 recorded the maximum starch content followed by S_0 and this was on par with S_2, S_3 and S_4. During the second year also same trend was observed. At full maturity, S_1 recorded the maximum starch content and was on par with S_0 and S_2. The lowest starch content was recorded by S_4 followed by S_3. During second year S_0 recorded maximum starch content which was on par with S_1 and S_2. The shade level S_2 was also on par with S_3. The shade level S_4 recorded the lowest fibre content which was on par with S_3. In general, the starch content under S_1 was significantly higher compared to open. Under higher shade levels (S_3 and S_4) the starch content was observed to be low.

4.1.10.4 Crude fibre content

The Table 37 shows the effect of shade on crude fibre content during the two seasons.

Among different shade levels S_0 recorded maximum crude fibre content of 4.12 per cent followed by S_1, S_2, S_3 and S_4 with the values of 3.87, 3.64, 3.33 and 2.96 per cent respectively. During second year also S_0 (4.26 per cent) recorded maximum crude fibre content which was on par with S_1 (3.97

Table 36. Effect of shade on starch content of ginger rhizome (%) on dry weight basis

Days after planting	Shade (S)									
	S_0 (open)		S_1 (20 per cent)		S_2 (40 per cent)		S_3 (60 per cent)		S_4 (80 per cent)	
	I	II	I	II	I	II	I	II	I	II
120	24.19	24.75	24.39	25.13	22.28	22.00	20.75	20.75	19.75	20.50
150	27.65	25.00	28.13	27.75	30.19	29.38	28.00	27.00	24.50	25.00
180	29.63	29.63	30.63	28.75	29.88	28.75	28.63	26.75	27.88	25.88
210	32.25	32.25	36.80	38.80	32.00	31.00	31.50	32.00	30.75	30.25
240	45.00	44.50	45.25	44.00	42.50	41.25	37.63	37.00	33.90	34.00
Mean	31.74	31.23	33.04	32.89	31.37	30.48	29.30	28.70	27.36	27.13

	I year		II year	
Effect	SE	CD(0.05)	SE	CD(0.01)
Shade	0.380	**1.145**	0.519	**1.563**
Shade x period	1.260	**3.564**	1.603	-

Table 37. Effect of shade on crude fibre content of ginger rhizome (%) on dry weight basis

Days after planting	Shade (S)									
	S_0 (open)		S_1 (20 per cent)		S_2 (40 per cent)		S_3 (60 per cent)		S_4 (80 per cent)	
	I	II	I	II	I	II	I	II	I	II
120	1.93	1.90	1.80	1.93	1.55	1.45	1.34	1.25	1.10	1.45
150	2.93	2.80	2.69	2.70	2.39	2.33	2.31	2.35	2.09	2.08
180	4.25	4.30	3.74	3.75	3.69	3.80	3.43	2.90	3.30	3.20
210	5.53	6.00	5.38	5.48	4.96	4.93	4.30	4.08	4.14	3.90
240	6.00	6.30	5.73	6.00	5.60	5.50	5.26	5.13	4.18	3.83
Mean	4.12	4.26	3.87	3.97	3.64	3.60	3.33	3.14	2.96	2.89

	I year		II year	
Effect	SE	CD	SE	CD
Shade	0.076	0.229	0.124	0.373
Shade x period	0.222	0.627	0.291	0.824

per cent). The shade level S_2 registered a crude fibre content of 3.60 per cent was on par with S_1. The lowest crude fibre content was registered by S_4 (2.89 per cent) which was on par with S_3 (3.14 per cent).

During 120, 150 and 180 DAP, there was not much variations in crude fibre content at different shade levels over periods. During 210 and 240 DAP, S_0 recorded the maximum crude fibre content which was on par with S_1 and S_2. The shade levels S_4 recorded the lowest crude fibre content which was on par with S_3. In general crude fibre content was maximum under open situation, which gradually reduced as the intensity of shade level increased.

4.2 EXPERIMENT - II

The results of the experiment on the requirement of NPK for ginger in coconut garden are presented hereunder in different sub-headings.

The various observations are grouped into five, viz., biometric observation, physiological parameters, yield parameters, plant analysis at critical stage of plant growth and analysis of soil nutrient status after experiment. The results obtained are presented in tables 38 to 50.

4.2.1 Growth characters

Various characters of growth at three stages of plant growth, viz., 60, 120 and 180 days after planting were recorded, analysed and the results are presented in tables 38 to 39.

4.2.1.1 Height of the plants

The effect of treatments on the height of plants and number of tillers per plant at various stages of crop growth during first and second year are presented in Tables 38 a and 38 b.

At 60 DAP, application of nitrogen was found to result in a significant increase the plant height significantly at all levels of N. The level n_2 recorded maximum plant height. The phosphorus level p_2 registered maximum plant height. The effect of potassium on plant height was not significant.

N x P, N x K and P x K interactions on plant height was non significant.

During second year the main effect of N, P and K and its interactions on plant height was non significant.

At 120 DAP, application of nitrogen at n_1 and n_2 levels were on par but registered maximum plant height. The influence of phosphorus on plant height was significant. The plant height was found to increase with higher levels of P. Response of potassium was non significant.

N x P, N x K and P x K interactions were found to be significant. Maximum plant height was observed under the combination n_2 p_2. The interaction N x K significantly influenced the plant height at higher doses. The maximum plant height was observed under the combination n_2 k_2 which was on par with n_2 k_1. In the case of P x K interaction not much variations in plant height was observed.

During second year, the levels n_1 and n_2 were on par but produced significantly higher plant height when compared to n_0. The height of the plant was not found to increase with higher levels of P.

N x P interaction on plant height was significant. In the absence of nitrogen, p_1 registered maximum plant height. At all levels of nitrogen and potassium non significant difference in plant height was observed.

Observations on plant height at 180 DAP, revealed that application of nitrogen increased the plant height. The levels n_1 and n_2 were on par and produced significantly more plant height when compared to n_0. The influence of phosphorus on plant height was significant. Plants receiving the highest level of P registered significantly higher plant height. The effect of K was significant but the difference between k_1 and k_2 were not significant.

The interactions N x P, N x K and P x K on plant height was significant. Maximum plant height was observed under the combination n_2 p_2. The interaction N x K, maximum plant height was observed under n_1 k_1. Among the P x K combinations, significantly higher plant height was observed at p_2 k_2 which was on par with p_2 k_1.

During second year, N was found to increase the plant height. The variation in plant height between n_1 and n_2 was not significant.

The interaction P x K was found to be significant and maximum plant height was recorded at p_2 k_0, but was on par with p_2 k_2 .

4.2.1.2 Number of tillers

The effect of treatments on the number of tillers per plant at various stages of crop growth during first and second year are presented in Tables 38 a and 38 b.

Significantly higher number of tillers were recorded by plants under n_2. During 60 DAP, the level of phosphorus and potassium had no significant effect on tillering.

Table 38 (a) Effect of N, P, K and N x P interaction on plant height (cm) and number of tillers

Treat ments	Height of the plant (cm)						Number of tillers					
	60 DAP		120 DAP		180 DAP		60 DAP		120 DAP		180 DAP	
	I	II	I	II	I	II	I	II	I	II	I	II
n_0	29.56	37.78	43.20	51.02	61.24	66.87	3.83	3.73	6.21	6.50	8.75	9.56
n_1	34.05	38.22	50.44	54.18	65.00	71.54	4.17	4.26	8.39	9.49	13.84	15.30
n_2	38.04	38.41	51.54	54.19	65.92	71.08	3.94	3.83	8.99	9.06	14.52	14.57
F	57.35**	0.35	51.11**	8.45**	14.32**	7.02**	7.99**	4.90*	125.89**	52.67**	145.64**	59.48**
p_0	32.16	38.00	44.43	51.84	59.94	68.50	3.91	3.94	7.26	8.13	11.23	12.86
p_1	33.56	37.97	47.66	54.14	64.83	70.17	4.09	4.18	8.15	8.47	12.39	13.09
p_2	35.92	38.44	53.09	53.40	67.40	70.81	3.93	3.69	8.19	8.44	13.49	13.48
F	11.54**	0.24	47.61**	3.50**	33.45**	1.50	2.65	3.77*	16.18**	0.73	18.57**	0.61
k_0	33.81	38.07	46.46	53.22	60.91	69.90	3.90	4.03	7.59	8.38	12.09	13.19
k_1	33.56	38.65	48.73	53.23	65.71	70.11	4.02	4.00	7.99	8.27	11.96	12.91
k_2	34.27	37.69	49.99	52.94	65.55	69.47	4.01	3.79	8.01	8.39	13.05	13.32
F	0.410	0.82	7.94**	0.07	17.36**	0.12	1.27	1.07	3.26*	0.09	5.20**	0.26
SE	0.560	0.539	0.634	0.628	0.655	0.972	0.061	0.126	0.130	0.223	0.261	0.405
CD	**1.587**	-	**1.795**	**1.778**	**1.855**	**2.752**	**0.172**	**0.357**	**0.369**	**0.632**	**0.740**	**1.148**
$n_0 p_0$	29.38	38.44	40.44	48.99	57.20	65.56	3.64	3.69	6.24	6.60	8.44	9.84
$n_0 p_1$	28.78	37.28	42.44	54.15	62.99	67.90	4.21	4.30	6.51	6.67	8.79	9.44
$n_0 p_2$	30.51	37.62	46.71	49.93	63.54	67.13	3.63	3.21	5.88	6.22	9.01	9.39
$n_1 p_0$	31.20	37.45	43.30	52.77	60.26	69.07	4.21	4.28	6.89	9.20	11.31	14.53
$n_1 p_1$	34.48	39.61	51.89	55.22	65.61	72.58	4.06	4.28	9.39	9.80	14.42	16.11
$n_1 p_2$	36.47	37.60	56.13	54.56	69.14	72.97	4.23	4.21	8.90	9.46	15.78	15.24
$n_2 p_0$	35.89	38.10	49.56	53.78	62.37	70.88	3.88	3.86	8.64	8.59	13.94	14.19
$n_2 p_1$	37.43	37.02	48.64	53.06	65.90	70.03	4.01	3.97	8.54	8.95	13.94	13.72
$n_2 p_2$	40.79	40.10	56.41	55.72	69.50	72.32	3.93	3.66	9.78	9.64	15.67	15.81
F	1.73	2.31	5.67**	2.93*	0.80	0.55	4.23**	1.52	14.73**	1.10	6.13**	1. 61
SE	0.971	0.933	1.098	1.087	1.134	1.683	0.105	0.218	0.226	0.386	0.453	0.702
CD	-	-	**3.109**	**3.079**	-	-	**0.298**	-	**0.639**	-	**1.282**	-

** Significant at 1 % level * Significant at 5 % level

Table 38 (b) Effect of N x K and P x K interactions on plant height (cm) and number of tillers

Treat ments	Height of the plant (cm)						Number of tillers					
	60 DAP		120 DAP		180 DAP		60 DAP		120 DAP		180 DAP	
	I	II	I	II	I	II	I	II	I	II	I	II
$n_0 k_0$	29.32	37.95	42.48	50.98	58.38	66.15	3.56	3.59	5.99	6.56	9.12	10.03
$n_0 k_1$	29.36	37.67	42.93	49.94	61.51	66.69	4.03	4.02	6.30	6.36	8.14	9.03
$n_0 k_2$	29.99	37.72	44.19	52.16	63.84	67.76	3.90	3.59	6.34	6.57	8.98	9.61
$n_1 k_0$	33.54	37.52	48.30	53.47	61.49	70.87	4.07	4.43	7.86	9.07	12.83	14.43
$n_1 k_1$	33.73	39.44	50.52	55.58	69.06	72.97	4.33	4.34	8.63	9.95	13.56	15.93
$n_1 k_2$	34.87	37.69	52.50	53.50	64.47	70.78	4.10	3.99	8.69	9.44	15.12	15.52
$n_2 k_0$	38.56	38.72	48.61	55.22	62.86	72.68	4.08	4.06	8.93	9.53	14.31	15.11
$n_2 k_1$	37.60	38.86	52.73	54.17	66.58	70.69	3.70	3.63	9.03	8.51	14.19	13.78
$n_2 k_2$	37.96	37.64	53.27	53.17	68.33	69.87	4.04	3.79	9.00	9.15	15.06	14.83
F	**0.26**	**0.50**	**0.89**	**1.55**	**2.93***	**0.70**	**5.04****	**1.19**	**0.89**	**1.55**	**1.96**	**1.24**
$p_0 k_0$	33.36	38.12	44.60	50.79	58.16	65.75	3.50	3.59	7.29	8.28	11.84	13.68
$p_0 k_1$	30.54	36.88	43.56	51.80	61.52	71.63	4.16	4.18	7.41	8.40	10.62	13.02
$p_0 k_2$	32.57	38.99	45.14	52.94	60.14	68.12	4.08	4.06	7.08	7.71	11.23	11.87
$p_1 k_0$	32.96	37.14	43.79	54.33	59.78	70.77	4.11	4.43	7.74	8.55	11.44	13.16
$p_1 k_1$	34.27	39.56	48.71	55.16	67.39	70.44	4.07	4.01	8.39	8.15	12.62	12.46
$p_1 k_2$	33.47	37.22	50.48	52.93	67.33	69.34	4.10	4.10	8.31	8.72	13.09	13.67
$p_2 k_0$	35.11	38.95	51.00	54.54	64.79	73.18	4.09	4.06	7.74	8.32	12.98	12.74
$p_2 k_1$	35.88	39.53	53.92	52.72	68.23	68.31	3.84	3.81	8.17	8.27	12.64	13.27
$p_2 k_2$	36.78	36.85	54.33	52.94	69.17	70.93	3.87	3.21	8.64	8.74	14.83	14.43
F	1.51	2.47	2.66*	1.41	1.95	2.63*	6.00**	2.99*	1.85	0.92	3.46*	1.86
SE	0.971	0.933	1.098	1.087	1.134	1.683	0.105	0.218	0.226	0.386	0.453	0.702
CD	-	-	**3.109**	**3.079**	**3.213**	**4.767**	**0.298**	**0.618**	-	-	**1.282**	-

** Significant at 1 % level * Significant at 5 % level

The effect of N x P, N x K and P x K interactions on tillering was significant and maximum number of tillers were recorded under n_0 p_1. At all levels of N the effect of P and K in increasing tillering was inconspicuous. The same trend was observed in the P x K interaction.

During second year also n_2 recorded the maximum number of tillers.

The effect of N x P and P x K interactions on tillering was significant but at all levels of N, the effect of P in increasing tiller production was inconspicuous. P x K interaction effect indicated that response of K was inconspicuous.

At 120 DAP, the effect of N on tiller production was significant and the level n_2 registered significantly higher number of tillers. Application of phosphorus was found to increase tillering but no significant difference was observed at p_1 and p_2 levels. Applications of K also increased the tiller production. The levels of k_1 and k_2 were on par but produced significantly higher number of tillers.

N x P, N x K and P x K interactions were found to be significant. The N x P interaction, maximum tillers were recorded under the combination n_2 p_2. The N x K interaction, at all levels of N the effect of K in increasing tillering was inconspicuous. P x K interaction effect indicate that, the response of K significantly increased tillering at the higher level of P.

During second year also the effect of nitrogen on tiller production was significant. The levels n_1 and n_2 were on par but resulted in significantly higher tillering. The interactions were found to be non significant.

At 180 DAP, application of nitrogen was found to be beneficial in tillering but not significantly different at n_1 and n_2 levels of N. Increased rates of phosphorus applications had significant effect on tillering. Application of phosphorus at p_2 level was found to enhance the tillering. Application of K was also found to increase the tillering significantly and maximum number recorded at k_2 level.

N x P, N x K and P x K interactions were found to be significant. The effect of N x P interaction on tillering was significant and maximum tillers were recorded under the combination n_2 p_2. Under N x K interaction, highest tiller production was recorded under the treatment n_1 k_2. P x K interaction was significant and k_2 p_2 recorded maximum number of tillers.

During the second year also application of nitrogen was found have beneficial effect on tillering but n_1 and n_2 levels of nitrogen were on par.

The interaction effect were non-significant during the second year.

4.2.1.3 Number of leaves

The effect of treatments on the number of leaves per plant at various stages of crop growth during first and second year are presented in Tables 39 a and 39 b.

The application of N did not have significant effect on leaf production during first year. Application of phosphorus was found to increase the leaf number, but no significant difference was observed at p_1 and p_2 levels.

The interaction effect were non-significant during the first year.

Table 39 (a) Effect of N, P, K and N x P interaction on number of leaves and leaf area (cm^2)

Treat ments	Number of leaves						Leaf area (cm^2)					
	60 DAP		120 DAP		180 DAP		60 DAP		120 DAP		180 DAP	
	I	II	I	II	I	II	I	II	I	II	I	II
n_0	29.57	29.18	65.72	70.83	109.71	111.97	1474.26	1547.70	3490.37	3512.01	5810.15	6066.57
n_1	31.52	30.05	86.58	97.10	151.75	152.32	1413.85	1509.78	4817.85	4892.40	8031.78	8371.53
n_2	31.11	28.38	96.90	104.59	159.96	153.03	1417.00	1431.40	5178.00	5325.47	8089.78	8065.37
F	2.11	0.77	54.55**	41.04**	75.33**	28.48**	0.65	0.77	51.65**	38.46**	130.85**	20.89**
p_0	28.81	28.68	76.05	85.99	128.78	135.64	1353.18	1416.62	4260.37	4369.53	6765.37	7135.64
p_1	32.33	30.82	83.29	89.15	142.53	137.94	1481.78	1598.91	4445.48	4526.67	7396.63	7544.77
p_2	31.06	28.11	89.86	97.39	150.10	143.74	1470.15	1473.34	4780.37	4833.68	7769.70	7823.06
F	6.35**	2.26	10.32**	4.53*	12.11**	0.90	2.83	1.92	4.54*	2.39	19.96**	1.59
k_0	30.89	30.69	80.77	94.45	138.19	142.24	1465.19	1596.68	4530.48	4755.75	7215.70	7720.91
k_1	30.10	29.03	79.56	85.22	137.99	134.76	1435.00	1474.52	4378.44	4349.18	7171.26	7389.44
k_2	31.21	27.89	88.86	92.85	145.24	140.32	1404.92	1417.68	4577.30	4624.95	7544.74	7393.12
F	0.65	2.20	5.53**	3.18*	1.77	0.78	0.51	1.84	0.71	1.85	3.22*	0.48
SE	0.708	0.951	2.151	2.767	3.106	4.404	42.295	67.404	123.673	152.703	113.624	273.915
CD	**2.005**	-	**6.093**	**7.838**	**8.798**	**12.476**	-	-	**350.326**	**432.558**	**321.860**	**775.909**
$n_0 p_0$	28.41	30.13	64.27	73.44	102.30	115.28	1396.33	1462.86	3682.22	3767.58	5658.44	6223.92
$n_0 p_1$	30.90	28.80	70.14	70.22	118.11	116.53	1520.44	1571.56	3584.44	3605.81	6179.78	6330.53
$n_0 p_2$	29.41	28.60	62.74	68.83	108.71	104.09	1506.00	1608.68	3204.44	3162.66	5592.22	5645.26
$n_1 p_0$	30.86	29.51	77.06	85.73	134.38	144.67	1342.66	1470.30	4308.00	4320.68	7287.78	7956.89
$n_1 p_1$	33.92	34.04	91.91	103.89	160.48	157.34	1547.11	1730.60	5095.56	5266.20	8530.33	8706.22
$n_1 p_2$	29.79	26.60	90.78	101.67	160.39	154.96	1351.78	1328.44	5050.00	5090.31	8277.22	8451.49
$n_2 p_0$	27.17	26.39	86.82	98.78	149.67	146.98	1320.56	1316.71	4790.89	5020.33	7349.89	7226.11
$n_2 p_1$	32.18	29.62	87.82	93.33	149.00	139.93	1377.78	1494.58	4656.44	4708.00	7479.78	7597.56
$n_2 p_2$	33.99	29.12	116.06	121.67	181.20	172.18	1552.67	1482.91	6086.67	6248.07	9439.67	937244
F	3.03*	2.14	7.78**	4.91**	4.80**	2.81*	1.62	1.14	7.35**	6.05**	14.62**	2.75*
SE	1.226	1.648	3.725	4.793	5.379	7.629	73.258	116.747	214.208	264.49	196.803	474.434
CD	**3.472**	-	**10.553**	**13.576**	**15.238**	**21.609**	-	-	**606.782**	**749.213**	**557.478**	**1343.914**

** Significant at 1 % level * Significant at 5 % level

Table 39 (b) Effect of N x K and P x K interactions on number of leaves and leaf area (cm^2)

Treatments	Number of leaves						Leaf area (cm^2)					
	60 DAP		120 DAP		180 DAP		60 DAP		120 DAP		180 DAP	
	I	II	I	II	I	II	I	II	I	II	I	II
$n_0 k_0$	28.56	28.81	65.58	78.83	112.29	122.29	1478.56	1627.03	3850.00	3998.41	6155.66	6656.29
$n_0 k_1$	29.80	28.02	64.21	67.00	107.87	107.91	1414.56	1441.29	3488.89	3489.29	5638.22	5846.28
$n_0 k_2$	30.37	30.70	67.37	66.67	108.97	105.70	1529.67	1574.77	3132.22	3048.34	5636.67	5700.14
$n_1 k_0$	33.13	33.49	83.47	96.19	143.93	146.36	1485.44	1675.15	4554.78	4715.67	7461.11	7936.67
$n_1 k_1$	31.31	31.52	85.76	93.99	151.87	152.57	1502.11	1587.79	4892.22	4779.86	8267.00	8485.04
$n_1 k_2$	31.12	25.14	90.52	101.11	159.44	158.04	1253.99	1266.40	5006.56	5181.67	8367.22	8692.89
$n_2 k_0$	30.98	29.78	93.28	108.33	158.33	158.07	1431.56	1487.85	5186.67	5553.18	8030.44	8569.78
$n_2 k_1$	29.20	27.53	88.72	94.67	154.22	143.80	1388.33	1394.47	4754.22	4778.39	7608.56	7840.00
$n_2 k_2$	33.16	27.82	108.70	110.78	167.31	157.22	1431.11	1411.88	5593.11	5644.83	8630.33	7786.33
F	**2.03**	**3.03***	**1.74**	**1.39**	**1.02**	**1.15**	**1.91**	**1.21**	**3.57***	**2.77***	**6.13****	**1.11**
$p_0 k_0$	27.83	28.34	80.69	95.63	140.01	148.51	1402.11	1457.78	4567.00	4849.81	6971.56	8048.92
$p_0 k_1$	29.40	31.10	73.04	85.66	130.47	141.29	1422.89	1490.72	4226.44	4348.44	7009.00	7627.72
$p_0 k_2$	29.20	26.59	74.41	76.67	115.87	117.12	1234.54	1301.36	3987.67	3910.33	6315.56	5730.28
$p_1 k_0$	32.64	34.70	73.88	88.00	128.32	132.38	1529.11	1808.37	4320.00	4444.13	6733.33	7184.22
$p_1 k_1$	32.18	28.73	85.71	84.17	143.04	132.32	1423.56	1454.11	4434.44	4319.68	7426.56	7397.00
$p_1 k_2$	32.18	29.03	90.29	95.28	156.22	149.11	1492.67	1534.26	4582.00	4816.20	8030.00	8053.09
$p_2 k_0$	32.19	29.03	87.76	99.72	146.22	145.82	1464.33	1523.89	4704.44	4973.31	7942.22	7929.59
$p_2 k_1$	28.73	27.24	79.93	85.83	140.44	130.67	1458.56	1478.72	4774.44	4379.41	7078.22	7143.60
$p_2 k_2$	32.27	28.04	101.89	106.61	163.63	154.73	1487.56	1417.42	5162.22	5148.31	8288.67	8396.00
F	1.30	2.08	4.88**	3.50*	7.55**	4.01**	1.03	0.83	2.09	2.29	10.80**	4.49**
SE	1.226	1.648	3.725	4.793	5.379	7.629	-	-	214.208	264.49	196.803	474.434
CD	-	**4.668**	**10.553**	**13.576**	**15.238**	**21.609**	-	-	**606.782**	**749.213**	**557.478**	**1343.914**

** Significant at 1 % level * Significant at 5 % level

During second year, the effect of N, P and K on production of leaves were absent.

N x K interaction was found to be significant but in all levels of N the response of K was not visible.

At 120 DAP, application of N, P and K found to be beneficial in leaf production. Application of N at n_2, P at p_2 and K at k_2 levels recorded highest leaf number.

N x P, N x K and P x K interactions were found to be significant. The effect of N x P interaction was significant and highest number of leaves was recorded by n_2 p_2. N x K interaction, maximum number of leaves was found under n_2 p_2. Among the P x K combinations, significantly higher leaf number was observed in p_2 k_2.

During second year, applications of N was found to be beneficial in leaf production, but not significantly different at n_1 and n_2 levels of N. Application of P at p_2 level was found to enhance the yield. Not much variations in leaf production was observed due to different levels of K.

N x P and P x K interactions were found to be significant. N x P interactions, maximum number of leaves was found under n_2 p_2. P x K interaction, maximum number leaf was found under p_2 k_2 which was on par with p_2 k_0.

4.2.1.4 Leaf area

The effect of treatments on the leaf area at various stages of crop growth during first and second year are presented in Tables 39 a and 39 b.

The main effect of N, P and K and its interaction effect were absent during both the years.

Application of highest level of nitrogen (n_2) helped to increase the leaf area. The effect of phosphorus on leaf area per plant was significant. The variation in leaf area per plant between p_1 and p_2 was not significant.

N x P and N x K interactions were found to be significant. N x P interaction, significantly higher leaf area was observed in n_2 p_2. N x K interaction at all levels of N, the response of K was not visible. However, n_2 k_2 recorded maximum leaf area which was on par with n_2 k_0.

During second year also application of nitrogen was found to be beneficial in increasing leaf area and maximum leaf area was recorded by n_2.

NP x NK interaction were found to be significant and similar to first year result.

At 180 DAP, application of nitrogen was found to increase the leaf area per plant but no significant difference was observed in n_1 and n_2 levels of nitrogen. Significantly higher leaf area per plant was registered in p_2. The treatment k_2 produced significantly higher leaf area when compared to k_0 and k_1.

N x P, N x K and P x K interactions were found to be significant. N x P interaction, significantly higher leaf area was observed in n_2 p_2. In the case of N x K interaction, n_2 k_2 found to better leaf area. The effect of P x K interaction on leaf area was significant and highest leaf area was seen in p_2 k_2 which was on par with p_2 k_0.

During second year, application of nitrogen was found to be beneficial in increasing leaf area per plant, but no significant difference were observed between n_1 and n_2 levels of nitrogen.

N x P and P x K interactions were found to be significant. In N x P interaction, maximum leaf area was registered by n_2 p_2. In case of P x K interaction, the effect of P on different levels of K was non-significant.

4.2.2 Physiological aspects

4.2.2.1 Leaf area index

The effect of treatments on the leaf area index (LAI) at various stages of crop growth during first and second year are presented in Tables 40 a and 40 b.

The mean effect of N, P, K and their interaction effects were insignificant during both the seasons on LAI.

At 120 DAP, application of highest level of nitrogen (n_2) helped to increase the leaf area index. The effect of phosphorus on leaf area index was significant. The variation in leaf area index between p_1 and p_2 was not significant.

N x P and N x K interactions were found to be significant. A marked increase in LAI was observed at the combination n_2 p_2. N x K interaction, at all levels of N, the response of K was non-significant. However, n_2 k_2 recorded maximum leaf area index which was on par with n_2 k_0.

During second year also application of nitrogen was found to be beneficial in increasing leaf area index and maximum leaf area index was recorded by n_2.

NP x NK interaction were found to be significant and was similar to the first year's result.

Table 40 (a) Effect of N, P, K and N x P interaction on leaf area index (LAI) and specific leaf weight (SLW) ($g\ cm^{-2}$)

Treatments	Leaf area index						Specific leaf weight					
	60 DAP		120 DAP		180 DAP		60 DAP		120 DAP		180 DAP	
	I	II	I	II	I	II	I	II	I	II	I	II
n_0	2.36	2.48	5.58	5.62	9.30	9.71	0.0030	0.0022	0.0041	0.0027	0.0045	0.0029
n_1	2.26	2.42	7.71	7.83	12.85	13.39	0.0038	0.0029	0.0033	0.0028	0.0047	0.0033
n_2	2.27	2.29	8.28	8.52	12.94	13.31	0.0038	0.0033	0.0036	0.0031	0.0073	0.0039
F	0.65	0.77	51.65**	38.46**	130.85**	32.94**	10.55**	6.48**	8.80**	2.22	99.50**	8.47**
p_0	2.17	2.27	6.82	6.99	10.82	11.83	0.0038	0.0029	0.0035	0.0026	0.0053	0.0029
p_1	2.37	2.56	7.11	7.24	11.83	12.07	0.0033	0.0026	0.0037	0.0030	0.0055	0.0037
p_2	2.35	2.36	7.65	7.73	12.43	12.52	0.0035	0.0029	0.0038	0.0030	0.0056	0.0036
F	2.83	1.92	4.54*	2.39	19.96**	0.91	2.80	0.45	1.00	3.03	0.77	6.80**
k_0	2.34	2.55	7.25	7.61	11.55	12.35	0.0034	0.0024	0.0035	0.0026	0.0051	0.0032
k_1	2.30	2.36	7.01	6.96	11.47	11.82	0.0033	0.0025	0.0037	0.0031	0.0057	0.0035
k_2	2.25	2.27	7.32	7.40	12.07	12.24	0.0040	0.0034	0.0038	0.0030	0.0057	0.0034
F	0.51	1.84	0.71	1.85	3.22*	0.58	6.75**	6.06**	1.49	3.63*	4.33*	1.21
SE	0.068	0.107	0.20	0.24	0.18	0.37	0.00014	0.00021	0.00014	0.00013	0.00016	0.00017
CD	-	-	**0.56**	**0.69**	**0.51**	**1.04**	**0.00040**	**0.00061**	**0.0004**	**0.00038**	**0.00044**	**0.00048**
$n_0 p_0$	2.23	2.34	5.89	6.03	9.05	9.96	0.0030	0.0021	0.0035	0.0022	0.0041	0.0024
$n_0 p_1$	2.43	2.51	5.74	5.77	9.89	10.13	0.0031	0.0021	0.0041	0.0028	0.0044	0.0029
$n_0 p_2$	2.41	2.57	5.13	5.06	8.95	9.03	0.0030	0.0024	0.0048	.00032	0.0049	0.0034
$n_1 p_0$	2.15	2.35	6.89	6.91	11.66	12.73	0.0045	0.0032	0.0033	0.0027	0.0044	0.0026
$n_1 p_1$	2.48	2.77	8.15	8.43	13.65	13.93	0.0035	0.0024	0.0031	0.0028	0.0047	0.0037
$n_1 p_2$	2.16	2.13	8.08	8.14	13.24	13.52	0.0035	0.0032	0.0036	0.0030	0.0049	0.0037
$n_2 p_0$	2.11	2.11	7.67	8.03	11.76	12.79	0.0039	0.0033	0.0038	0.0029	0.0075	0.0037
$n_2 p_1$	2.20	2.39	7.45	7.53	11.97	12.16	0.0034	0.0034	0.0039	0.0036	0.0074	0.0045
$n_2 p_2$	2.48	2.37	9.74	10.00	15.10	15.00	0.0040	0.0031	0.0030	0.0029	0.0069	0.0035
F	1.62	1.14	7.35**	6.05**	14.62**	3.19*	2.21	0.73	5.20**	2.17	1.98	2.50
SE	0.117	0.186	0.34	0.42	0.31	0.64	0.00024	0.00037	0.00024	0.00023	0.00027	0.0003
CD	-	-	**0.97**	**1.20**	**0.89**	**1.80**	-	-	**0.00069**	-	-	-

**** Significant at 1 % level** *** Significant at 5 % level**

Table 40 (b) Effect of N x K and P x K interactions on leaf area index (LAI) and specific leaf weight (SLW) (g cm^{-2})

Treat ments	Leaf area index						Specific leaf weight					
	60 DAP		120 DAP		180 DAP		60 DAP		120 DAP		180 DAP	
	I	II	I	II	I	II	I	II	I	II	I	II
$n_0 k_0$	2.37	2.60	6.16	6.40	9.85	10.65	0.0032	0.0021	0.0034	0.0022	0.0040	0.0024
$n_0 k_1$	2.26	2.31	5.58	5.58	9.02	9.35	0.0029	0.0022	0.0043	0.0029	0.0048	0.0032
$n_0 k_2$	2.45	2.52	5.01	4.88	9.02	9.12	0.0030	0.0023	0.0048	0.0032	0.0047	0.0031
$n_1 k_0$	2.38	2.68	7.29	7.55	11.94	12.70	0.0033	0.0023	0.0035	0.0026	0.0047	0.0035
$n_1 k_1$	2.40	2.54	7.83	7.65	13.23	13.58	0.0033	0.0025	0.0032	0.0031	0.0047	0.0034
$n_1 k_2$	2.01	2.03	8.01	8.29	13.39	13.91	0.0049	0.0040	0.0033	0.0028	0.0045	0.0031
$n_2 k_0$	2.29	2.38	8.30	8.89	12.85	13.71	0.0037	0.0030	0.0036	0.0030	0.0065	0.0036
$n_2 k_1$	2.22	2.23	7.61	7.65	12.17	12.54	0.0037	0.0029	0.0037	0.0032	0.0075	0.0040
$n_2 k_2$	2.29	2.26	8.95	9.03	13.81	13.68	0.0040	0.0040	0.0034	0.0032	0.0078	0.0040
F	**1.91**	**1.21**	**3.57***	**2.77***	**6.13****	**1.59**	**4.35****	**1.40**	**3.89****	**1.40**	**1.93**	**1.28**
$p_0 k_0$	2.24	2.33	7.31	7.76	11.15	12.88	0.0035	0.0025	0.0032	0.0024	0.0045	0.0024
$p_0 k_1$	2.28	2.39	6.76	6.96	11.21	12.20	0.0032	0.0024	0.0034	0.0026	0.0052	0.0027
$p_0 k_2$	1.98	2.08	6.38	6.26	10.10	10.39	0.0047	0.0038	0.0039	0.0029	0.0063	0.0035
$p_1 k_0$	2.45	2.89	6.91	7.11	10.77	11.49	0.0031	0.0025	0.0037	0.0028	0.0057	0.0038
$p_1 k_1$	2.28	2.33	7.10	6.91	11.88	11.84	0.0033	0.0024	0.0037	0.0032	0.0057	0.0040
$p_1 k_2$	2.39	2.45	7.33	7.71	12.85	12.88	0.0036	0.0030	0.0037	0.0031	0.0051	0.0033
$p_2 k_0$	2.34	2.44	7.53	7.96	12.71	12.69	0.0035	0.0024	0.0035	0.0026	0.0051	0.0033
$p_2 k_1$	2.33	2.37	7.16	7.01	11.33	11.43	0.0035	0.0029	0.0041	0.0034	0.0060	0.0039
$p_2 k_2$	2.38	2.27	8.26	8.24	13.26	13.43	0.0036	0.0034	0.0038	0.0031	0.0056	0.0034
F	1.03	0.83	2.09	2.29	10.80**	3.67*	2.60*	0.67	1.04	0.71	5.76**	2.62*
SE	0.117	0.186	0.34	0.42	0.31	0.64	0.00024	0.00037	0.00024	0.00023	0.00027	0.00030
CD	-	-	**0.97**	**1.20**	**0.89**	**1.80**	**0.00068**	-	**0.00069**	-	**0.00077**	**0.00084**

** Significant at 1 % level * Significant at 5 % level

At 180 DAP, application of nitrogen was found to increase the leaf area index per plant but non-significant differences were observed between n_1 and n_2 levels of nitrogen. Significantly higher leaf area index per plant was registered in p_2. The treatment k_2 produced significantly higher leaf area index when compared to k_0 and k_1.

N x P, N x K and P x K interactions were found to be significant. Under N x P interaction, significantly higher leaf area index was observed at n_2 p_2. In the case of N x K interaction, n_2 k_2 had better leaf area. The effect of P x K interaction on leaf area index was significant and highest leaf area index was seen in p_2 k_2 which was on par with p_2 k_0.

During second year, application of nitrogen was found to be beneficial in increasing leaf area index per plant, but no significant differences were observed between at n_1 and n_2 levels of nitrogen.

N x P and P x K interactions were found to be significant. In N x P interaction, maximum leaf area index was registered by n_2 p_2. In case of P x K interaction, the effect of P on different levels of K was non-significant.

4.2.2.2 Specific leaf weight

The data on effect of treatments on specific leaf weight (SLW) for both the years are presented in the Tables 40 a and 40 b.

At 60 DAP, application of nitrogen significantly increased the SLW during both the years. SLW was on par at nitrogen levels n_1 and n_2, but was significantly superior to n_0. The effect of potassium on SLW was significant with higher SLW at k_2 level. The interaction P x K was significant during the first year. At p_0 , k_2 recorded the maximum SLW.

At 120 DAP, significantly higher SLW was recorded at n_0 level during first year. In the second year, the effect of potassium on SLW was significant. The treatments k_1 and k_2 were on par but significantly superior to k_0. The interaction N x P and N x K on SLW was significant only during the first year. In the case of N x P interaction maximum SLW was recorded at n_0 p_2. Under N x K interaction, the effect of K on SLW was significant only at n_0.

The effect of nitrogen was significant at 180 DAP during both the years. Significantly higher SLW was recorded at n_2 level. In the first year, the effect of potassium on SLW was significant and k_1 and k_2 levels of K recorded higher SLW. The effect of phosphorus on SLW was significant during second year. Maximum SLW was recorded by p_1 which was on par with p_2 level. The interaction P x K was significant during both the years. Maximum SLW was observed under the combination p_0 k_2. At p_0, the effect of K on SLW was significant.

4.2.2.3 Dry matter production

The effect of treatments on the dry matter production at various stages of crop growth during first and second years are presented in Tables 41 a and 41 b.

At 60 DAP application of nitrogen was found to be beneficial in enhancing dry matter production but no significant differences were observed between at n_1 and n_2 levels of N. The treatment k_2 produced significantly higher DMP when compared to k_0 and k_1.

N x P interaction was found to be significant. Maximum DMP was recorded at n_2 p_2.

During second year also application of nitrogen and potassium were found to be beneficial effect in DMP. The levels n_1 and n_2 were on par but resulted in significantly higher DMP per plant.

At 210 DAP, with increase in levels of nitrogen there was significant increase in dry matter production. Highest DMP was observed under the highest level of nitrogen. The influence of phosphorus on DMP was significant and the plant receiving the highest level of P registered significantly higher DMP. In the case of potassium, the effect was significant. Higher levels of potassium registered higher levels of DMP.

N x P interaction on DMP was significant and maximum DMP per plant was observed under the combination n_2 p_2.

During the second year, with an increase in levels of nitrogen there was significant increase in DMP. The plants receiving the highest level of P registered significantly higher DMP but the difference between p_1 and p_2 were not significant. In the case of potassium, the effect was significant. However, the difference between k_0 and k_2 were not significant.

At 180 DAP, with an increase in levels of nitrogen there was significant increase in DMP. Maximum DMP per plant was found under the highest level of nitrogen. Plants receiving the highest level of P registered significantly higher DMP per plant. In the case of potassium, the effect was significant but the difference between k_1 and k_2 was not significant.

The interaction P x K on DMP was significant. Maximum DMP was observed under the combination p_2 k_2.

Table 41 (a) Effect of N, P, K and N x P interaction on dry matter production (DMP) (g) and net assimilation rate (g m^{-2} day^{-1}) of ginger

Treat ments	Dry matter production						Net assimilation rate			
	60 DAP		120 DAP		180 DAP		Between 60 DAP and 120 DAP		Between 120 DAP and 180 DAP	
	I	II	I	II	I	II	I	II	I	II
n_0	5.82	5.89	16.44	15.72	32.89	31.46	0.05	0.04	0.04	0.04
n_1	7.00	7.09	19.59	20.65	53.47	53.87	0.04	0.04	0.05	0.05
n_2	6.90	6.84	23.42	23.41	81.92	80.15	0.05	0.05	0.09	0.09
F	12.51**	3.34*	66.24 **	24.51**	341.61**	232.28**	7.93**	4.16*	151.82**	54.51**
p_0	6.40	6.78	17.93	18.63	52.11	51.29	0.04	0.04	0.06	0.06
p_1	6.43	6.26	19.40	19.55	54.61	54.42	0.05	0.05	0.06	0.06
p_2	6.90	6.79	22.13	21.60	61.56	59.77	0.05	0.05	0.06	0.06
F	2.29	0.78	24.63**	3.75*	13.50**	7.19**	4.42*	1.39	0.09	0.60
k_0	6.40	6.29	19.23	19.38	51.93	52.17	0.04	0.04	0.06	0.05
k_1	6.23	6.04	19.36	18.86	57.34	55.87	0.05	0.05	.007	0.07
k_2	7.09	7.49	20.87	21.54	59.01	57.44	0.05	0.05	0.06	0.06
F	5.95**	5.08**	4.48*	3.27*	7.74**	2.87	1.11	1.01	5.13**	2.14
SE	0.185	0.345	0.430	0.787	1.332	1.599	0.002	0.0026	0.0024	0.0037
CD	**0.525**	**0.978**	**1.217**	**2.228**	**3.773**	**4.530**	**0.01**	**0.01**	**0.01**	**0.01**
$n_0 p_0$	5.48	6.03	15.24	15.78	30.52	28.86	0.04	0.04	0.03	0.03
$n_0 p_1$	5.84	5.72	16.84	15.49	31.64	29.66	0.05	0.04	0.03	0.03
$n_0 p_2$	6.13	5.93	17.23	15.90	36.51	36.03	0.05	0.05	0.05	0.05
$n_1 p_0$	7.10	7.78	16.58	17.57	47.86	50.14	0.04	0.04	0.06	0.05
$n_1 p_1$	7.24	6.73	19.16	21.54	52.71	52.67	0.04	0.05	0.05	0.05
$n_1 p_2$	6.67	6.77	23.04	22.84	59.84	58.80	0.06	0.05	0.06	0.06
$n_2 p_0$	6.61	6.53	21.96	22.53	77.97	75.03	0.05	0.05	0.10	0.09
$n_2 p_1$	6.19	6.32	22.12	21.63	79.47	80.93	0.6	0.05	0.10	0.11
$n_2 p_2$	7.89	7.65	26.11	26.07	88.32	84.48	0.05	0.05	0.08	0.08
F	3.62*	0.86	3.15*	1.65	0.56	0.21	3.56*	1.41	5.05**	4.17**
SE	0.321	0.598	0.744	1.363	2.307	2.769	0.0047	0.0047	0.0041	0.02
CD	**0.909**	-	**2.108**	-	-	-	**0.01**	-	**0.01**	**0.01**

** Significant at 1 % level * Significant at 5 % level

Table 41 (b) Effect of N x K and P x K interactions on dry matter production (DMP) (g) and net assimilation rate (g m^{-2} day^{-1})

Treatments	Dry matter production						Net assimilation rate			
	60 DAP		120 DAP		180 DAP		Between 60 DAP and 120 DAP		Between 120 DAP and 180 DAP	
	I	II	I	II	I	II	I	II	I	II
$n_0 k_0$	6.26	5.78	15.67	14.94	30.04	29.13	0.04	0.03	0.03	0.03
$n_0 k_1$	5.31	5.42	16.79	16.28	34.26	32.50	0.05	0.05	0.04	0.04
$n_0 k_2$	5.89	6.48	16.87	15.94	34.38	32.74	0.05	0.04	0.04	0.04
$n_1 k_0$	6.36	6.60	18.72	19.77	50.68	52.46	0.04	0.04	0.05	0.05
$n_1 k_1$	6.80	6.37	19.07	19.18	55.42	54.27	0.04	0.04	0.06	0.06
$n_1 k_2$	7.86	8.31	20.99	23.00	54.31	54.87	0.04	0.05	0.05	0.05
$n_2 k_0$	6.60	6.51	23.29	23.44	75.06	74.90	0.05	0.05	0.08	0.08
$n_2 k_1$	6.58	6.31	22.23	21.11	82.36	80.83	0.05	0.05	0.10	0.10
$n_2 k_2$	7.51	7.69	24.74	25.68	88.34	84.72	0.05	0.05	0.10	0.09
F	**2.38**	**0.22**	**0.95**	**1.04**	**1.44**	**0.53**	**1.66**	**0.65**	**1.45**	**0.77**
$p_0 k_0$	6.48	6.71	17.97	18.57	46.79	50.18	0.04	0.04	0.05	0.05
$p_0 k_1$	5.67	5.61	17.27	17.06	55.84	52.45	0.04	0.04	0.07	0.06
$p_0 k_2$	7.04	8.03	18.54	20.25	53.71	51.22	0.05	0.05	0.07	0.06
$p_1 k_0$	6.20	6.06	19.04	19.53	52.57	50.72	0.05	0.05	0.06	0.06
$p_1 k_1$	6.22	5.72	19.19	18.25	56.80	57.84	0.05	0.05	0.07	0.07
$p_1 k_2$	6.86	6.99	19.98	20.88	54.46	54.70	0.05	0.04	0.05	0.05
$p_2 k_0$	6.53	6.12	20.68	20.05	56.42	55.59	0.05	0.04	0.06	0.06
$p_2 k_1$	6.80	6.77	21.63	21.26	59.39	57.30	0.05	0.05	0.06	0.06
$p_2 k_2$	7.36	7.47	24.08	23.50	68.87	66.41	0.05	0.05	0.07	0.07
F	0.88	0.75	1.13	0.34	2.63*	1.68	0.36	0.69	3.93**	0.77
SE	0.321	0.598	0.744	1.363	2.307	2.769	0.0035	0.0047	0.0041	0.02
CD	-	-	-	-	**6.535**	-	-	-	**0.01**	-

** Significant at 1 % level * Significant at 5 % level

During the second year, an increase in the level of nitrogen application significantly increased the DMP. Maximum DMP was found under the highest level of nitrogen. Plants receiving the highest level of P registered significantly higher DMP per plant.

4.2.2.4 Net assimilation rate

The effect of treatments on net assimilation rate (NAR) for both the years are presented in the Tables 41 a and 41b.

At the first phase (60 to 120 days) the effect of nitrogen was not significant on net assimilation rate (NAR). However, n_2 recorded the maximum NAR during both the seasons. At the second phase (120 to 180 days) increase in levels of nitrogen significantly increased the NAR during both the years. Significantly higher NAR was recorded at n_2 level at the above phase.

The relation N x P on NAR was significant during both the seasons. Maximum NAR was found under n_2 p_1 which was on par with n_2 p_0 during first year. But in the second year, treatment n_2 p_1 resulted in significantly higher NAR. P x K interaction was significant only during first year.

4.2.2.5 Crop growth rate

The data on effect of treatments on crop growth rate (CGR) for both the years are presented in the Tables 42 a and 42 b.

At the first phase (60 to 120 days) increase in levels of nitrogen and phosphorus significantly increased CGR during both the years. In both the years the effect of phosphorus was significant. Significantly higher CGR was recorded at p_2 level at first year but during the second year, p_2 and p_1 were on par.

Table 42 (a) Effect of N, P, K and N x P interaction on crop growth rate (CGR) (g m^{-2} day^{-1}) and relative growth rate (RGR) (g g^{-1} day)

Treatment	Crop growth rate				Relative growth rate			
	Between 60 to 120 DAP		Between 120 to 180 DAP		Between 60 to 120 DAP		Between 120 to 180 DAP	
	I	II	I	II	I	II	I	II
n_0	0.25	0.23	0.34	0.33	0.0173	0.0167	0.0116	0.0116
n_1	0.32	0.35	0.71	0.70	0.0171	0.0179	0.0168	0.0161
n_2	0.43	0.44	1.19	1.16	0.0204	0.0209	0.0209	0.0207
F	67.31**	35.85**	193.88**	124.90**	10.18**	7.45**	91.33**	33.55**
p_0	0.29	0.30	0.70	0.68	0.0171	0.0170	0.0168	0.0159
p_1	0.32	0.33	0.73	0.72	0.0185	0.0192	0.0162	0.0161
p_2	0.39	0.38	0.81	0.79	0.0193	0.0193	0.0162	0.0164
F	18.02**	5.07**	3.58*	1.94	3.72*	2.752	0.508	0.093
k_0	0.33	0.33	0.67	0.67	0.0181	0.0187	0.0156	0.0156
k_1	0.33	0.32	0.79	0.77	0.0189	0.0190	0.0172	0.0172
k_2	0.35	0.36	0.79	0.74	0.0179	0.0177	0.0163	0.0155
F	1.54	1.70	5.10**	1.91	0.785	0.674	2.586	1.543
SE	0.01	0.02	0.03	0.04	0.006	0.008	0.005	0.008
CD	**0.03**	**0.05**	**0.09**	**0.10**	**0.0016**	**0.0022**	**0.0014**	**0.0022**
n_0 p_0	0.24	0.24	0.31	0.27	0.0170	0.0163	0.0116	0.0103
n_0 p_1	0.26	0.23	0.31	0.30	0.0176	0.0166	0.0106	0.0108
n_0 p_2	0.25	0.22	0.41	0.43	0.0174	0.0172	0.0125	0.0137
n_1 p_0	0.24	0.25	0.65	0.70	0.0144	0.0139	0.0175	0.0173
n_1 p_1	0.30	0.37	0.70	0.65	0.0163	0.0195	0.0168	0.0151
n_1 p_2	0.43	0.42	0.76	.075	0.0207	0.0202	0.0158	0.0158
n_2 p_0	0.40	0.42	1.13	1.08	0.0199	0.0207	0.0212	0.0201
n_2 p_1	0.41	0.39	1.17	1.22	0.0214	0.0214	0.0213	0.0223
n_2 p_2	0.48	0.50	1.26	1.17	0.0200	0.0206	0.0201	0.0193
F	5.54**	3.80**	0.08	0.89	3.57*	1.859	1.188	1.739
SE	0.02	0.03	0.053	0.064	0.001	0.0014	0.008	0.0014
CD	**0.06**	**0.09**	-	-	**0.0029**	-	-	-

** Significant at 1 % level *Significant at 5 % level

Table 42 (b) Effect of N x K and P x K interactions on crop growth rate (CGR) ($g\ m^{-2}\ day^{-1}$) and relative growth rate (RGR) ($g\ g^{-1}$ day)

Treat-ment	Crop growth rate				Relative growth rate			
	Between 60 to 120 DAP		Between 120 to 180 DAP		Between 60 to 120 DAP		Between 120 to 180 DAP	
	I	II	I	II	I	II	I	II
$n_0 k_0$	0.23	0.22	0.29	0.29	0.0152	0.0159	0.0110	0.0113
$n_0 k_1$	0.27	0.25	0.36	0.34	0.0193	0.0183	0.0119	0.0117
$n_0 k_2$	0.24	0.21	0.38	0.37	0.0175	0.0158	0.0118	0.0118
$n_1 k_0$	0.31	0.33	0.66	0.69	0.0179	0.0181	0.0165	0.0159
$n_1 k_1$	0.31	0.32	0.77	0.75	0.0171	0.0182	0.0179	0.0177
$n_1 k_2$	0.35	0.39	0.69	0.67	0.0164	0.0122	0.0159	0.0145
$n_2 k_0$	0.44	0.44	1.04	1.04	0.0212	0.0220	0.0195	0.0195
$n_2 k_1$	0.40	0.38	1.24	1.23	0.0203	0.0204	0.0218	0.0223
$n_2 k_2$	0.46	0.48	1.29	1.19	0.0199	0.0202	0.0213	0.0202
F	**1.51**	**1.77**	**1.21**	**0.69**	**2.209**	**0.574**	**0.693**	**0.485**
$p_0 k_0$	0.30	0.31	0.58	0.65	0.0164	0.0164	0.0150	0.0152
$p_0 k_1$	0.29	0.28	0.81	0.75	0.0184	0.0186	0.0187	0.0179
$p_0 k_2$	0.29	0.31	0.71	0.65	0.0163	0.0159	0.0167	0.0145
$p_1 k_0$	0.32	0.32	0.67	0.64	0.0187	0.0201	0.0159	0.0148
$p_1 k_1$	0.33	0.31	0.78	0.83	0.0187	0.0192	0.0172	0.0184
$p_1 k_2$	0.33	0.35	0.73	0.70	0.0179	0.0181	0.0156	0.0150
$p_2 k_0$	0.36	0.36	0.75	0.73	0.0191	0.0196	0.0161	0.0168
$p_2 k_1$	0.37	0.36	0.77	0.74	0.0193	0.0191	0.0158	0.0153
$p_2 k_2$	0.43	0.42	0.91	0.89	0.0196	0.0192	0.0167	0.0170
F	1.36	0.23	1.68	1.53	0.672	0.521	1.806	1.500
SE	0.02	0.03	0.053	0.064	0.001	0.0014	0.008	0.0014
CD	-	-	-	-	-	-	-	-

At the second phase (120 to 180 days) the effect of nitrogen was significant on CGR during both the years. Significantly higher CGR was recorded at n_2 level. In the first year the effect of phosphorus on CGR was significant. Significantly higher CGR was recorded at p_2 level and was on par with p_1. Potassium excerted marked influence on CGR during first year. The CGR of k_1 and k_2 were on par.

4.2.2.6 Relative growth rate

The effect of treatments on relative growth rate (RGR) for both the years are presented in the Tables 42 a and 42 b.

At the first phase (60 to 120 DAP) and second phase (120 to 180 DAP) the effect of nitrogen on RGR was significant. At the above phases, significantly higher RGR was observed at n_2 level of nitrogen during the both the years. The effect of phosphorus on RGR was significant only at first year, between 60 to 120 DAP. Significantly higher RGR was recorded at p_2 level of phosphorus which was on par with p_1. The effect of potassium on RGR was not significant during both the phases.

The interaction effect were non-significant during both the seasons.

4.2.3 Biochemical aspects

4.2.3.1 Chlorophyll content

The effect of treatments on chlorophyll content for both the years are presented in Tables 43 a and 43 b.

Nitrogen application at higher levels significantly increased the chlorophyll 'a' content in both the years. Maximum chlorophyll 'a' content

Table 43 (a) Effect of N, P, K and N x P interaction on mean chlorophyll content (mg g^{-1} fresh weight of leaf) at 180 DAP

Treat-ment	Chlorophyll a		Chlorophyll b		Chlorophyll (total)	
	I	II	I	II	I	II
n_0	0.38	0.36	0.42	0.39	0.81	0.75
n_1	0.44	0.38	0.39	0.36	0.83	0.75
n_2	0.48	0.47	0.48	0.48	0.96	0.94
F	33.90**	35.51**	61.38**	281.57**	58.14**	112.38**
p_0	0.40	0.36	0.40	0.38	0.80	0.74
p_1	0.43	0.40	0.42	0.41	0.85	0.81
p_2	0.47	0.44	0.46	0.44	0.94	0.89
F	19.50**	16.39**	28.66**	93.79**	39.82**	47.05**
k_0	0.43	0.40	0.41	0.40	0.84	0.80
k_1	0.43	0.38	0.43	0.40	0.86	0.79
k_2	0.45	0.42	0.45	0.43	0.89	0.86
F	1.58	3.99*	8.12**	27.59**	5.73**	12.31**
SE	0.008	0.010	0.006	0.003	0.011	0.011
CD	**0.024**	**0.027**	**0.016**	**0.010**	**0.030**	**0.030**
$n_0 p_0$	0.35	0.33	0.42	0.38	0.77	0.71
$n_0 p_1$	0.37	0.34	0.40	0.38	0.77	0.72
$n_0 p_2$	0.43	0.41	0.46	0.42	0.89	0.83
$n_1 p_0$	0.42	0.37	0.38	0.35	0.80	0.72
$n_1 p_1$	0.43	0.37	0.38	0.36	0.81	0.73
$n_1 p_2$	0.46	0.40	0.41	0.38	0.87	0.79
$n_2 p_0$	0.42	0.40	0.42	0.40	0.84	0.80
$n_2 p_1$	0.50	0.49	0.49	0.50	0.98	0.99
$n_2 p_2$	0.53	0.52	0.52	0.52	1.05	1.04
F	2.30	3.03*	7.23**	23.92**	6.20**	9.46**
SE	0.015	0.017	0.010	0.006	0.019	0.018
CD	-	**0.047**	**0.027**	**0.017**	**0.053**	**0.052**

** Significant at 1 % level *Significant at 5 % level

Table 43 (b) Effect of N x K and P x K interactions on mean chlorophyll content (mg g^{-1} fresh weight of leaf) at 180 DAP

Treat ments	Chlorophyll 'a'		Chlorophyll 'b'		Chlorophyll (total)	
	I	II	I	II	I	II
$n_0 k_0$	0.38	0.35	0.38	0.37	0.76	0.71
$n_0 k_1$	0.37	0.34	0.44	0.38	0.81	0.72
$n_0 k_2$	0.40	0.39	0.46	0.43	0.86	0.82
$n_1 k_0$	0.43	0.39	0.40	0.37	0.83	0.76
$n_1 k_1$	0.44	0.36	0.38	0.36	0.82	0.72
$n_1 k_2$	0.45	0.40	0.38	0.36	0.83	0.76
$n_2 k_0$	0.47	0.46	0.46	0.46	0.94	0.92
$n_2 k_1$	0.48	0.46	0.47	0.46	0.95	0.91
$n_2 k_2$	0.49	0.48	0.50	0.51	0.99	0.99
F	**0.29**	**0.31**	7.24**	**10.82****	**1.86**	**2.18**
$p_0 k_0$	0.39	0.34	0.37	0.32	0.75	0.67
$p_0 k_1$	0.39	0.35	0.40	0.38	0.79	0.73
$p_0 k_2$	0.42	0.40	0.44	0.43	0.86	0.83
$p_1 k_0$	0.42	0.40	0.41	0.40	0.83	0.80
$p_1 k_1$	0.44	0.40	0.43	0.42	0.87	0.81
$p_1 k_2$	0.44	0.41	0.43	0.42	0.87	0.83
$p_2 k_0$	0.48	0.46	0.46	0.47	0.94	0.93
$p_2 k_1$	0.46	0.41	0.45	0.41	0.92	0.82
$p_2 k_2$	0.48	0.46	0.47	0.45	0.95	0.91
F	0.89	1.65	3.64*	34.32**	2.42	9.27**
SE	0.015	0.017	0.010	0.006	0.019	0.018
CD	-	-	**0.027**	**0.017**	-	**0.052**

** Significant at 1 % level *Significant at 5 % level

was recorded at n_2 level. Increased rates of phosphorus nutrition was found to increase chlorophyll 'a' content during both the years. Effect of potassium on chlorophyll 'a' content was significant only during the second year. Maximum chlorophyll 'a' content was recorded at k_2 level which was on par with k_0 level of potassium.

N x P interaction was found to be significant only in second year. Significantly higher chlorophyll 'a' content was found at n_2 p_2 level. However, n_2 p_1 and n_2 p_2 were on par.

Nitrogen application at higher levels significantly increased chlorophyll 'b' content in both the years. Maximum chlorophyll 'b' content was recorded at n_2 level during both years. Increased rate of phosphorus nutrition was found to increase chlorophyll 'b' content during both the years. Higher value for chlorophyll 'b' were registered under p_2 during both the periods.

Effect of potassium on chlorophyll 'b' content was significant during both the years. Maximum chlorophyll 'b' content was recorded at k_2 level.

The interactions N x P, N x K and P x K on chlorophyll 'b' content was significant at 180 DAP in both the years. Under N x P interaction, n_2 p_2 recorded the maximum chlorophyll 'b' content during both the years. Under N x K interaction, maximum chlorophyll 'b' content was found under n_2 k_2 for both the years. In the case of P x K interaction, at all levels of P the effect of K in increasing chlorophyll 'b' content was inconspicuous during both the years.

The response of N on total chlorophyll content was significant during both the years. The nitrogen level n_2 recorded the maximum total chlorophyll content during both the years. Increased rates of phosphorus application had significant effect on total chlorophyll content during both the years. Maximum increase was observed under p_2. However incremental dosages of potassium significantly enhanced the total chlorophyll content during both the years. Maximum increase was observed under k_2, which was on par with k_1 during first year. Maximum total chlorophyll content was recorded at k_2 during second year.

The effect of N x P interaction on total chlorophyll content was significant during both the years. Maximum total chlorophyll content was observed under n_2 p_2 during both the years and was on par with n_2 p_1 during second year. Maximum increase of total chlorophyll content was observed under p_2 k_0 which was on par with n_2 p_2.

4.2.4 Yield and yield components

4.2.4.1 Fresh ginger yield

The effect of treatments on fresh ginger yield for both the years are presented in the Tables 44 a and 44 b.

Application of nitrogen increased fresh ginger yield. An increase of 10.4 per cent in fresh ginger yield was obtained when 150 kg ha^{-1} N was used compared to 75 kg ha^{-1} N. Application of phosphorus was also found to have effect on yield. However no significant difference was observed in p_1 and p_2 levels of phosphorus. Application of K at 100 kg ha^{-1} was found to increase the yield by 9.9 per cent than K at 50 kg ha^{-1}. The influence of nitrogen, phosphorus and potassium on fresh ginger yield was also significant during second year. Maximum fresh ginger yield was obtained at increased level of

Table 44 (a) Effect of N, P, K and N x P interaction on fresh rhizome yield (t ha^{-1}), dry ginger yield (kg ha^{-1})

Treatments	Fresh rhizome yield (t ha^{-1})		Pooled mean	Dry ginger yield (kg ha^{-1})		Pooled mean
	I	II		I	II	
n_0	9.68	10.69	10.18	2133.00	2358.19	2245.59
n_1	12.96	13.27	13.12	2866.48	2926.30	2896.39
n_2	14.31	13.86	14.09	3136.33	3038.22	3087.28
F	**73.90****	**70.92****	**141.25****	**72.78****	**69.81****	**138.89****
p_0	11.61	11.99	11.80	2552.63	2651.85	2602.24
p_1	12.47	12.18	12.32	2742.89	2682.59	2712.40
p_2	12.88	13.65	13.26	2840.30	2958.26	2914.80
F	**5.47****	**20.48****	**18.82****	**5.78****	**18.16****	**17.85****
k_0	11.95	11.88	11.91	2624.11	2615.89	2620.00
k_1	11.85	12.93	12.39	2608.44	2852.78	2730.61
k_2	13.16	13.01	13.09	2903.26	2854.04	2878.65
F	6.91**	9.89**	11.86**	7.43**	9.87**	12.01**
SE	0.28	0.20	0.17	60.86	43.64	37.44
CD	**0.78**	**0.57**	**0.48**	**172.40**	**123.62**	**105.38**
$n_0 p_0$	9.68	10.26	9.97	2133.89	2274.44	2204.17
$n_0 p_1$	10.00	10.54	10.27	2202.00	2322.44	2262.22
$n_0 p_2$	9.36	11.26	10.31	2063.11	2477.67	2770.39
$n_1 p_0$	11.94	12.74	12.34	2638.33	2818.00	2728.17
$n_1 p_1$	13.71	13.37	13.54	3016.67	2944.11	2980.39
$n_1 p_2$	13.23	13.71	13.47	2944.44	3016.78	2980.61
$n_2 p_0$	13.20	12.99	13.10	2885.67	2863.11	2874.39
$n_2 p_1$	13.69	12.62	13.15	3010.00	2781.22	2895.61
$n_2 p_2$	16.04	15.98	16.01	3513.33	3470.33	3491.83
F	**4.30****	**5.91****	**9.19****	**4.11****	**5.19****	**8.36****
SE	0.48	0.35	0.30	105.41	75.59	64.86
CD	**1.36**	**0.98**	**0.83**	**298.6**	**214.12**	**182.52**

** Significant at 1 % level * Significant at 5 % level

Table 44 (b) Effect of N x K and P x K interactions on fresh rhizome yield (t ha^{-1}), dry ginger yield (kg ha^{-1})

Treatments	Fresh rhizome yield (t ha^{-1})		Pooled mean	Dry ginger yield (kg ha^{-1})		Pooled mean
	I	II		I	II	
$n_0 k_0$	9.17	10.24	9.70	2022.33	2255.56	2138.94
$n_0 k_1$	9.65	11.22	10.43	2124.67	2484.00	2304.33
$n_0 k_2$	10.23	10.60	10.41	2252.00	2335.00	2293.50
$n_1 k_0$	12.68	12.57	12.62	2788.89	2764.00	2776.44
$n_1 k_1$	12.78	13.74	13.26	2816.11	3030.67	2923.39
$n_1 k_2$	13.43	13.52	13.47	2994.44	2984.22	2989.33
$n_2 k_0$	14.00	12.84	13.42	3061.11	2828.11	2944.61
$n_2 k_1$	13.12	13.83	13.47	2884.56	3040.67	2964.11
$n_2 k_2$	15.81	14.93	15.37	3463.33	3242.89	3353.11
F	**1.61**	**2.23**	**3.22***	**1.40**	**1.78**	**2.74***
$p_0 k_0$	11.09	11.74	11.42	2427.33	2584.78	2506.06
$p_0 k_1$	11.40	12.41	11.91	2514.56	2753.67	2634.11
$p_0 k_2$	12.33	11.83	12.08	2716.00	2617.11	2666.56
$P_1 k_0$	12.27	12.04	12.16	2697.78	2653.78	2675.78
$p_1 k_1$	12.47	12.78	12.62	2742.11	2812.89	2777.50
$p_1 k_2$	12.67	11.72	12.19	2788.78	2581.11	2684.94
$P_2 k_0$	12.48	11.86	12.17	2747.22	2609.11	2678.14
$p_2 k_1$	11.67	13.60	12.64	2568.67	2991.78	2780.22
$p_2 k_2$	14.48	15.50	14.99	3205.00	3363.89	3284.44
F	**2.05**	**10.54****	**8.13****	**2.21**	**9.46****	**7.75****
SE	0.48	0.35	0.30	105.41	75.59	64.86
CD	-	**0.98**	**0.83**	-	**214.12**	**182.52**

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

nitrogen. The levels n_1 and n_2 were on par and produced significantly higher fresh ginger yield when compared to n_0. Application of phosphorus was also found to have effect on yield. The level p_2 produced significantly higher yield when compared to p_0 and p_1 which were on par. Application of potassium was found to have effect on yield. The level k_1 and k_2 were on par but produced significantly higher yield when compared to k_0.

The results of the pooled analysis of fresh ginger yield data showed that, significantly higher fresh ginger yield was obtained when nitrogen, phosphorus and potassium were applied at 150 : 100 : 100 kg ha^{-1} respectively.

The N x P interaction significantly influenced the fresh ginger yield in the first year. In the absence of nitrogen no effect for P was observed. When nitrogen was applied at 75 kg ha^{-1} maximum yield was obtained at n_1 p_1 but was on par with n_1 p_2. When nitrogen was applied at 150 kg ha^{-1}, maximum yield was obtained at n_2 p_2. The N x P and P x K interactions significantly influenced the fresh ginger yield in the second year. In the absence of nitrogen and n_1 levels the response of P was non-significant. But when p_2 was combined with n_2, a marked increase in yield was observed at n_2 p_2. In the case of P x K interaction, in the absence of phosphorus (p_0) and p_1 level the response of K was non-significant. Highest fresh ginger yield was obtained under the combination p_2 k_2.

The results of the pooled analysis of fresh ginger yield data showed that, N x P, N x K and P x K interactions were significant and highest rhizome yield was recorded under the combinations n_2 p_2, n_2 k_2 and p_2 k_2 respectively.

4.2.4.2 Dry ginger

The effect of treatments on dry ginger yield for both the years are presented in the Tables 44 a and 44 b.

Application of N was found to increase dry ginger yield. Application of N with 150 kg ha^{-1} was found to increase the yield by 9.4 per cent than application of N at 75 kg ha^{-1}. Application of P was also found to have effect on yield. However no significant difference was observed between p_1 and p_2 levels. Application of K at 100 kg ha^{-1} was found to increase the yield by 11.3 per cent than application of K at 50 kg ha^{-1}. During second year, application of N was found to have beneficial effect on yield but no significant differences were recorded between n_1 and n_2 levels of nitrogen. Application of phosphorus at p_2 level was found to enhance the yield. Application of potassium was also found to increase the yield but no significant difference was observed at k_1 and k_2 levels.

The results of the pooled analysis of dry ginger showed that, significantly higher dry ginger yield was obtained when nitrogen, phosphorus and potassium were applied at 150 kg ha^{-1}, 100 kg ha^{-1} and 100 kg ha^{-1} respectively.

Significant interaction was observed for N x P while N x K and P x K interactions where non-significant. In the absence of N no effect of P was observed. When N was applied at 75 kg ha^{-1} the effect of P was significant, however no significant difference was observed between p_1 and p_2. When N was applied at 150 kg ha^{-1} , yield increase was observed with higher doses of P i.e., at n_2 p_2 combination. If N is increased there should be a proportional increase in P also for better dry ginger yield. The interactions N x P and N x K, on dry ginger yield were found to be significant during the second year. In the absence and in the presence of nitrogen at n_1 level, the response of P was not visible i.e., at all the levels of n_0 and n_1 combinations the differences in yield were not observed. But when P was combined with n_1, a marked increase in yield was observed at n_2 p_2. In the case of P x K interaction, in the absence of K the response of P was non-significant. When P was combined with k_1, p_2 k_1 led to better yield. When K was increased to k_2 maximum production was obtained with p_2 k_2 combination. While p_1 k_2 was on par with p_0 k_2. So if P is increased there should be a proportionate increase in K also.

The results of pooled analysis of the dry ginger yield data showed that, the N x P, N x K and P x K interactions were significant and highest dry ginger yield was recorded under the combinations n_2 p_2, n_2 k_2 and p_2 k_2 respectively.

4.2.4.3 Shoot dry weight

The effect of treatments on shoot dry weight for both the years are presented in the Tables 45 a and 45 b.

The influence of nitrogen on shoot dry weight was significant during both the years. Significantly higher shoot dry weight was obtained at n_2. The shoot dry weight at n_1 level was also significantly superior to that of n_0. The influence of phosphorus application on shoot dry weight was significant during both the years. But the difference in shoot dry weight between p_2 and p_1 was not significant. The influence of potassium on shoot dry weight was significant only at highest level of K application during both the years.

The interaction P x K on shoot dry weight was significant only during second year. Maximum shoot dry weight was found under p_2 k_2.

Table 45 (a) Effect of N, P, K and N x P interaction on shoot dry weight (kg ha^{-1}), harvest index and root : shoot ratio

Treatment	Shoot dry weight (kg ha^{-1})		Harvest index		Root : shoot ratio	
	I	II	I	II	I	II
n_0	1413.74	1290.45	0.57	0.62	0.14	0.17
n_1	1506.37	1452.89	0.61	0.63	0.19	0.20
n_2	1759.15	1744.00	0.60	0.59	0.19	0.20
F	**31.96****	**26.51****	**11.61****	**6.73****	**9.06****	**9.00****
p_0	1482.56	1365.40	0.59	0.62	0.16	0.19
p_1	1574.93	1555.56	0.60	0.60	0.17	0.18
p_2	1621.78	1566.39	0.59	0.62	0.18	0.20
F	**5.02***	**6.42****	**0.06**	**3.94***	**0.65**	**1.38**
k_0	1531.07	1443.94	0.59	0.61	0.17	0.18
k_1	1505.30	1446.63	0.59	0.63	0.17	0.19
k_2	1642.89	1596.77	0.60	0.60	0.18	0.19
F	5.35**	3.84*	0.33	3.18*	0.25	0.69
SE	31.63	44.63	0.01	0.01	0.01	0.01
CD	**89.58**	**126.43**	**0.02**	**0.02**	**0.02**	**0.02**
$n_0 p_0$	1397.33	1171.80	0.57	0.62	0.14	0.17
$n_0 p_1$	1426.11	1405.83	0.58	0.60	0.13	0.15
$n_0 p_2$	1417.78	1293.72	0.56	0.62	0.16	0.17
$n_1 p_0$	1424.22	1352.17	0.61	0.64	0.18	0.18
$n_1 p_1$	1575.33	1543.50	0.62	0.62	0.19	0.20
$n_1 p_2$	1519.56	1463.00	0.62	0.63	0.19	0.22
$n_2 p_0$	1626.11	1522.22	0.60	0.61	0.18	0.20
$n_2 p_1$	1723.33	1717.33	0.59	0.58	0.19	0.20
$n_2 p_2$	1928.00	1942.44	0.60	0.60	0.19	0.20
F	**2.46**	**1.62**	**0.55**	**0.11**	**0.25**	**1.16**
SE	54.78	77.31	0.011	0.011	0.015	0.011
CD	-	-	-	-	-	-

**** Significant at 1 % level** *** Significant at 5 % level**

Table 45 (b) Effect of N x K and P x K interactions on shoot dry weight (kg ha^{-1}), harvest index and root : shoot ratio

Treatment	Shoot dry weight (kg ha^{-1})		Harvest index		Root : shoot ratio	
	I	II	I	II	I	II
$n_0 k_0$	1381.67	1339.33	0.56	0.60	0.15	0.14
$n_0 k_1$	1391.33	1226.06	0.57	0.64	0.13	0.18
$n_0 k_2$	1468.22	1305.97	0.57	0.61	0.15	0.17
$n_1 k_0$	1424.78	1285.67	0.62	0.64	0.19	0.21
$n_1 k_1$	1461.33	1432.67	0.62	0.64	0.19	0.19
$n_1 k_2$	1633.00	1640.33	0.61	0.61	0.19	0.19
$n_2 k_0$	1786.78	1706.83	0.59	0.59	0.18	0.19
$n_2 k_1$	1663.22	1681.17	0.59	0.60	0.19	0.20
$n_2 k_2$	1827.44	1844.00	0.61	0.59	0.19	0.20
F	**0.98**	**1.66**	**0.74**	**1.62**	**0.34**	**1.87**
$p_0 k_0$	1525.44	1459.50	0.58	0.61	0.15	0.16
$p_0 k_1$	1419.89	1889.17	0.60	0.64	0.17	0.20
$p_0 k_2$	1502.33	1347.56	0.60	0.62	0.17	0.20
$p_1 k_0$	1562.67	1468.83	0.59	0.61	0.17	0.18
$p_1 k_1$	1513.33	1559.83	0.61	0.61	0.16	0.17
$p_1 k_2$	1648.78	1638.00	0.59	0.58	0.17	0.19
$p_2 k_0$	1505.11	1403.50	0.60	0.61	0.19	0.20
$p_2 k_1$	1582.67	1490.89	0.58	0.63	0.16	0.19
$p_2 k_2$	1777.56	1804.78	0.60	0.61	0.18	0.19
F	**1.91**	**3.03***	**1.59**	**0.85**	**0.62**	**2.24**
SE	54.78	77.31	0.011	0.011	0.015	0.011
CD	-	**218.98**	-	-	-	-

** Significant at 1 % level * Significant at 5 % level

4.2.4.4 Harvest index

The effect of treatments on harvest index for both the years are presented in the Tables 45 a and 45 b.

Increased levels of nitrogen had significant effect on HI during first year. In the second year, increased levels of nitrogen had depressing effect on HI. The influence of potassium on HI was significant only during second year. However, treatment k_1 resulted in significantly higher HI which was on par with k_o.

4.2.4.5 Root : shoot ratio

The effect of treatments on root : shoot ratio for both the years are presented in the Tables 45 a and 45 b.

The effect of nitrogen on root : shoot ratio was significant during both the years. Maximum root : shoot ratio was recorded by n_1 and n_2 during both years. The root : shoot ratio of n_1 and n_2 were on par. The effect of P and K on root : shoot ratio was not significant during the two seasons.

4.2.5 Quality aspects

4.2.5.1 Volatile oil

The effects of treatments on volatile oil content for both the years are presented in Tables 46 a and 46 b.

Effect of fertilizer treatments and their interactions on volatile oil content were found to be non-significant during both the years.

Table 46 (a) Effect of N, P, K and N x P interaction on volatile oil (v / w) and non-volatile ether extract (percentage), starch (percentage) and crude fibre content (percentage) on dry weight basis

Treat ments	Volatile oil		Non-volatile ether extract		Starch		Crude fibre	
	I	II	I	II	I	II	I	II
n_0	1.91	1.91	4.89	4.97	33.46	35.13	5.89	5.53
n_1	1.91	1.94	4.87	4.96	34.56	35.07	5.96	5.04
n_2	1.92	1.93	4.89	4.94	36.97	40.75	6.10	5.42
F	**0.07**	**0.18**	**0.07**	**0.26**	**6.09****	**52.46****	**4.38***	**4.05***
p_0	1.93	1.90	4.87	4.95	34.35	32.84	5.94	5.32
p_1	1.90	1.94	4.87	4.94	34.80	37.95	5.97	5.14
p_2	1.91	1.95	4.90	4.98	35.84	40.16	6.05	5.53
F	0.60	0.91	0.27	0.49	1.11	69.65**	1.24	2.39
k_0	1.91	1.94	4.88	4.97	33.90	36.40	5.96	5.34
k_1	1.91	1.91	4.87	4.95	34.87	37.11	5.96	5.26
k_2	1.92	1.94	4.89	4.95	36.21	37.44	6.04	5.39
F	0.10	0.41	0.06	0.30	2.54	1.40	0.80	0.24
SE	0.0254	0.032	0.033	0.027	0.727	0.450	0.050	0.128
CD	-	-	-	-	**2.060**	**1.275**	**0.143**	**0.361**
$n_0 p_0$	1.93	1.84	4.83	4.99	31.92	31.68	5.82	5.36
$n_0 p_1$	1.91	1.96	4.89	4.94	35.26	33.35	5.89	5.38
$n_0 p_2$	1.89	1.94	4.93	4.97	33.21	40.34	5.97	5.85
$n_1 p_0$	1.92	1.94	4.87	4.98	37.82	32.77	5.93	5.23
$n_1 p_1$	1.88	1.93	4.86	4.94	33.24	37.88	5.93	4.63
$n_1 p_2$	1.93	1.94	4.89	4.97	32.60	34.57	6.02	5.26
$n_2 p_0$	1.94	1.90	4.91	4.89	33.31	34.06	6.07	5.36
$n_2 p_1$	1.90	1.93	4.87	4.93	35.89	42.60	6.08	5.40
$n_2 p_2$	1.92	1.97	4.88	5.00	41.71	45.57	6.16	5.49
F	**0.24**	**0.42**	**0.37**	**0.65**	**8.73****	**17.45****	**0.05**	**0.92**
SE	0.041	0.055	0.057	0.047	1.259	0.780	0.087	0.221
CD	-	-	-	-	**3.568**	**2.208**	-	-

** Significant at 1 % level * Significant at 5 % level

Table 46 (b) Effect of N x K and P x K interactions on volatile oil (v / w) and non-volatile ether extract (percentage), starch (percentage) and crude fibre content (percentage) on dry weight basis

Treatments	Volatile oil		Non-volatile ether extract		Starch		Crude fibre	
	I	II	I	II	I	II	I	II
$n_0 k_0$	1.89	1.94	4.87	4.99	31.81	35.21	5.89	5.73
$n_0 k_1$	1.90	1.89	4.89	4.96	33.64	35.05	5.82	5.44
$n_0 k_2$	1.94	1.92	4.90	4.96	34.93	35.11	5.97	5.43
$n_1 k_0$	1.90	1.96	4.88	4.98	33.26	33.77	5.92	4.90
$n_1 k_1$	1.92	1.93	4.88	4.96	35.72	35.69	5.94	4.95
$n_1 k_2$	1.91	1.93	4.86	4.96	34.69	35.77	6.02	5.27
$n_2 k_0$	1.93	1.93	4.89	4.96	36.64	40.21	6.08	5.39
$n_2 k_1$	1.92	1.90	4.86	4.93	35.26	40.58	6.10	5.40
$n_2 k_2$	1.91	1.97	4.91	4.93	39.01	41.45	6.12	5.46
F	**0.28**	**0.13**	**0.16**	**0.01**	**1.13**	**0.69**	**0.15**	**0.60**
$p_0 k_0$	1.91	1.88	4.89	4.93	34.27	33.22	5.89	5.18
$p_0 k_1$	1.92	1.88	4.88	4.96	33.63	32.46	5.96	5.40
$p_0 k_2$	1.97	1.92	4.84	4.97	35.16	32.83	5.98	5.37
$p_1 k_0$	1.88	1.99	4.86	4.99	32.29	36.15	6.00	5.00
$p_1 k_1$	1.92	1.90	4.84	4.92	35.52	38.59	5.90	5.02
$p_1 k_2$	1.89	1.93	4.91	4.91	36.58	39.10	6.00	5.39
$p_2 k_0$	1.93	1.96	4.89	5.00	35.16	39.82	6.00	5.83
$p_2 k_1$	1.90	1.93	4.90	4.97	35.47	40.26	6.01	5.37
$p_2 k_2$	1.91	1.97	4.91	4.97	36.90	40.40	6.13	5.40
F	**0.45**	**0.21**	**0.27**	**0.40**	**0.76**	**1.54**	**0.32**	**1.22**
SE	0.041	0.055	0.057	0.047	1.259	0.780	0.087	0.221
CD	-	-	-	-	-	-	-	-

4.2.5.2 Non-volatile ether extract

Effect of fertilizer treatments and their interactions on non-volatile ether extract (NVEE) were found to be non significant during both the seasons (Table 46 a and 46 b) .

4.2.5.3 Starch content

The effects of treatments on starch content for both the years are presented in Tables 46 a and 46 b.

The influence of nitrogen on starch content was significant during the first year. Nitrogen application at the highest level produced significant effect on starch content. N x P interaction was found to be significant. Highest starch content was obtained under the combination n_2 p_2.

During second year also nitrogen application at the highest level produced significant effect on starch content. Significantly higher starch content was obtained at p_2. N x P interaction was found to be significant. Highest starch content was obtained under the combination n_2 p_2.

4.2.5.4 Crude fibre content

The effects of treatments on crude fibre content for both the years are presented in Tables 46 a and 46 b.

Nitrogen application at higher levels significantly increased the crude fibre content but no significant difference was observed at n_1 and n_2 levels of N.

During second year the maximum crude fibre content was recorded by n_0 which was on par with n_2.

4.2.6 Uptake of nutrients

4.2.6.1 Uptake of nitrogen

The effects of treatments on uptake of nitrogen for both the years are presented in Tables 47 a and 47 b.

The effect of applied nitrogen on the uptake of nitrogen at harvest stage was significant during both the years. Plant uptake of nitrogen significantly increased with higher rates of N nutrition.

4.2.6.2 Uptake of phosphorus

The data on the effects of treatments on uptake of phosphorus for both the years are presented in Tables 47 a and 47 b.

Plant uptake of phosphorus was significantly increased with higher rates of P nutrition during both the years.

4.2.6.3 Uptake of potassium

The uptake of potassium as influenced by the treatments for both the seasons are presented in Tables 47 a and 47 b.

Increased rates of potassium application significantly influenced the uptake of the nutrients during both the years. At all stages maximum uptake was recorded at the highest level of K application. During the first season, plant uptake of potassium was significantly influenced by the level of applied nitrogen. Significant increase in uptake of potassium was observed with increased rates of nitrogen application and maximum values were recorded at n_2 level.

Table 47 (a) Effect of N, P, K and N x P interaction on uptake of N, P and K of ginger plant (kg ha^{-1})

Treat-ment	N (kg ha^{-1})		P (kg ha^{-1})		K (kg ha^{-1})	
	I	II	I	II	I	II
n_0	64.44	43.88	11.63	13.57	80.76	82.34
n_1	80.07	87.22	11.98	13.23	85.67	82.57
n_2	103.06	108.58	12.21	13.65	88.54	83.89
F	**597.39****	**1067.07****	**3.39***	**3.08**	**13.66****	**0.37**
p_0	81.93	78.96	8.93	9.45	83.88	83.90
p_1	82.96	80.44	11.34	15.11	84.52	82.90
p_2	82.67	80.27	15.54	15.89	86.57	82.01
F	**0.45**	**0.64**	**442.88****	**771.21****	**1.74**	**0.48**
k_0	82.25	79.28	11.76	13.33	76.43	54.23
k_1	83.01	79.68	12.19	13.52	80.07	89.53
k_2	82.30	80.72	11.86	13.60	98.47	105.04
F	0.29	0.55	1.98	1.18	123.11**	361.05**
SE	0.795	1.009	0.159	0.126	1.065	1.370
CD	**2.252**	**2.859**	**0.451**	**0.358**	**3.016**	**3.882**
$n_0 p_0$	62.82	43.73	8.87	9.29	81.27	84.12
$n_0 p_1$	65.30	44.31	11.29	15.31	80.54	83.64
$n_0 p_2$	65.19	43.60	14.72	16.10	80.47	79.27
$n_1 p_0$	79.12	85.82	8.64	9.23	84.29	83.81
$n_1 p_1$	80.31	87.75	11.24	15.06	87.10	81.94
$n_1 p_2$	80.77	88.11	16.04	15.40	85.62	81.96
$n_2 p_0$	103.84	107.34	9.27	9.83	86.09	83.76
$n_2 p_1$	103.27	109.27	11.49	14.96	85.92	83.11
$n_2 p_2$	102.07	109.11	15.87	16.16	93.62	84.80
F	**0.70**	**0.14**	**2.46**	**1.81**	**2.29**	**0.56**
SE	1.376	1.748	0.276	0.219	1.844	2.374
CD	-	-	-	-	-	-

**** Significant at 1 % level** *** Significant at 5 % level**

Table 47 (b) Effect of N x K and P x K interactions on uptake of N, P and K of ginger plant (kg ha^{-1})

Treat-ment	N (kg ha^{-1})		P (kg ha^{-1})		K (kg ha^{-1})	
	I	II	I	II	I	II
$n_0 k_0$	63.04	43.39	11.57	13.32	76.94	54.79
$n_0 k_1$	66.91	44.33	11.90	13.57	77.89	88.31
$n_0 k_2$	63.36	43.81	11.41	13.81	87.46	103.93
$n_1 k_0$	80.80	87.12	11.67	13.09	75.29	54.23
$n_1 k_1$	80.14	86.14	12.23	13.20	78.04	89.99
$n_1 k_2$	79.26	88.42	12.03	13.40	103.68	103.49
$n_2 k_0$	102.90	107.22	12.04	13.58	77.07	53.68
$n_2 k_1$	101.98	108.57	12.43	13.79	84.29	90.28
$n_2 k_2$	104.30	109.94	12.14	13.58	104.28	107.71
F	**1.59**	**0.27**	**0.23**	**0.45**	**8.66****	**0.42**
$p_0 k_0$	81.36	77.11	8.71	9.04	76.73	55.14
$p_0 k_1$	82.38	80.11	9.39	9.64	78.41	89.84
$p_0 k_2$	82.06	79.67	8.68	9.67	96.50	106.70
$p_1 k_0$	83.61	80.62	11.07	15.11	76.27	52.81
$p_1 k_1$	83.68	79.82	11.51	15.09	78.48	91.13
$p_1 k_2$	81.59	80.89	11.44	15.12	98.82	104.76
$p_2 k_0$	81.78	80.10	15.50	15.83	76.29	54.74
$p_2 k_1$	82.98	79.11	15.67	15.82	83.33	87.60
$p_2 k_2$	83.27	81.61	15.47	16.00	100.09	103.68
F	**0.46**	**0.47**	**0.52**	**0.82**	**0.80**	**0.39**
SE	1.376	1.748	0.276	0.219	1.844	2.374
CD	-	-	-	-	**5.224**	-

**** Significant at 1 % level**

Table 48 (a) Effect of N, P, K and N x P interaction on available N, P and K content of the soil (kg ha^{-1})

Treat-ment	N (kg ha^{-1})		P (kg ha^{-1})		K (kg ha^{-1})	
	I	II	I	II	I	II
n_0	204.62	165.45	39.14	40.50	125.65	154.62
n_1	224.96	242.70	39.59	33.82	125.65	164.88
n_2	262.91	270.95	40.04	33.70	125.09	155.27
F	**406.24****	**255.94****	**0.62**	**4.14***	**0.18**	**0.67**
p_0	228.51	217.29	29.14	33.16	124.41	157.52
p_1	230.87	227.19	35.20	37.67	125.33	157.19
p_2	233.10	234.63	54.44	37.20	126.65	160.06
F	**2.45**	**6.49****	**527.07****	**1.68**	**2.19**	**0.05**
k_0	230.22	223.07	39.40	33.01	96.18	120.61
k_1	230.39	228.84	39.74	39.96	124.77	165.76
k_2	231.88	227.20	39.63	35.06	155.43	188.41
F	0.39	0.76	0.09	3.48*	1511.64**	24.25**
SE	1.468	3.414	0.575	1.914	0.762	7.009
CD	**4.158**	**9.670**	**1.630**	**5.423**	**2.159**	**19.853**
$n_0 p_0$	203.93	156.36	29.57	32.71	123.90	159.80
$n_0 p_1$	203.91	163.51	34.39	40.25	125.90	153.06
$n_0 p_2$	206.02	176.49	53.47	48.55	127.16	151.00
$n_1 p_0$	222.54	226.42	28.67	34.75	124.54	156.83
$n_1 p_1$	225.41	245.43	36.03	37.70	125.13	170.47
$n_1 p_2$	226.91	256.24	54.07	29.03	127.27	167.34
$n_2 p_0$	259.06	269.08	29.18	32.01	124.78	155.94
$n_2 p_1$	263.30	272.63	35.17	35.07	124.94	148.06
$n_2 p_2$	266.38	271.14	55.79	34.02	125.53	161.83
F	**0.32**	**1.55**	**0.87**	**3.01***	**0.31**	**0.38**
SE	2.542	5.913	0.996	3.316	1.320	12.139
CD	--	-	-	**9.392**	-	-

**** Significant at 1 % level** *** Significant at 5 % level**

Table 48 (b) Effect of N x K and P x K interactions on available N, P and K content of the soil (kg ha^{-1})

Treat-ment	N (kg ha^{-1})		P (kg ha^{-1})		K (kg ha^{-1})	
	I	II	I	II	I	II
$n_0 k_0$	203.93	164.33	38.90	30.35	96.46	111.54
$n_0 k_1$	204.84	163.16	39.50	43.84	126.08	160.22
$n_0 k_2$	205.09	168.88	39.02	47.32	154.42	192.09
$n_1 k_0$	225.13	232.84	39.06	33.71	96.63	121.78
$n_1 k_1$	224.63	250.76	39.54	40.26	125.38	171.46
$n_1 k_2$	225.10	244.50	40.17	27.50	154.93	201.40
$n_2 k_0$	261.60	272.02	40.26	34.96	95.44	128.50
$n_2 k_1$	261.69	272.61	40.17	35.77	122.87	165.59
$n_2 k_2$	265.44	268.22	39.71	30.35	156.94	171.73
F	**0.21**	**1.01**	**0.21**	**4.16****	**1.36**	**0.80**
$p_0 k_0$	226.47	215.22	28.40	24.45	95.73	123.58
$p_0 k_1$	229.03	218.73	29.23	38.69	124.77	170.12
$p_0 k_2$	230.03	217.91	29.78	36.33	152.72	178.87
$p_1 k_0$	229.02	224.13	35.89	34.97	96.13	116.19
$p_1 k_1$	231.12	230.17	35.38	44.07	123.71	172.66
$p_1 k_2$	232.48	227.28	34.32	33.98	156.13	182.74
$p_2 k_0$	235.18	229.84	53.92	39.60	96.67	122.06
$p_2 k_1$	231.01	237.62	54.60	37.12	125.84	154.49
$p_2 k_2$	233.12	236.41	54.80	34.87	157.44	203.62
F	**0.64**	**0.05**	**0.63**	**2.57***	**1.00**	**0.96**
SE	2.542	5.913	0.996	3.316	1.320	12.139
CD	-	-	-	**9.392**	-	-

** Significant at 1 % level   * Significant at 5 % level

4.2.7 Available nutrients in the soil

4.2.7.1 Available nitrogen

The effect of treatments on available nitrogen content of the soil, after each crop year is provided in the Tables 48 a and 48 b.

Available N increased with increase in applied N. Significant effect of applied phosphorus was observed during both the years.

4.2.7.2 Available phosphorus

The effect of treatments on available phosphorus content of the soil, after each crop year is provided in the Tables 48 a and 48 b.

In the first year, the available P status on the soil enhanced with increased rates of P fertilizer. But during the second year there was no significant effect of different levels of P application on available P content of the soil. Higher rates of applied nitrogen had no effect on the available P status of the soil during second year. The effect of applied potassium on available P was similar to that of nitrogen.

4.2.7.3 Available potassium

The effect of treatments on available potassium content of the soil, after each crop year is provided in the Tables 48 a and 48 b.

Significant increase in available K in the soil was recorded during both the years with increased levels of K application. Maximum content of available K was observed at k_2 followed by k_1.

Table 49 Economics of fertilizer application (1996-97)

Sl. No.	Treatments N, P_2O_5 and K_2O (kg ha^{-1})	Cost of cultivation (Rs. ha^{-1})	Dry ginger yield (kg ha^{-1})	Value (Rs.)	Profit / loss (Rs. ha^{-1})	Benefit : cost ratio
1	No fertilizers	82, 200	1977.0	86355.40	4155.40	1.05
2	0 : 0 : 50	82, 682	2180.0	95222.40	12540.40	1.15
3	0 : 0 : 100	83, 163	2247.7	98048.50	14885.50	1.19
4	0 : 50 : 0	82, 623	1946.7	84900.80	2277.80	1.03
5	0 : 50 : 50	83, 105	2413.0	1,05,399.80	22294.80	1.27
6	0 : 50 : 100	83, 586	2246.3	98118.40	14532.40	1.17
7	0 : 100 : 0	83, 047	2143.3	93606.25	10559.25	1.13
8	0 : 100 : 50	83, 529	1781.0	77794.00	-5735.00	0.93
9	0 : 100 : 100	84, 010	2265.0	98935.20	14925.20	1.18
10	75 : 0 : 50	82, 893	2463.3	1,07,596.90	24703.90	1.30
11	75 : 0 : 50	83, 375	2631.7	1,14,952.65	31577.65	1.38
12	75 : 0 : 100	83, 856	2820.0	1,23,177.60	39321.60	1.47
13	75 : 50 : 0	83, 316	2893.3	1,26,379.30	43063.30	1.52
14	**75 : 50 : 50**	**83, 798**	**3176.7**	**1,38,758.25**	**54960.25**	**1.66**
15	75 : 50 : 100	84, 279	2980.0	1,30,166.40	45887.40	1.54
16	75 : 100 : 0	83, 740	3010.0	1,31,476.80	47736.80	1.57
17	75 : 100 : 50	84, 222	2640.0	1,15,315.20	31093.20	1.37
18	75 : 100 : 100	84, 703	3183.3	1,39,046.50	54343.50	1.64
19	150 : 0 : 0	83, 586	2841.7	1,24,125.45	40539.45	1.49
20	150 : 0 : 50	84, 068	2732.0	1,19,333.75	35265.75	1.42
21	150 : 50 : 100	84, 549	3083.3	1,34,678.50	50129.50	1.59
22	150 : 50 : 0	84, 009	3253.3	1,42,104.10	58095.10	1.69
23	150 : 50 : 50	83, 105	2636.7	1,15,171.00	32066.00	1.39
24	150 : 50 : 100	84, 972	3140.0	1,37,155.20	52183.20	1.61
25	150 : 100 : 0	84, 433	3088.3	1,34,896.90	50463.90	1.60
26	150 : 100 : 50	84, 915	3285.0	1,43,488.80	58573.80	1.69
27	**150 : 100 : 100**	**85, 396**	**4166.7**	**1,82,001.45**	**96605.45**	**2.13**

Cost of fertilizer N @ Rs. 9.24 per kg, P_2O_5 @ 8.47 per kg, K_2O @ Rs. 9.63 per kg.
Price of dry ginger (Unbleached) Rs. 43.68 per kg.

Table 50 Economics of fertilizer application (1997-98)

Sl. No.	Treatments N, P_2O_5 and K_2O (kg ha^{-1})	Cost of cultivation (Rs. ha^{-1})	Dry ginger yield (kg ha^{-1})	Value (Rs.)	Profit / loss (Rs. ha^{-1})	Benefit : cost ratio
1	No fertilizers	82200	2150.67	93554	11354	1.14
2	0 : 0 : 50	82553	2421.33	105328	22775	1.28
3	0 : 0 : 100	82906	2251.33	97933	15027	1.18
4	0 : 50 : 0	82686	2288.00	99528	16842	1.20
5	0 : 50 : 50	83038	2506.33	109025	25987	1.31
6	0 : 50 : 100	83391	2173.00	94526	11135	1.13
7	0 : 100 : 0	83171	2323.00	101268	18097	1.22
8	0 : 100 : 50	83653	2524.33	109808	26155	1.31
9	0 : 100 : 100	83877	2580.67	112259	28382	1.33
10	75 : 0 : 50	82803	2795.67	121812	38809	1.47
11	75 : 0 : 50	83156	2826.67	122960	39804	1.48
12	75 : 0 : 100	83509	2831.67	123178	39699	1.48
13	75 : 50 : 0	83289	2805.00	122018	38729	1.46
14	**75 : 50 : 50**	**83614**	**3180.33**	**138344**	**54730**	**1.65**
15	75 : 50 : 100	83994	2847.00	123845	39851	1.47
16	75 : 100 : 0	83774	2691.33	117073	33299	1.40
17	75 : 100 : 50	84127	3085.00	134198	50071	1.60
18	75 : 100 : 100	84480	3274.00	142419	57939	1.69
19	150 : 0 : 0	83406	2808.00	122148	38742	1.46
20	150 : 0 : 50	83759	3013.00	131066	47307	1.56
21	150 : 50 : 100	84112	2768.33	120422	36310	1.43
22	150 : 50 : 0	83892	2868.33	124772	40880	1.49
23	150 : 50 : 50	84245	2752.00	119712	35467	1.42
24	150 : 50 : 100	84597	2723.33	118465	33868	1.40
25	150 : 100 : 0	84377	2808.00	122148	37771	1.45
26	150 : 100 : 50	84730	3366.00	146421	61691	1.73
27	**150 : 100 : 100**	**85083**	**4237.00**	**184310**	**99227**	**2.17**

Cost of fertilizer N @ Rs. 8.04 per kg, P_2O_5 @ Rs. 9.71 per kg, K_2O @ Rs. 7.06 per kg.
Price of dry ginger (Unbleached) Rs. 43.50 per kg.

4.2.8 Economics of fertilizer application

The economics of fertilizer application are presented in Tables 49 and 50. It is evident that when ginger intercropped in the coconut garden, application of fertilizers at the rate of 150 kg N, 100 kg P_2O_5 and 100 kg K_2O ha^{-1}, produced the maximum net return of Rs. 96605.45 and Rs. 99227 during first and second year respectively. Among the fertilizer levels tried, 150 : 100 : 100 kg N, P_2O_5 and K_2O ha^{-1} gave maximum benefit : cost ratio when ginger was -intercropped in coconut garden.

4.3 Experiment III

The results of the experiment "effect of K levels, mulching and triazole" are presented below.

4.3.1 Growth characters

4.3.1.1 Height of the plant

The effect of treatments on height of the plant for both the years are presented in the Table 51.

At 60 DAP, the effect of potassium on plant height was not significant during both the years. The effect of triazole on plant height was significant during first year. The plants treated with higher level of triazole registered increased plant height. But the difference between T_1 and T_2 was not significant. The influence of mulch on plant height was significant only during second year. Maximum plant height was recorded at lowest level of mulch m_1 which was on par with m_2.

Table 51 Effect of Potassium (K), Mulch (M), Triazole (T) and K x M interaction on plant height (cm)

Treat-ments	Height of the plant (cm)					
	60 DAP		120 DAP		180 DAP	
	I	II	I	II	I	II
k_0	39.03	39.86	48.60	52.43	56.83	71.51
k_1	38.39	40.27	47.90	53.83	58.72	70.88
k_2	39.93	40.47	48.44	57.22	61.85	71.45
F	**0.517**	**0.067**	**0.189**	**10.192***	**17.628****	**0.095**
SE	1.073	1.192	0.846	0.770	0.604	1.128
CD	**3.713**	**4.124**	**2.927**	**2.666**	**2.089**	**3.904**
m_1	38.25	41.91	47.50	54.11	59.18	67.99
m_2	39.95	40.88	49.83	54.73	59.43	70.94
m_3	39.15	37.81	47.60	54.64	58.78	74.91
F	0.527	9.222*	1.998	0.189	0.641	13.625**
SE	1.173	0.703	0.934	0.768	0.407	0.940
CD	-	**2.433**	-	-	-	**3.254**
t_0	37.22	39.52	47.45	54.24	58.03	70.71
t_1	39.28	41.11	49.28	55.30	59.84	71.90
t_2	40.85	39.96	48.20	53.94	59.52	71.22
F	**9.784****	**1.842**	**2.685**	**0.953**	**2.309**	**1.022**
SE	0.584	0.605	0.560	0.729	0.634	0.586
CD	**1.656**	-	-	-	-	-
k_0 m_1	37.74	40.05	49.60	53.61	58.01	69.96
k_0 m_2	39.69	41.08	49.06	49.54	56.62	63.91
k_0 m_3	39.66	38.45	47.13	54.15	55.86	80.65
k_1 m_1	37.22	41.10	46.15	50.34	56.15	64.58
k_1 m_2	39.23	41.22	48.53	56.14	59.97	73.95
k_1 m_3	38.73	38.49	49.01	55.02	60.02	74.10
k_2 m_1	39.80	44.57	46.75	58.38	63.38	69.43
k_2 m_2	40.94	40.36	51.91	58.51	61.70	74.96
k_2 m_3	39.06	36.47	46.65	54.76	60.46	69.97
F	**0.383**	**6.547****	**7.972****	**8.265****	**5.015***	**13.904****
SE	1.185	0.723	0.701	1.100	0.890	1.640
CD	-	**2.229**	**2.161**	**3.391**	**2.742**	**5.054**

**** Significant at 1 % level** *** Significant at 5 % level**

K x M interaction was significant during the second year. Maximum plant height was observed under the combination k_2 m_1.

At 120 DAP, the effect of potassium on plant height was significant during second year. Maximum plant height was recorded at k_2 level. The mulch and triazole had no effect on plant height during both the years.

The interaction K x M on plant height was significant at 120 DAP during both the years. Maximum plant height was observed under the combination k_2 m_3 whereas during the second year, k_2 m_2 recorded the maximum plant height which was on par with k_2 m_1 and k_1 m_2.

At 180 DAP, the influence of potassium on plant height was significant only at higher level of potassium (k_2). But during the second year the effect of potassium was not significant. The effect of mulch on plant height was significant in the second year. The mulch level m_3 recorded significantly higher plant height.

During both the years the K x M interactions was significant. Maximum plant height was observed under the combination k_2 m_1 during first year but in the second year highest plant height was recorded under the combination k_0 m_3.

4.3.1.2 Number of tillers

The effect of treatments on number of tillers per plant for both the years are presented in the Table 52.

At 60 DAP, the effect of potassium on tiller production was significant during first year. Maximum number of tillers per plant was registered under k_1 which was on par with k_2. During both the years, mulch levels had no effect on tiller production. Application of triazole had significant effect on tiller

Table 52 Effect of Potassium (K), Mulch (M), Triazole (T) and K x M interaction on number of tillers

Treat ments	Number of tillers per plant					
	60 DAP		120 DAP		180 DAP	
	I	II	I	II	I	II
k_0	5.58	5.39	10.35	9.46	13.88	14.98
k_1	6.63	5.84	10.75	10.85	15.91	17.33
k_2	6.41	5.51	12.09	11.30	18.59	16.61
F	**8.071***	**0.902**	**7.798***	**17.181****	**84.674****	**7.388***
SE	0.195	0.248	0.326	0.231	0.256	0.442
CD	**0.675**	-	**1.127**	**0.801**	**0.887**	**1.529**
m_1	5.61	5.44	10.58	10.67	15.65	16.82
m_2	6.44	5.56	10.82	10.50	16.16	16.18
m_3	6.57	5.74	11.79	10.44	16.58	15.92
F	**3.211**	**0.398**	**12.287****	**0.379**	**1.766**	**1.627**
SE	0.291	0.236	0.182	0.198	0.349	0.362
CD	-	-	**0.631**	-	-	-
t_0	5.87	5.31	10.73	10.47	15.89	16.16
t_1	6.40	5.90	11.58	10.73	16.50	16.53
t_2	6.35	5.53	10.88	10.41	15.99	16.23
F	**1.889**	**3.246***	**2.608**	**0.621**	**0.965**	**0.237**
SE	0.214	0.166	0.280	0.219	0.332	0.407
CD	-	**0.470**	-	-	-	-
k_0 m_1	5.20	5.33	9.63	9.33	13.26	14.77
k_0 m_2	6.06	5.71	10.57	9.65	14.33	14.71
k_0 m_3	5.48	5.13	10.85	9.41	14.07	15.48
k_1 m_1	6.12	6.02	10.93	10.95	15.73	17.58
k_1 m_2	6.36	5.46	10.03	10.54	15.77	17.19
k_1 m_3	7.40	6.05	11.29	11.08	16.23	17.21
k_2 m_1	5.51	4.99	11.17	11.75	17.96	18.10
k_2 m_2	6.90	5.50	11.88	11.31	18.38	16.65
k_2 m_3	6.83	6.04	13.22	10.83	19.43	15.07
F	**1.347**	**2.068**	**1.311**	**0.782**	**0.634**	**1.500**
SE	0.412	0.314	0.513	0.471	0.499	0.794
CD	-	-	-	-	-	-

** Significant at 1 % level * Significant at 5 % level

production during second year. Maximum number of tillers were produced when plants treated with t_2 level of triazole and was on par with t_1.

K x M interaction was not significant during both the years.

At 120 DAP, the influence of potassium on tiller production was significant during both the years. During first year k_2 registered maximum tiller numbers and it was on par with k_1 in the second year. The effect of mulch on tiller number was significant only at first year and mulch level m_3 registered highest number of tillers per plant.

K x M interaction on tiller number was not significant during both the years.

At 180 DAP, the effect of potassium on tiller number was significant during both the years. During first year, significantly higher number of tillers per plant was recorded under k_2 which was on par with k_1 during second year. Application of different levels of mulch and triazole had no effect on tiller production during both the years.

K x M interaction had no effect on tiller production during both the years.

4.3.1.3 Number of leaves

The effect of treatments on number of leaves per plant for both the years are presented in the Table 53.

At 60 DAP, during the first year application of potassium had significant effect on number of leaves per plant. Significantly higher number of leaves per plant was recorded in plants under k_2 which was on par with k_1. Different levels of mulch and triazole had no effect on leaf production.

Table 53 Effect of Potassium (K), Mulch (M), Triazole (T) and K x M interaction on number of leaves

Treat ments	Number of leaves per plant					
	60 DAP		120 DAP		180 DAP	
	I	II	I	II	I	II
k_0	38.23	33.06	85.52	93.74	167.74	145.71
k_1	43.27	37.96	89.11	99.79	176.40	162.04
k_2	43.72	34.76	92.18	128.04	212.10	212.72
F	**6.628***	**1.838**	**20.233****	**15.372****	**25.818****	**14.596****
SE	1.184	1.832	0.742	4.670	4.628	9.146
CD	**4.099**	-	**2.567**	**16.161**	**16.016**	**31.651**
m_1	41.99	35.75	89.82	108.76	187.50	172.88
m_2	43.23	35.12	89.24	104.50	185.45	173.80
m_3	39.99	34.91	87.75	108.31	183.30	173.80
F	**1.280**	**0.097**	**0.699**	**1.947**	**0.087**	**0.012**
SE	1.444	1.401	1.275	1.675	7.131	4.766
CD	-	-	-	-	-	-
t_0	41.31	34.04	89.18	105.95	182.72	172.32
t_1	42.71	36.66	88.50	110.22	187.56	178.43
t_2	41.19	35.08	89.13	105.40	185.97	169.73
F	0.713	1.586	0.173	1.136	0.193	0.604
SE	1.000	1.047	0.901	2.476	5.607	5.750
CD	-	-	-	-	-	-
k_0 m_1	38.675	33.72	86.41	95.32	177.88	151.00
k_0 m_2	40.17	33.87	85.91	87.93	159.02	134.21
k_0 m_3	35.84	31.61	84.23	97.97	166.32	151.91
k_1 m_1	45.41	40.85	90.84	102.09	178.49	156.44
k_1 m_2	44.15	37.43	88.62	95.53	173.51	157.07
k_1 m_3	40.26	35.58	87.87	101.76	177.22	172.62
k_2 m_1	41.90	32.68	92.22	128.87	206.13	211.20
k_2 m_2	45.38	34.05	93.18	130.05	223.83	230.11
k_2 m_3	43.88	37.55	91.16	125.21	206.35	196.86
F	**0.996**	**1.913**	**0.419**	**0.992**	**0.755**	**3.783***
SE	1.884	1.944	1.249	3.933	11.130	7.802
CD	-	-	-	-	-	**24.042**

** Significant at 1 % level   * Significant at 5 % level

K x M interaction also had no effect on leaf production.

At 120 DAP, the effect of potassium on leaf production was significant during both the years. At this stage k_2 registered maximum number of leaves per plant during both the years. Different mulch and triazole treatments had no effect on leaf production.

Effect of potassium on leaf number was significant at 180 DAP during both the years. Significantly higher number of leaves per plant was registered by k_2.

The influence of K x M interaction on number of leaves per plant was significant only during the second year. The highest number of leaves per plant was recorded by k_2 m_2 which was on par with k_2 m_1.

4.3.1.4 Leaf area

The effect of treatments on leaf area for both the years is presented in the Table 54.

Different levels of potassium, mulch and triazole had no effect on leaf area per plant at 60 DAP.

K x M interaction on leaf area was not significant during both the years.

At 120 DAP different levels of potassium had significant effect on leaf area during both the seasons. Significantly higher leaf area was recorded at k_2 level of K during both the seasons. Different combinations of mulch and triazole had no effect on production of leaf area per plant during both the years.

K x M interaction on production of leaf area was significant only at first year. Significantly higher leaf area was recorded under the combination k_2 m_3 which was on par with k_2 m_2.

Table 54 Effect of Potassium (K), Mulch (M), Triazole (T) and K x M interaction on leaf area (cm²)

Treatments	Leaf area (cm²)					
	60 DAP		120 DAP		180 DAP	
	I	II	I	II	I	II
k_0	857.46	895.74	4098.14	3924.85	6732.17	6634.75
k_1	917.56	1042.29	4683.50	4674.36	8644.72	8757.92
k_2	1006.75	1076.13	6011.70	5897.35	10920.25	11202.08
F	**4.593**	**3.533**	**26.838****	**19.189****	**23.425****	**19.510****
SE	35.050	51.010	189.268	227.298	433.247	517.446
CD	-	-	**654.976**	**786.585**	**1499.284**	**1790.662**
m_1	901.35	1016.86	4803.08	4871.96	8598.50	8816.39
m_2	940.11	1005.80	4978.20	4839.13	8926.61	8935.89
m_3	940.31	991.49	5012.06	4785.47	8772.03	8842.47
F	**0.946**	**0.107**	**1.561**	**0.266**	**0.561**	**0.039**
SE	23.068	38.916	89.793	84.769	219.192	318.690
CD	-	-	-	-	-	-
t_0	915.44	981.25	4933.45	4745.26	8646.63	8802.89
t_1	938.97	1044.25	5668.22	4993.81	8735.56	8888.61
t_2	927.36	988.68	4791.67	4757.49	8915.56	8903.25
F	**0.293**	**1.002**	**1.546**	**1.063**	**0.473**	**0.045**
SE	21.729	34.401	111.209	135.881	201.641	254.785
CD	-	-	-	-	-	-
$k_0 m_1$	868.31	919.42	4247.42	3888.58	6857.17	6762.42
$k_0 m_2$	871.25	914.40	4139.42	4089.43	6696.58	6579.17
$k_0 m_3$	832.83	853.43	3907.58	3796.54	6642.75	6562.67
$k_1 m_1$	866.17	1103.57	4583.75	4786.33	8205.00	8445.17
$k_1 m_2$	1000.33	1063.58	4635.50	4464.81	8596.25	8445.17
$k_1 m_3$	886.17	959.71	4831.25	4771.94	9132.92	9383.42
$k_2 m_1$	969.58	1027.64	5578.08	5940.96	10733.33	11241.58
$k_2 m_2$	948.75	1039.42	6159.67	5963.17	11487.00	11783.33
$k_2 m_3$	1101.92	1161.34	6297.33	5787.92	10540.42	10581.33
F	**2.522**	**1.473**	**13.446****	**1.597**	**1.555**	**1.655**
SE	46.880	63.444	75.965	135.673	358.124	445.297
CD	-	-	**234.091**	-	-	-

**** Significant at 1 % level** *** Significant at 5 % level**

The influence of potassium on leaf area at 180 DAP was significant during both the years. Significantly higher leaf area was registered by k_2 during both the years. Different combinations of mulch and triazole had no effect on production of leaf area.

K x M interaction on production of leaf area was not significant during both the seasons.

4.3.2 Physiological aspects

4.3.2.1 Dry matter production

The effect of treatments on dry matter production (DMP) for both the years are presented in the Table 55.

At 60 DAP, the different combinations of potassium and mulch had no effect on DMP. The effect of triazole on dry matter production was significant during both the years. The variations in DMP between t_1 and t_2 were not significant.

K x M interaction on DMP was not significant during both the years.

The effect of potassium on DMP at 120 DAP was significant during the first year. The application of potassium at k_2 level registered significantly higher DMP. The influence of triazole on DMP was significant during first year. Significantly higher DMP was obtained at t_2 which was on par with t_1.

K x M interaction had no effect on DMP.

At 180 DAP, during both the years, the increased DMP was registered by higher rates of K application. Significantly higher DMP was recorded at k_3. Different combinations of mulch and triazole had no effect on DMP.

K x M interaction had no effect on DMP.

Table 55 Effect of Potassium (K), Mulch (M), Triazole (T) and K x M interaction on dry matter production (g)

Treatments	Dry matter production					
	60 DAP		120 DAP		180 DAP	
	I	II	I	II	I	II
k_0	7.04	6.63	19.20	19.28	62.61	60.58
k_1	6.69	6.28	18.88	20.22	76.18	77.69
k_2	6.95	6.42	21.77	20.80	93.77	85.26
F	**2.912**	**0.802**	**37.533****	**4.637**	**1314.341****	**49.354****
SE	0.106	0.199	0.259	0.357	1.492	1.800
CD	-	-	**0.897**	-	**0.431**	**6.228**
m_1	6.56	6.08	19.53	19.59	77.29	75.67
m_2	7.03	6.53	20.61	20.66	77.23	73.87
m_3	7.09	6.72	19.71	20.05	77.55	73.99
F	**2.268**	**1.016**	**2.261**	**0.979**	**0.096**	**0.496**
SE	0.190	0.325	0.385	0.540	0.706	1.425
CD	-	-	-	-	-	-
t_0	6.38	5.94	19.06	19.89	76.24	73.46
t_1	7.05	6.71	20.19	19.48	78.11	76.27
t_2	7.25	6.68	20.60	20.92	78.21	73.80
F	**4.972***	**3.101***	**3.811***	**2.563**	**1.933**	**1.326**
SE	0.206	0.248	0.408	0.464	0.793	1.329
CD	**0.583**	**0.703**	**1.158**	-	-	-
$k_0 m_1$	6.74	6.40	19.35	18.74	61.64	62.13
$k_0 m_2$	7.22	6.60	19.52	20.49	62.97	59.07
$k_0 m_3$	7.16	6.90	18.73	18.61	63.22	60.54
$k_1 m_1$	6.24	5.82	17.89	19.79	77.07	78.29
$k_1 m_2$	7.03	6.65	19.81	19.97	75.05	77.74
$k_1 m_3$	6.80	6.37	18.93	20.90	76.41	77.04
$k_2 m_1$	6.71	6.03	21.34	21.25	93.15	86.58
$k_2 m_2$	6.85	6.35	22.50	21.52	95.17	84.80
$k_2 m_3$	7.29	6.89	21.48	20.64	93.01	84.39
F	**0.264**	**0.266**	**0.539**	**0.435**	**1.112**	**0.114**
SE	0.380	0.460	0.676	1.084	1.178	2.166
CD	-	-	-	-	-	-

**** Significant at 1 % level** *** Significant at 5 % level**

4.3.2.2 Relative growth rate

The data on effect of treatments on relative growth rate (RGR) for both the seasons are presented in the Table 56.

At the first phase (60 to 120 DAP) increase in levels of potassium significantly increased the RGR during both the years. In the first year significantly higher RGR was recorded at k_2 level but it was on par with k_1 during second year. Different combinations of mulch and triazole had no effect on RGR during both the years.

The influence of K x M interaction on relative growth rate was not significant during both the seasons.

During the second phase (120 to 180 DAP), the levels of k_1 and k_2 were on par and resulted in significantly higher RGR when compared to k_0 during both the seasons.

K x M interaction on RGR was not significant during both the seasons.

4.3.2.3 Net assimilation rate

The effect of treatments on net assimilation rate (NAR) for both the seasons are presented in the Table 57.

At k_0 level of potassium, significantly higher NAR was recorded during both the years. Increased levels of potassium had no beneficial effect on NAR at the early growth phase (60 to 120 DAP). Different combinations of mulch and triazole had no effect on NAR during both the years.

K x M interaction on NAR was not significant during both the years.

Table 56 Effect of Potassium (K), Mulch (M), Triazole (T) and K x M interaction on relative growth rate (g g^{-1} day)

Treat-ment	Relative growth rate			
	Between 60 to 120 DAP		Between 120 to 180 DAP	
	I	II	I	II
k_0	0.0169	0.0178	.00198	0.0192
k_1	0.0176	0.0198	0.0224	0.0225
k_2	0.0192	0.0203	0.0244	0.0236
F	**14.935****	**6.899****	**90.556****	**51.276****
SE	0.0007	0.001	0.0006	0.0007
CD	**0. 001**	**0. 002**	**0. 001**	**0. 001**
m_1	0.0183	0.0198	0.0229	0.0224
m_2	0.0181	0.0196	0.0221	0.0212
m_3	0.0173	0.0185	0.0227	0.0217
F	**1.281**	**1.119**	**1.599**	**1.315**
SE	0.001	0. 001	0.0008	0. 001
CD	-	-	-	-
t_0	0.0184	0.0203	0.0230	0.0218
t_1	0.0177	0.0184	0.0225	0.0226
t_2	0.0176	0.0192	0.0221	0.0209
F	**0.608**	**2.504**	**1.443**	**2.615**
SE	0. 001	0. 001	0.001	0. 001
CD	-	-	-	-
k_0 m_1	0.0176	0.0181	0.0195	0.0200
k_0 m_2	0.0166	0.0187	0.0197	0.0179
k_0 m_3	0.0164	0.0167	0.0203	0.0197
k_1 m_1	0.177	0.0208	0.0245	0.0229
k_1 m_2	0.0177	0.0187	0.0223	0.0228
k_1 m_3	0.0172	0.0200	0.0233	0.0219
k_2 m_1	0.0195	0.0206	0.0246	0.0242
k_2 m_2	0.0200	0.0213	0.0242	0.0229
k_2 m_3	0.0182	0.0189	0.0245	0.0236
F	**0.462**	**1.644**	**0.926**	**0.444**
SE	0. 001	0. 001	0. 001	0. 001
CD	-	-	-	-

**** Significant at 1 % level** *** Significant at 5 % level**

Table 57 Effect of Potassium (K), Mulch (M), Triazole (T) and K x M interaction on net assimilation rate (g m^{-2} day^{-1})

Treat-ments	Net assimilation rate			
	Between 60 to 120 DAP		Between 120 to 180 DAP	
	I	II	I	II
k_0	0.0518	0.0556	0.0854	0.0840
k_1	0.0459	0.0524	0.0915	0.0931
k_2	0.0447	0.0436	0.0896	0.0799
F	**11.410****	**14.049****	**0.59**	**1.582**
SE	0.001	0.002	0.004	0.005
CD	**0.004**	**0.006**	-	-
m_1	0.0483	0.0497	0.0912	0.0892
m_2	0.0485	0.0521	0.0865	0.0829
m_3	0.0456	0.0497	0.0889	0.0849
F	**0.694**	**0.378**	**0.958**	**0.483**
SE	0.002	0.002	0.002	0.005
CD	-	-	-	-
t_0	0.0459	0.0522	0.0891	0.0852
t_1	0.0467	0.0461	0.0887	0.0881
t_2	0.0498	0.0533	0.0888	0.0837
F	**1.425**	**3.341***	**0.007**	**0.403**
SE	0.002	0.002	0.002	0.004
CD	-	**0.006**	-	-
k_0 m_1	0.0524	0.0545	0.0811	0.0876
k_0 m_2	0.0516	0.0588	0.0843	0.0762
k_0 m_3	0.0514	0.0535	0.0909	0.0883
k_1 m_1	0.0453	0.0514	0.0997	0.0985
k_1 m_2	0.0474	0.0516	0.0887	0.0972
k_1 m_3	0.0448	0.0541	0.0861	0.0837
k_2 m_1	0.0471	0.0432	0.0927	0.0816
k_2 m_2	0.0465	0.0460	0.0864	0.0753
k_2 m_3	0.0404	0.0416	0.0898	0.0828
F	**0.676**	**0.284**	**0.642**	**2.304**
SE	0.002	0.004	0.004	0.005
CD	-	-	-	-

**** Significant at 1 % level** *** Significant at 5 % level**

During the second phase (120 to 180 DAP), the effect of different levels of potassium, mulch and triazole had no effect on NAR.

K x M interaction on NAR was not significant during both the years.

4.3.2.4 Crop growth rate

The effect of treatments on crop growth rate (CGR) for both the seasons are presented in the Table 58.

At the first phase, (60 to 120 DAP) an increase in the levels of potassium significantly increased the CGR during both the years. During the first year, k_2 registered significantly higher CGR but k_1 and k_2 were on par in the second year. The levels of mulch and triazole had no effect on CGR during both the years.

K x M interaction on CGR was not significant during both the seasons.

At the second phase (120 to 180 DAP), increase in the levels of potassium significantly increased the CGR during both the years. The maximum CGR was recorded at k_2. The levels of mulch and triazole had no effect on CGR during both the years.

K x M interactions on CGR was not significant during both the years.

4.3.2.5 Specific leaf weight

The effect of treatments on specific leaf weight (SLW) for both the seasons are presented in the Table 59.

At 60 DAP, during first year, application of potassium had no significant effect on SLW. The levels of mulch and triazole had no effect on SLW during both the years.

Table 58 Effect of Potassium (K), Mulch (M), Triazole (T) and K x M interaction on crop growth rate (g m^{-2} day^{-1})

Treat-ments	Crop growth rate			
	Between 60 to 120 DAP		Between 120 to 180 DAP	
	I	II	I	II
k_0	0.3343	0.3423	0.8926	0.8569
k_1	0.3395	0.3795	1.2342	1.2461
k_2	0.4233	0.4059	1.5451	1.4041
F	**24.841****	**9.178****	**230.491****	**40.096****
SE	0.010	0.011	0.074	0. 044
CD	**0.035**	**0.037**	**0.021**	**0. 154**
m_1	0.3635	0.3714	1.2334	1.1994
m_2	0.3796	0.3887	1.2189	1.1508
m_3	0.3539	0.3677	1.2195	1.1569
F	**1.561**	**0.853**	**0.241**	**2.946**
SE	0. 010	0. 012	0. 017	0. 015
CD	-	-	-	-
t_0	0.3561	0.3839	1.2120	1.1570
t_1	0.3688	0.3518	1.2190	1.2065
t_2	0.3722	0.3921	1.2408	1.1436
F	**0.504**	**2.788**	**0.461**	**0.989**
SE	0. 012	0. 013	0. 022	0. 033
CD	-	-	-	-
$k_0\ m_1$	0.3478	0.3317	0.8713	0.9184
$k_0\ m_2$	0.3377	0.3758	0.8927	0.7904
$k_0\ m_3$	0.3174	0.3195	0.9139	0.8619
$k_1\ m_1$	0.3268	0.3781	1.2573	1.2375
$k_1\ m_2$	0.3495	0.3587	1.1929	1.2568
$k_1\ m_3$	0.3421	0.4017	1.2523	1.2439
$k_2\ m_1$	0.4160	0.4045	1.5717	1.4422
$k_2\ m_2$	0.4517	0.4315	1.5711	1.4050
$k_2\ m_3$	0.4020	0.3819	1.4925	1.3650
F	**0.918**	**1.459**	**1.643**	**0.542**
SE	0. 017	0. 023	0. 033	0. 508
CD	-	-	-	-

**** Significant at 1 % level** *** Significant at 5 % level**

Table 59 Effect of Potassium (K), Mulch (M), Triazole (T) and K x M interaction on specific leaf weight (g m^{-2})

Treat-ments	Specific leaf weight					
	60 DAP		120 DAP		180 DAP	
	I	II	I	II	I	II
k_0	0.0066	0.0040	0.0040	0.0027	0.0056	0.0038
k_1	0.0053	0.0034	0.0033	0.0028	0.0048	0.0036
k_2	0.0055	0.0033	0.0029	0.0032	0.0039	0.0031
F	**11.067****	**2.566**	**3.952**	**1.027**	**4.914**	**2.336**
SE	0.0002	0.0003	0.0001	0.0002	0.0004	0.0001
CD	**0.001**	-	-	-	-	-
m_1	0.0056	0.0034	0.0034	0.0028	0.0049	0.0036
m_2	0.0057	0.0036	0.0034	0.0026	0.0045	0.0034
m_3	0.0060	0.0036	0.0033	0.0026	0.0049	0.0035
F	**0.288**	**0.291**	**0.446**	**1.397**	**3.133**	**0.296**
SE	0.0004	0.0002	0.0001	0.0001	0.0001	0.0002
CD	-	-	-	-	-	-
t_0	0.0054	0.0033	0.0033	0.0026	0.0048	0.0034
t_1	0.0059	0.0037	0.0033	0.0026	0.0047	0.0035
t_2	0.0061	0.0036	0.0035	0.0028	0.0048	0.0035
F	**2.258**	**1.170**	**2.509**	**0.514**	**0.172**	**0.268**
SE	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
CD	-	-	-	-	-	-
$k_0 m_1$	0.0063	0.0036	0.0039	0.0030	0.0054	0.0038
$k_0 m_2$	0.0063	0.0041	0.0040	0.0024	0.0053	0.0034
$k_0 m_3$	0.0071	0.0043	0.0039	0.0028	0.0059	0.0041
$k_1 m_1$	0.0053	0.0032	0.0032	0.0028	0.0050	0.0040
$k_1 m_2$	0.0052	0.0036	0.0034	0.0031	0.0047	0.0039
$k_1 m_3$	0.0055	0.0033	0.0032	0.0026	0.0046	0.0030
$k_2 m_1$	0.0053	0.0033	0.0031	0.0025	0.0042	0.0031
$k_2 m_2$	0.0057	0.0032	0.0029	0.0025	0.0036	0.0029
$k_2 m_3$	0.0054	0.0033	0.0026	0.0025	0.0041	0.0033
F	**0.440**	**0.608**	**1.996**	**2.170**	**3.847**	**3.771**
SE	0.0004	0.0003	0.0001	0.0002	0.0001	0.0002
CD	-	-	-	-	-	-

**** Significant at 1 % level** *** Significant at 5 % level**

K x M interaction on SLW was also not significant during both the years.

At 120 DAP and 180 DAP, during both the years, different levels of potassium, mulch and triazole had no significant effect on SLW.

4.3.2.6 Leaf area index

The effect of treatments on leaf area index for both the years are presented in the Table 60.

The different levels of potassium, mulch and triazole had no significant effect on LAI during both years at 60 DAP.

K x M interaction on LAI was also not significant.

At 120 DAP, significantly higher LAI was observed at k_2 level of potassium during both the years. Application of different levels of mulch and triazole had no effect on LAI.

K x M interaction on LAI was significant only during first year. Significantly higher LAI was observed under the combination k_2 m_3 which was on par with k_2 m_2.

The influence of potassium on leaf area index at 180 DAP was significant during both the years. Significantly higher leaf area index was registered by k_2 during both the years. Application of mulch and triazole at different levels had no significant effect on LAI.

K x M interaction had no effect on LAI.

Table 60 Effect of Potassium (K), Mulch (M), Triazole (T) and K x M interaction on leaf area index

Treatments	Leaf area index					
	60 DAP		120 DAP		180 DAP	
	I	II	I	II	I	II
k_0	1.372	1.433	6.557	6.280	10.771	10.616
k_1	1.468	1.668	7.494	7.479	13.832	14.013
k_2	1.611	1.722	9.619	9.436	17.472	17.923
F	**4.593**	**3.533**	**26.841****	**19.188****	**23.419****	**19.510****
SE	0.056	0.082	0.303	0.364	0.693	0.828
CD	-	-	**1.048**	**1.259**	**2.399**	**2.865**
m_1	1.442	1.627	7.685	7.795	13.758	14.106
m_2	1.504	1.609	7.965	7.743	14.283	14.297
m_3	1.504	1.586	8.019	7.657	14.035	14.148
F	**0.945**	**0.107**	**1.559**	**0.265**	**0.560**	**0.039**
SE	0.037	0.062	0.144	0.136	0.351	0.510
CD	-	-	-	-	-	-
t_0	1.465	1.570	7.894	7.592	13.834	14.085
t_1	1.502	1.671	8.109	7.990	13.977	14.222
t_2	1.484	1.582	7.667	7.612	14.265	14.245
F	**0.294**	**1.001**	**1.546**	**1.063**	**0.463**	**0.045**
SE	0.035	0.055	0.178	0.217	0.323	0.408
CD	-	-	-	-	-	-
$k_0 m_1$	1.389	1.471	6.796	6.222	10.971	10.820
$k_0 m_2$	1.394	1.463	6.623	6.543	10.715	10.527
$k_0 m_3$	1.333	1.365	6.252	6.074	10.628	10.500
$k_1 m_1$	1.386	1.766	7.334	7.658	13.128	13.512
$k_1 m_2$	1.601	1.702	7.417	7.144	13.754	13.512
$k_1 m_3$	1.418	1.536	7.730	7.635	14.613	15.013
$k_2 m_1$	1.551	1.644	8.925	9.506	17.173	17.987
$k_2 m_2$	1.518	1.663	9.855	9.541	18.379	18.853
$k_2 m_3$	1.763	1.858	10.076	9.261	16.865	16.930
F	**2.523**	**1.473**	**13.444****	**1.598**	**1.555**	**1.655**
SE	0.075	0.102	0.122	0.217	0.573	0.712
CD	-	-	**0.375**	-	-	-

**** Significant at 1 % level** *** Significant at 5 % level**

4.3.3 Biochemical aspects

4.3.3.1 Chlorophyll content

The effect of treatments on chlorophyll content for both the years are presented in the Table 61.

Potassium application had no effect on chlorophyll 'a' content during both the years. The influence of mulch levels had significant effect on chlorophyll 'a' content during second year. Significantly higher levels of chlorophyll 'a' content was recorded at m_2 level. The influence of triazole on chlorophyll 'a' content was significant during both the years. The triazole levels t_1 and t_2 were on par and produced significantly higher chlorophyll 'a' content. But during the second year, t_1 produced significantly higher chlorophyll 'a' content the rest.

The K x M interaction was significant on chlorophyll 'a' content during both the years. In the presence of K at k_1 level, plants grown with m_2 levels of mulch produced maximum chlorophyll 'a' content. At k_2 level mulch level m_1 and m_3 were on par and produced significantly higher chlorophyll 'b' content during both the years.

Effect of potassium on chlorophyll 'b' content was significant during both the years. Significantly higher chlorophyll 'b' content was registered at k_1. The influence of mulch on chlorophyll 'b' content was significant during both the years. The plants receiving the m_2 level of mulch registered significantly higher chlorophyll 'b' content during both the years. The influence of triazole on chlorophyll 'b' content was significant during both the years. The triazole levels t_1 and t_2 were on par and produced significantly higher chlorophyll 'b' content during both the seasons.

Table 61 Effect of Potassium (K), Mulch (M), Triazole (T) and K x M interaction on chlorophyll 'a', chlorophyll 'b' and chlorophyll (total) content (mg g^{-1})

Treatments	Chlorophyll 'a'		Chlorophyll 'b'		Chlorophyll (total)	
	I	II	I	II	I	II
k_0	0.50	0.53	0.59	0.61	1.09	1.14
k_1	0.53	0.54	0.65	0.68	1.20	1.23
k_2	0.51	0.47	0.60	0.54	1.110	1.01
F	**2.032**	**17.257****	**74.625****	**272.585****	**7.817****	**151.054****
SE	0.010	0.009	0.004	0.004	0.021	0.009
CD	-	**0.030**	**0.013**	**0.014**	**0.072**	**0.031**
m_1	0.50	0.47	0.57	0.54	1.07	1.03
m_2	0.52	0.57	0.64	0.67	1.16	1.24
m_3	0.52	0.50	0.63	0.61	1.17	1.11
F	**0.677**	**58.867****	**111.008****	**625.778****	**15.959****	**144.769****
SE	.0013	0.007	0.004	0.003	0.013	0.009
CD	-	**0.024**	**0.013**	**0.009**	**0.046**	**0.031**
t_0	0.50	0.47	0.56	0.53	1.06	1.00
t_1	0.52	0.55	0.64	0.67	1.16	1.24
t_2	0.53	0.52	0.65	0.62	1.19	1.15
F	**4.884****	**67.566****	**51.849****	**458.524****	**19.033****	**123.252****
SE	0.007	0.005	0.006	0.003	0.016	0.011
CD	**0.021**	**0.015**	**0.018**	**0.009**	**0.045**	**0.031**
k_0 m_1	0.46	0.44	0.52	0.48	0.98	0.92
k_0 m_2	0.52	0.62	0.66	0.73	1.18	1.36
k_0 m_3	0.53	0.53	0.60	0.61	1.12	1.14
k_1 m_1	0.51	0.46	.056	0.52	1.07	1.02
k_1 m_2	0.56	0.66	0.74	0.80	1.30	1.46
k_1 m_3	0.52	0.49	0.66	0.72	1.24	1.21
k_2 m_1	0.53	0.50	0.64	0.64	1.17	1.14
k_2 m_2	0.47	0.44	0.55	0.48	1.02	0.91
k_2 m_3	0.53	0.48	0.62	0.51	1.14	0.99
F	**8.152****	**40.259****	**105.979****	**1160.097****	**26.889****	**141.219****
SE	0.014	0.012	0.0007	0.004	0.021	0.016
CD	**0.042**	**0.038**	**0.022**	**0.011**	**0.064**	**0.049**

**** Significant at 1 % level** *** Significant at 5 % level**

K x M interaction was significant on chlorophyll 'b' content and maximum chlorophyll 'b' content was recorded under the combination k_1 m_2 during both the seasons. At k_2 level, combination k_2 m_1 recorded the maximum chlorophyll 'b' content during both the years.

The effect of potassium on total chlorophyll content was significant during both the years. Significantly higher chlorophyll (total) content was registered at k_1 during both the seasons. The influence of mulch on chlorophyll (total) content was significant in both the years. The mulch levels m_2 and m_3 were on par but produced significantly higher chlorophyll (total) content when compared to m_1. During the second year mulch level m_2 registered significantly higher chlorophyll (total) content when compared to m_1 and m_3. The influence of triazole on chlorophyll (total) content was significant during both the years. In the first year highest chlorophyll (total) content was obtained under t_2 level of triazole which was on par with t_1. During the second year highest chlorophyll (total) content was recorded under the triazole level t_1.

K x M interaction on total chlorophyll content was significant during both the years. During the first year, at k_1 level, plants grown with m_2 and m_3 levels of mulch provided better chlorophyll (total) content and also no significant difference in total chlorophyll content was observed between m_2 and m_3 levels of mulch. During the second year, significantly higher chlorophyll (total) content was observed under the combination k_1 m_2.

4.3.3.2 Proline content

The effect of treatments on proline content for both the years are presented in the Table 62.

The levels of potassium had no significant effect on proline content. The influence of mulch on proline content was significant at the second year. Significantly higher proline content was recorded at m_3 level of mulch which was on par with m_1. With increase in levels of triazole there was significant increase in proline content. Plants receiving the highest level of triazole registered significantly higher proline content during both the years.

K x M interaction on proline content was significant at the first year. At k_0 level, highest proline content was recorded under the combination k_0 m_3. At k_1 and k_2 levels, different levels of mulch had no significant effect on proline content.

4.3.4 Yield and yield components

4.3.4.1 Shoot dry weight

The effect of treatments on shoot dry weight for both the seasons are presented in the Table 62.

In the first year, the effect of K on shoot dry weight was significant. Highest shoot dry weight was recorded at k_2 level. However, the variation in shoot dry weight between k_1 and k_2 was not significant. The levels of mulch and triazole had no significant effect on shoot dry weight during both the years.

K x M interaction on shoot dry weight was not significant during both the years.

4.3.4.2 Fresh ginger yield

The effect of treatment on fresh ginger yield for both the years are presented in Table 63.

Table 62 Effect of Potassium (K), Mulch (M), Triazole (T) and K x M interaction on proline content (μ g g^{-1} fresh weight) and shoot dry weight (kg ha^{-1})

Treat-ments	Proline		Shoot dry weight	
	I	II	I	II
k_0	0.451	0.461	1767.646	1711.333
k_1	0.441	0.460	1924.542	1848.750
k_2	0.446	0.450	1943.313	1848.042
F	**3.175**	**2.964**	**9.568***	**1.974**
SE	0.003	0.004	31.184	56.328
CD	-	-	**107.915**	-
m_1	0.443	0.456	1876.729	1866.813
m_2	0.446	0.448	1848.750	1788.188
m_3	0.450	0.468	1910.021	1753.125
F	**1.188**	**6.528***	**0.444**	**4.275**
SE	0.003	0.004	46.026	28.158
CD	-	-	-	-
t_0	0.410	0.429	1869.646	1830.333
t_1	0.437	0.454	1920.646	1834.229
t_2	0.492	0.488	1845.208	1743.563
F	**124.989****	**71.022****	**1.607**	**2.287**
SE	0.004	0.004	30.355	33.894
CD	**0.011**	**0.010**	-	-
k_0 m_1	0.442	0.464	1845.563	1871.063
k_0 m_2	0.448	0.453	1608.625	1704.250
k_0 m_3	0.464	0.467	1848.75	1558.688
k_1 m_1	0.447	0.452	1889.125	1862.563
k_1 m_2	0.439	0.449	1965.625	1871.063
k_1 m_3	0.438	0.480	1918.875	1812.625
k_2 m_1	0.441	0.453	1895.500	1866.813
k_2 m_2	0.449	0.442	1972.000	1789.250
k_2 m_3	0.448	0.457	1962.438	1888.063
F	**3.764***	**1.050**	**2.822**	**3.026**
SE	0.004	0.007	58.583	54.483
CD	**0.013**	-	-	-

**** Significant at 1 % level** *** Significant at 5 % level**

Table 63 Effect of Potassium (K), Mulch (M), Triazole (T) and K x M interaction on fresh ginger yield (t ha^{-1}) and dry ginger yield (kg ha^{-1})

Treat-ments	Fresh ginger yield		Dry ginger yield	
	I	II	I	II
k_0	11.340	11.375	2477.167	2488.139
k_1	14.317	14.589	3143.75	3208.667
k_2	14.814	15.307	3258.722	3367.028
F	**58.621****	**141.445****	**72.266****	**120.526****
SE	0.245	0.176	49.639	42.670
CD	**0.849**	**0.609**	**171.779**	**147.663**
m_1	13.232	13.499	2899.444	2969.111
m_2	13.551	13.861	2976.722	3036.611
m_3	13.688	13.912	3003.472	3058.111
F	**0.501**	**1.426**	**0.651**	**1.421**
SE	0.331	0.189	66.951	38.949
CD	-	-	-	-
t_0	13.441	13.788	2942.861	3021.194
t_1	13.691	13.749	3001.833	3023.194
t_2	13.339	13.734	2934.944	3019.444
F	**0.812**	**0.050**	**0.630**	**0.005**
SE	0.201	0.123	46.022	25.520
CD	-	-	-	-
$k_0 m_1$	11.411	11.433	2498.75	2513.417
$k_0 m_2$	11.284	11.408	2465	2471.583
$k_0 m_3$	11.326	11.283	2467.75	2479.417
$k_1 m_1$	12.888	13.785	2832.083	3032.583
$k_1 m_2$	15.039	15.023	3318.333	3304.333
$k_1 m_3$	15.024	14.96	3280.833	3289.083
$k_2 m_1$	15.398	15.279	3367.5	3361.333
$k_2 m_2$	14.329	15.151	3146.833	3333.917
$k_2 m_3$	14.715	15.491	3261.833	3405.833
F	**6.096****	**3.061**	**5.655****	**3.016**
SE	0.369	0.246	82.503	55.618
CD	**1.139**	-	**254.237**	-

** Significant at 1 % level * Significant at 5 % level

4.3.4.2 Fresh ginger yield

The effect of treatment on fresh ginger yield for both the years are presented in Table 63.

The influence of potassium on fresh ginger yield was significant during both the years. During the first year, treatments k_1 and k_2 were on par and produced significantly higher fresh ginger yield when compared to k_0. But in the second year potassium level k_2 produced significantly higher fresh ginger yield. The increased levels of mulch application had no significant effect on fresh ginger yield in either of the years. The triazole also had no effect on fresh ginger yield.

K x M interaction effect on fresh ginger yield was significant only during the first year. In the absence of K, no significant difference in fresh ginger yield was observed with three different levels of mulch. But in the presence of K, at k_1 level plants grown with m_2 and m_3 levels of mulch provided better yield and yield was on par. However, when K applied at k_2 level, m_1 mulch was found to be most acceptable than m_2. Also no significant difference in yield was observed between m_1 and m_3 levels of mulches with an application of k_2. During the second year, the K x M interaction on fresh ginger yield was not significant.

4.3.4.3 Dry ginger yield

The effect of treatments on dry ginger yield for both the years are presented in Table 63.

The influence of potassium on dry ginger yield was significant during both the years. The potassium level k_2 produced significantly higher dry ginger yield during both the years. The increased levels of mulch and triazole had no significant effect on dry ginger yield in either of the years.

K x M interaction effect on dry ginger yield was significant only during the first year. In the absence of K no significant effect on dry ginger yield was observed with three levels of mulch. But in the presence of K at k_1 level, plant grown with m_2 and m_3 levels of mulch recorded better dry ginger yield and also no significant difference in yield was observed between m_2 and m_3. At k_2 level of potassium, no significant effect on dry ginger yield was observed between different levels of mulch. However, K at k_2 level, m_1 was found to be more acceptable than other levels of mulch. During second year K x M interaction on dry ginger yield was not significant.

4.3.4.4 Harvest index

The effect of treatments on harvest index (HI) for both the seasons are presented in the Table 64.

Application of potassium significantly enhanced the HI during both the years. Harvest index was significantly higher at k_2 level which was on par with k_1. Different combinations of mulch and triazole had no significant effect on HI.

K x M interaction had no significant influence on the HI during both the years.

Table 64 Effect of Potassium (K), Mulch (M), Triazole (T) and K x M interaction on harvest index and root : shoot ratio

Treat-ments	Harvest index		Root : shoot ratio	
	I	II	I	II
k_0	0.549	0.555	0.167	0.185
k_1	0.586	0.598	0.149	0.168
k_2	0.591	0.610	0.159	0.175
F	**12.818****	**15.826****	**11.684****	**1.425**
SE	0.006	0.007	0.003	0.007
CD	**0.022**	**0.025**	**0.009**	-
m_1	0.569	0.575	0.157	0.169
m_2	0.582	0.591	0.165	0.182
m_3	0.574	0.597	0.154	0.179
F	**1.293**	**3.370**	**0.600**	**2.727**
SE	0.006	0.006	0.007	0.004
CD	-	-	-	-
t_0	0.573	0.584	0.161	0.172
t_1	0.574	0.584	0.155	0.174
t_2	0.579	0.595	0.160	0.183
F	**0.536**	**1.814**	**0.642**	**1.453**
SE	0.004	0.005	0.004	0.005
CD	-	-	-	-
$k_0 m_1$	0.538	0.535	0.164	0.169
$k_0 m_2$	0.573	0.556	0.185	0.188
$k_0 m_3$	0.537	0.573	0.153	0.200
$k_1 m_1$	0.563	0.583	0.152	0.167
$k_1 m_2$	0.595	0.602	0.151	0.172
$k_1 m_3$	0.599	0.610	0.145	0.164
$k_2 m_1$	0.606	0.608	0.156	0.169
$k_2 m_2$	0.580	0.613	0.157	0.185
$k_2 m_3$	0.587	0.608	0.163	0.172
F	**2.872**	**1.554**	**2.352**	**1.794**
SE	0.012	0.008	0.007	0.007
CD	**0.037**	**0.024**	**0.020**	**0.002**

**** Significant at 1 % level** *** Significant at 5 % level**

4.3.4.5 Root : shoot ratio

The effect of treatments on root : shoot ratio for both the seasons are presented in the Table 64.

The different levels of potassium, mulch and triazole had no significant effect on root : shoot ratio during both the years.

K x M interaction on root : shoot ratio was significant during both the seasons. In the absence of potassium the effect of mulch was very significant. Highest root : shoot ratio was obtained at combination k_0 m_2. During second year, at k_0 level of K, m_2 and m_3 level of mulch recorded maximum root : shoot ratio.

4.3.5 Quality aspects

4.3.5.1 Volatile oil content

The effect of treatments on volatile oil content for both the years are presented in the Table 65.

At harvest, the influence of potassium on volatile oil content was significant during first year. Significantly higher volatile oil content was recorded at k_2 level of potassium. The different levels of mulch and triazole had no significant effect on volatile oil content.

K x M interaction on volatile oil content was not significant during both the years.

4.3.5.2 Non-volatile ether extract

The effect of treatments on non-volatile ether extract (NVEE) for both the years are presented in the Table 65.

Table 65 Effect of Potassium (K), Mulch (M), Triazole (T) and K x M interaction on volatile oil (v/w %) and non-volatile ether extract (%) on dry weight basis

Treat-ments	Volatile oil		Non-volatile ether extract	
	I	II	I	II
k_0	2.036	1.908	4.844	4.886
k_1	2.044	1.953	4.956	4.908
k_2	2.094	1.958	4.961	4.936
F	**11.472****	**2.960**	**9.925***	**1.210**
SE	0.009	0.016	0.021	0.023
CD	**0.032**	-	**0.072**	-
m_1	2.064	1.947	4.906	4.894
m_2	2.042	1.936	4.911	4.911
m_3	2.069	1.936	4.944	4.925
F	**0.811**	**0.139**	**0.511**	**1.346**
SE	0.016	0.017	0.029	0.013
CD	-	-	-	-
t_0	2.053	1.950	4.914	4.897
t_1	2.069	1.942	4.925	4.925
t_2	2.053	1.928	4.922	4.908
F	**0.434**	**0.629**	**0.074**	**0.771**
SE	0.014	0.014	0.019	0.016
CD	-	-	-	-
$k_0 m_1$	2.042	1.908	4.817	4.858
$k_0 m_2$	2.042	1.892	4.855	4.900
$k_0 m_3$	2.025	1.925	4.883	4.900
$k_1 m_1$	2.058	1.975	4.967	4.917
$k_1 m_2$	2.042	1.967	4.933	4.892
$k_1 m_3$	2.033	1.917	4.967	4.917
$k_2 m_1$	2.092	1.958	4.933	4.908
$k_2 m_2$	2.042	1.950	4.967	4.942
$k_2 m_3$	2.150	1.967	4.983	4.958
F	**3.203**	**0.384**	**0.212**	**0.771**
SE	0.020	0.040	0.046	0.016
CD	-	-	-	-

**** Significant at 1 % level** *** Significant at 5 % level**

At harvest, the influence of potassium on NVEE content was significant only during the first year. Highest NVEE content was recorded at k_2 level which was on par with NVEE at k_1. Different levels of mulch and triazole had no significant influence on NVEE content at harvest.

K x M interaction had no significant influence on NVEE.

4.3.5.3 Starch content

The effect of treatments on starch content for both the years are presented in the Table 66.

The influence of potassium on starch content was significant during both the years. There was significant increase in starch content with increased levels of K application. Highest starch content was recorded at k_2 level. The levels of mulch and triazole had no significant effect on starch content.

K x M interaction on starch content was not significant during both the seasons.

4.3.5.4 Crude fibre content

The effect of treatments on crude fibre content for both the years are presented in the Table 66.

The influence of potassium on crude fibre content was significant during both the years. In the first year, the difference between k_1 and k_2 were not significant but superior to k_0 in crude fibre content. But during second year significantly higher crude fibre content was recorded at k_2 level of potassium.

Table 66 Effect of Potassium (K), Mulch (M), Triazole (T) and K x M interaction on starch content (%) and crude fibre content (%) on dry weight basis

Treat-ments	Starch content		Crude fibre content	
	I	II	I	II
k_0	41.699	38.42	5.39	4.95
k_1	43.68	45.17	5.55	5.06
k_2	46.48	46.60	5.55	5.43
F	**121.011****	**117.432****	**14.443****	**73.958****
SE	0.219	0.403	0.023	0.029
CD	**0.757**	**1.396**	**0.081**	**0.101**
m_1	43.44	42.85	5.50	5.06
m_2	44.01	43.43	5.48	5.17
m_3	44.41	43.90	5.52	5.20
F	**1.376**	**3.385**	**0.794**	**3.342**
SE	0.415	0.285	0.023	0.040
CD	-	-	-	-
t_0	43.83	43.25	5.50	5.16
t_1	44.08	43.20	5.50	5.15
t_2	44.29	43.75	5.48	5.13
F	**2.343**	**0.824**	**0.319**	**0.173**
SE	0.273	0.342	0.024	0.027
CD	-	-	-	-
$k_0\ m_1$	41.38	37.83	5.38	4.92
$k_0\ m_2$	41.73	38.45	5.36	4.97
$k_0\ m_3$	41.97	38.98	5.44	4.97
$k_1\ m_1$	43.22	44.54	5.55	4.96
$k_1\ m_2$	43.86	45.11	5.54	5.14
$k_1\ m_3$	43.97	45.87	5.55	5.07
$k_2\ m_1$	45.73	46.19	5.55	5.31
$k_2\ m_2$	46.43	46.75	5.53	5.40
$k_2\ m_3$	47.28	46.86	5.56	5.58
F	**0.177**	**0.111**	**0.068**	**2.522**
SE	0.655	0.575	0.066	0.048
CD	-	-	-	-

**** Significant at 1 % level** *** Significant at 5 % level**

Table 67 Effect of Potassium (K), Mulch (M), Triazole (T) and K x M interaction on uptake of K (kg ha^{-1}) and available K content (kg ha^{-1}) in the soil

Treat-ments	Uptake of K		Available K	
	I	II	I	II
k_0	58.18	62.50	125.26	143.93
k_1	101.34	105.00	191.23	191.08
k_2	129.33	129.62	278.89	280.05
F	**3243.193****	**1482.250****	**274.818****	**78.112****
SE	0.629	0.882	4.649	7.821
CD	**2.178**	**3.052**	**16.088**	**27.065**
m_1	95.46	97.82	204.48	214.62
m_2	96.78	100.13	197.73	204.59
m_3	96.61	99.17	193.17	195.86
F	**1.248**	**1.065**	**0.907**	**0.725**
SE	0.643	1.124	5.971	11.023
CD	-	-	-	-
t_0	95.23	98.35	192.06	200.51
t_1	95.92	99.45	201.57	217.47
t_2	97.71	99.33	201.75	197.09
F	**3.308**	**0.429**	**2.986**	**4.263**
SE	0.709	0.924	3.209	5.286
CD	-	-	-	-
$k_0 m_1$	55.98	62.38	126.57	143.60
$k_0 m_2$	58.89	60.97	124.91	140.54
$k_0 m_3$	59.67	64.17	124.29	147.64
$k_1 m_1$	101.27	101.17	211.06	212.45
$k_1 m_2$	100.56	110.24	187.44	215.85
$k_1 m_3$	102.21	103.58	175.18	144.96
$k_2 m_1$	129.13	129.93	275.79	287.81
$k_2 m_2$	130.89	129.19	280.83	257.37
$k_2 m_3$	127.95	129.75	280.03	294.97
F	**1.359**	**1.796**	**1.886**	**7.204****
SE	1.371	2.402	8.049	11.007
CD	-	-	-	**33.918**

**** Significant at 1 % level** *** Significant at 5 % level**

K x M interaction on crude fibre content was not significant during both the years.

4.3.6 Uptake of potassium

The effect of treatments on uptake of potassium for both the seasons are presented in the Table 67.

During both the years, significantly higher rate of uptake of potassium was recorded at the highest levels of potassium application. The influence of different levels of mulch and triazole on uptake of potassium was not significant during both the years.

K x M interaction on uptake of potassium was not significant during both the years.

4.3.7 Available potassium

The effect of treatments on available potassium content of the soil, after each crop year is provided in Table 67.

Available potassium increased with increase in the levels of applied potassium during both the years. Highest available K content was registered under k_2 which was followed by k_1 during both the years.

K x M interaction on available potassium content of the soil was significant only during second year. During the second year, at k_2 level, significantly higher value for available potassium was observed with an application of mulch at m_3 level which was on par with m_1 level.

DISCUSSION

5. DISCUSSION

Studies conducted in India and elsewhere revealed that ginger is a shade tolerant / loving crop. In the coconut based intercropping situations ginger is found to be a compatible intercrop. The coconut palm utilizes only 25 per cent of the land area and top 30 cm soil is practically free of functional roots (Nair, 1979). According to Wahid *et al.* (1993) over 80 per cent of the active roots are confined to within an area of 2.0 m radius around the palm. Ginger being a shallow rooted crop, 85 per cent of the roots are distributed within a depth of 20 cm and 10 per cent roots between 20 and 30 cm depth (Jayachandran, 1993b). The phyllotaxy and other features of coconut crown permit sizable amount of light transmission through its canopy. Hence ginger and coconut constitute a compatible crop combination. Scope for expansion of area under monocropping in Kerala is limited. But there is ample scope for utilizing the area under shaded situations that exists in coconut gardens. Studies conducted under artificial shade revealed that the existing recommendation of 75: 50 :50 NPK kg ha^{-1} is inadequate (Ancy, 1992). Further studies revealed that the mulch and planting material requirement were in lesser quantities under shaded situations (Babu, 1993 and Nizam, 1995). The present investigation was envisaged with the objectives of studying the production potential of ginger under open and different shade levels and analysing the morphological, physiological and biochemical aspects involved in its shade loving nature. Study also aimed to standardise optimum dose of nutrients and mulch for ginger intercropped in coconut garden. The efficacy of triazole in the improvement of yield and other desirable characters were also evaluated.

5.1 EXPERIMENT - I

The study on production potential of ginger under open and shade levels was conducted to analyse the morphological, physiological and biochemical aspects and also to evaluate the potentiality of ginger under different shade levels.

5.1.1 Growth characters

5.1.1.1 Plant height

The effect of shade levels on plant height was significant. An increasing trend in plant height with increasing shade intensity, from zero to 80 per cent, was observed (Table 5). The plants grown under open condition registered a lower plant height in all growth stages. This findings was in agreement with the results reported by Aclan and Quisumbing (1976), Susan Varughese (1989), Jayachandran *et al.* (1991), Ancy (1992) and Babu (1993).

According to Meyer *et al.* (1973) high irradiance may result in high rates of transpiration which likely to result in internal deficiencies of water and consequent retardation of cell division and cell enlargement which ultimately results in a low plant height at open.

5.1.1.2 Number of tillers

There was significant difference between shade levels with respect to tiller production (Table 6). Among different shade levels, at 20 and 40 per cent shade level, tiller number was maximum. Up to 60 DAP there was no significant difference in tiller production in different shade levels. From 90

DAP onwards 20 and 40 per cent shade levels recorded highest number of tillers in almost all growth stages. At 240 DAP, the shade level 40 per cent recorded highest tiller number during both the years. From these observations it is evident that the shade levels 20 and 40 per cent was favourable for obtaining highest tiller number during both the years. At almost all stages of growth, 80 per cent shade recorded lowest tiller number followed by open and 60 per cent shade. The results in the present study was parallel with the findings of Ancy (1992), George (1992) and Babu (1993). Contrary to this, Aclan and Quisumbing (1976) and Bai (1981) reported that tiller production was not influenced by shade.

5.1.1.3 Number of leaves

The effect of shade on production of leaves was significant (Table 7). During early growth stages there was not much variation in leaf production due to the different intensities of shade over periods. From 120 DAP onwards plants under 20 and 40 per cent shade recorded significantly higher number of leaves. Plants grown under full sunlight and heavy shade recorded lowest number of leaves per plant. These results are in conformity with the findings of Ancy (1992) and Babu (1993).

5.1.1.4 Leaf area

Ginger plants grown under 20 and 40 per cent shade levels produced significantly higher leaf area (Table 8). An increased leaf area under reduced light intensity was reported in ginger by Ravisankar and Muthuswamy (1988), Ancy (1992), George (1992) and Babu (1993). Contrary to this, Bai (1981) reported that leaf area was not influenced by different intensities of shade in ginger, turmeric and coleus.

Leaf area varied significantly among the different shade levels at different growth stages. Up to 150 DAP, not much variations in leaf area was observed due to the shading. From 180 to 240 DAP, in general the shade levels 20 and 40 per cent resulted in maximum leaf area at different growth stages. The lowest leaf area was registered when plants were grown under 80 per cent shade.

The increased leaf area under shade may perhaps be a plant adaptation to expose larger photosynthetic surface under limited illumination (Attridge, 1990). Under low light intensities reduced irradiation may prevent scorching or wilting of leaf caused by marked increase in temperature within leaf tissue from strong sunlight (Aasha, 1986) and thereby increases leaf area under shade resulting in the retention of more number of leaves at any stage of the crop growth. But under medium and heavy shade, leaf area was found to be again decreasing and this might be due to decreased rates of leaf production and low photosynthetic efficiency. Under open condition high irradiance may result in high rates of transpiration which are likely to lead internal deficiencies of water within the plant. This may lead to retardation or cessation of cell enlargement which adversely affect the leaf size.

5.1.1.5 Leaf dry weight

The shade x period interaction was significant in leaf dry weight

(Table 9). Up to 120 DAP, not much variations in leaf dry weight was observed due to shade over periods. During later stages of growth, at 180 DAP, during first year, plants under 20 per cent shade recorded maximum leaf dry weight followed by 40 per cent shade. But during second year, 40 per cent shade recorded maximum leaf dry weight followed by 20 per cent shade. In general, at 120 DAP during both the years, plants under 20 per cent shade level recorded maximum leaf dry weight followed by 40 per cent shade level and open condition. At 240 DAP, plants grown under 20 per cent shade registered the highest leaf dry weight and was on par with 40 per cent shade and open condition. But during second year, plants grown under 40 per cent shade recorded maximum leaf dry weight and was on par with 20 per cent shade. In general, in all growth stages, the lowest leaf dry weight was registered in plants grown under 80 per cent shade followed by 60 per cent shade. In general, plants under 20 and 40 per cent shade levels exhibited more number of tillers and leaves compared to open and intense shade levels (60 and 80 per cent). Under 20 and 40 per cent shade levels higher biomass in terms of tillers and leaves were produced. This may be the reason for more leaf dry weight observed under 20 and 40 per cent shade levels.

5.1.2 Root characters

5.1.2.1 Root length

Not much variation in root length was observed due to shade over periods up to 120 DAP (Table 10). In general under 20 and 40 per cent shade, root length was maximum and in certain cases on par with open condition and

60 per cent shade. Intense shade reduced the root length.

Towards the end of the growing season, there was a noticeable reduction in root length due to the branching pattern of the rhizomes. According to Jayachandran (1993b), the number of roots originating from the first daughter rhizome is more than that from the later produced daughter rhizomes. The reason for reduction in root length (average root length) may be due to the fact that the fresh rhizomes (daughter rhizomes) are also producing roots which may not get sufficient growing period to produce longer roots as in the case of initial roots.

5.1.2.2 Root spread

In general, in later stages of growth, the highest root spread was recorded at open and 20 and 40 per cent shade levels (Table 11). The lowest root spread was recorded by the plants grown under 60 and 80 per cent shade levels. The rhizome spread was maximum under 20 and 40 per cent shade levels (Table 14) and this aspect influenced root spread.

5.1.2.3 Root dry weight

The effect of shade on root dry weight was significant during both the years (Table 12). Not much variations in root dry weight per plant was observed due to shade over periods up to 90 DAP. At 120 DAP, during both the years, plants grown under 40 per cent shade recorded maximum root dry weight, but during 150 and 180 DAP root dry weight was on par with plants grown under 40 per cent shade level. At 210 DAP, the root dry weight recorded when plants grown at open condition, 20 per cent and 40 per cent shade levels were on par but significantly higher when compared to other shade levels. At 240 DAP, during both the years significantly higher root dry weight was recorded when plants grown at 20 per cent shade level. In general, from 120 DAP, plants grown under 60 per cent and 80 per cent shade levels recorded lowest root dry weight. The results indicate that the root growth is affected by higher levels of shade.

5.1.2.4 Root volume

The effect of shade on root volume was significant during both the seasons (Table 13). Not much variations in root volume was observed due to shade over different periods during early crop growth stages. During later stages of growth, 20 and 40 per cent shade levels recorded maximum root volume which was on par with plants grown under open condition. In general, open condition and 20 and 40 per cent shade levels significantly increased the root volume. However, the shade levels 60 and 80 per cent significantly decreased the root volume. Therefore it can be concluded that lower levels of shade (20 and 40 per cent) favoured more root growth and subsequent root volume.

5.1.3 Rhizome characters

5.1.3.1 Rhizome spread

The effect of shade on rhizome spread was significant during both the seasons (Table 14). In general, maximum rhizome spread was resulted by providing open, 20 and 40 per cent shade levels. At 240 DAP, maximum rhizome spread of 25.75 cm was recorded by providing 20 and 40 per cent shade levels. But during second year, maximum rhizome spread of 24.5 cm was observed under 40 per cent shade which was on par with the rhizome spread of 23.75 cm resulted by providing open condition and 20 per cent shade. The lowest rhizome spread was resulted of providing 60 and 80 per cent shade levels.

Contrary to this, Ancy (1992) observed that rhizome spread of ginger at 50 per cent shade was found to be significantly higher than that under open and 25 per cent shade but was on par with that under heavy shade (75 per cent). According to Babu (1993) rhizome spread at 25 per cent shade was higher than any other shade levels but the plants under open condition recorded the lowest rhizome spread. Nizam (1995) reported that ginger variety Rio-de-Janeiro under intercropped condition in coconut garden recorded the higher rhizome spread compared to open. The results of the present study clearly indicate that providing low levels of shade will enhance the rhizome spread of ginger.

5.1.3.2 Rhizome thickness

The effect of shade significantly influenced the rhizome thickness (Table 15). In general, from 180 DAP onwards the rhizome thickness was significantly higher by providing open condition, 20 and 40 per cent shade levels. The present study revealed that the rhizome thickness was higher under shade during early stages of growth.

5.1.3.3 Finger rhizomes

Shade levels significantly influenced the production of finger rhizomes

(Table 16). In general, maximum number of finger rhizomes was resulted by providing 20 per cent shade which was on par with 40 per cent shade level during all growth stages. The plants grown in open condition ranked third in the production of finger rhizomes per plant. The lowest number of finger rhizomes was resulted by providing 60 and 80 per cent shade levels.

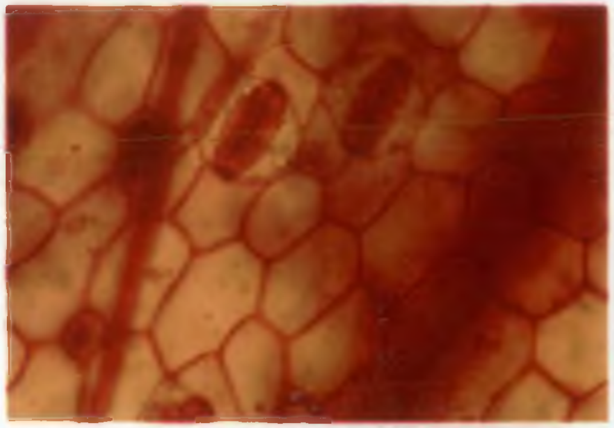
5.1.4 Leaf thickness

Among the different shade levels, plants under 40 per cent shade recorded the maximum leaf thickness of 209.70 μ m which was on par with plants at 20 per cent shade level (188.74 μ m) and open condition (181.76 μ m) (Table 17). As the shade increase to 60 and 80 per cent there was significant reduction in leaf thickness. In general, increase in leaf thickness in full sun is accomplished by the marked increase in spongy and palisade mesphyll thickness (Ashton and Beryln, 1992). However, in the present investigation, no significant variation in leaf thickness was observed when plants grown at open condition, 20 per cent and 40 per cent shade levels. This may be the leaf adaptation of ginger, which is considered as a shade loving/tolerant crop. The low leaf thickness observed under 60 and 80 per cent shade levels may be due to the lack of spongy and palisade mesophyll tissues (Ashton and Beryln, 1992).

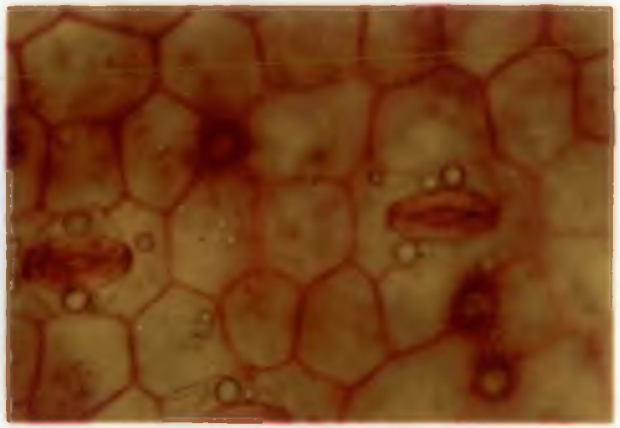
5.1.5 Stomatal characters

5.1.5.1 Stomatal index

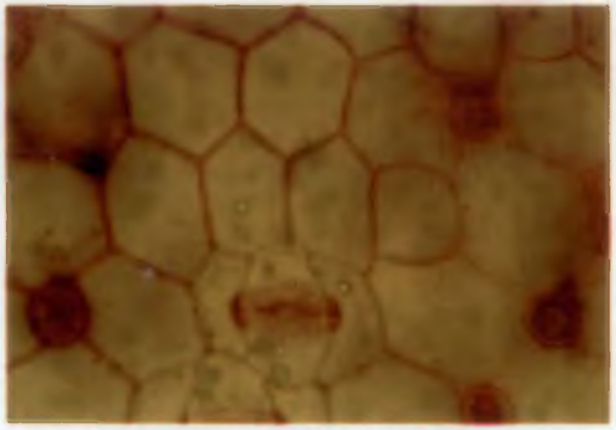
Among different shade levels, stomatal index at open condition and 20 per cent shade level were on par but significantly superior to all other shade



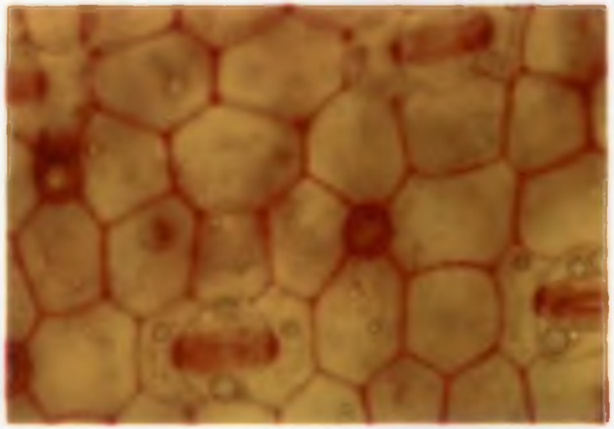
OPEN CONDITION



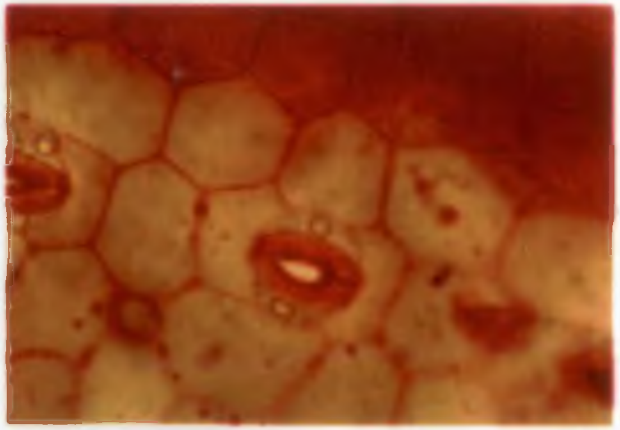
20 PER CENT SHADE



80 PER CENT SHADE



40 PER CENT SHADE



60 PER CENT SHADE

Plate 6. Distribution of stomata on the leaf surface

levels (Table 17 and Plate 6). As the shade increased there was reduction in stomatal index. This clearly indicated the plant adaptation to the low shade level.

5.1.5.2 Stomatal frequency

Among the different shade levels, stomatal frequency of plants at open condition, 20 per cent and 40 per cent shade levels were on par but significantly superior to all other shade levels (Table 17 and Plate 6). The lowest stomatal frequency was observed when plants grown at 60 per cent and 80 per cent shade levels. The exchange of water vapour, CO_2 and O_2 are largely influenced by the stomatal pores. The photosynthetic efficiency may be enhanced by the high stomatal frequency at open and low shade levels.

5.1.6 Physiological aspects

5.1.6.1 Dry matter production

The dry matter production during both the seasons was significantly influenced by the shade (Table 18). At 120 DAP onwards there was significant variation in DMP in different shade levels over periods. In general, maximum DMP was observed during the two seasons in 20 and 40 per cent shade, followed by open condition. The lowest DMP was observed in plants grown under heavy shade (80 per cent). In general, plants under 20 and 40 per cent shade levels exhibited more number of tillers, leaves, leaf area, leaf dry weight, root length, root spread, rhizome spread, rhizome thickness and finger rhizomes. This may be the reason for more DMP observed under 20 and 40 per cent shade levels. The result of the present study was in accordance with the findings of Ravisankar and Muthuswamy (1988), Susan Varughese (1989), Ancy (1992) and Babu (1993).

5.1.6.2 Crop growth rate

Crop growth rate (CGR) varied significantly due to different shade levels (Table 19 a, 19 b and Fig. 4a, 4b)). Between 30 - 60 DAP, maximum crop growth rate of 0.2707 g m^{-2} d^{-1} was recorded under 40 per cent shade followed by 20 per cent (0.1944 g m^{-2} d^{-1}). During the second year, highest CGR of 0.1979 g m^{-2} d^{-1} was recorded under 40 per cent shade which was on par with CGR under 20 per cent shade (0.1260 g m^{-2} d^{-1}). Between 60 - 90 DAP, during first year highest CGR of 0.6371 g m^{-2} d^{-1} was observed under 20 per cent shade. No significant variation in CGR was observed during second year. Between 90 - 120 DAP, during both the years, maximum CGR recorded under 40 per cent shade followed 20 per cent shade. Between 120 - 150 DAP, during both the seasons, highest CGR was recorded under 20 per cent shade which was followed by 40 per cent shade. No significant variations in CGR was observed between 150 - 180 DAP. Between 180 - 210 DAP, during first year, highest CGR of 1.3024 g m^{-2} d^{-1} was recorded under open condition which was on par with CGR under 20 per cent (1.2070 g m^{-2} d^{-1}) and 40 per cent (1.2133 g m^{-2} d^{-1}) shade levels.

Between 210 - 240 DAP, highest CGR of 0.9247 g m^{-2} d^{-1} was recorded under 40 per cent shade which was on par with CGR under open condition (0.7460 g m^{-2} d^{-1}) and 20 per cent shade (0.6759 g m^{-2} d^{-1}).

Fig. 4a Effect of shade on crop growth rate (g m^{-2} day^{-1}) during the first year

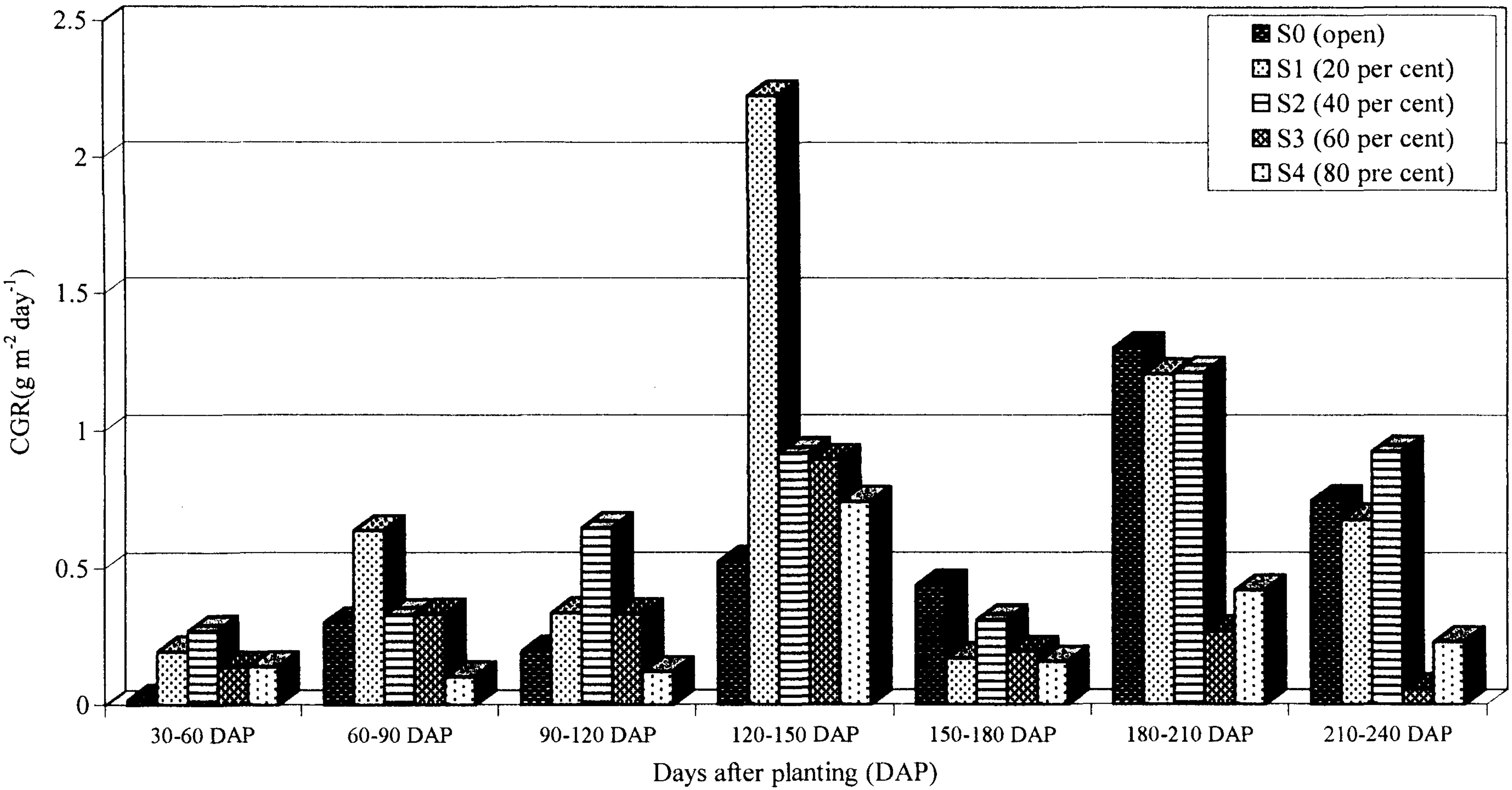
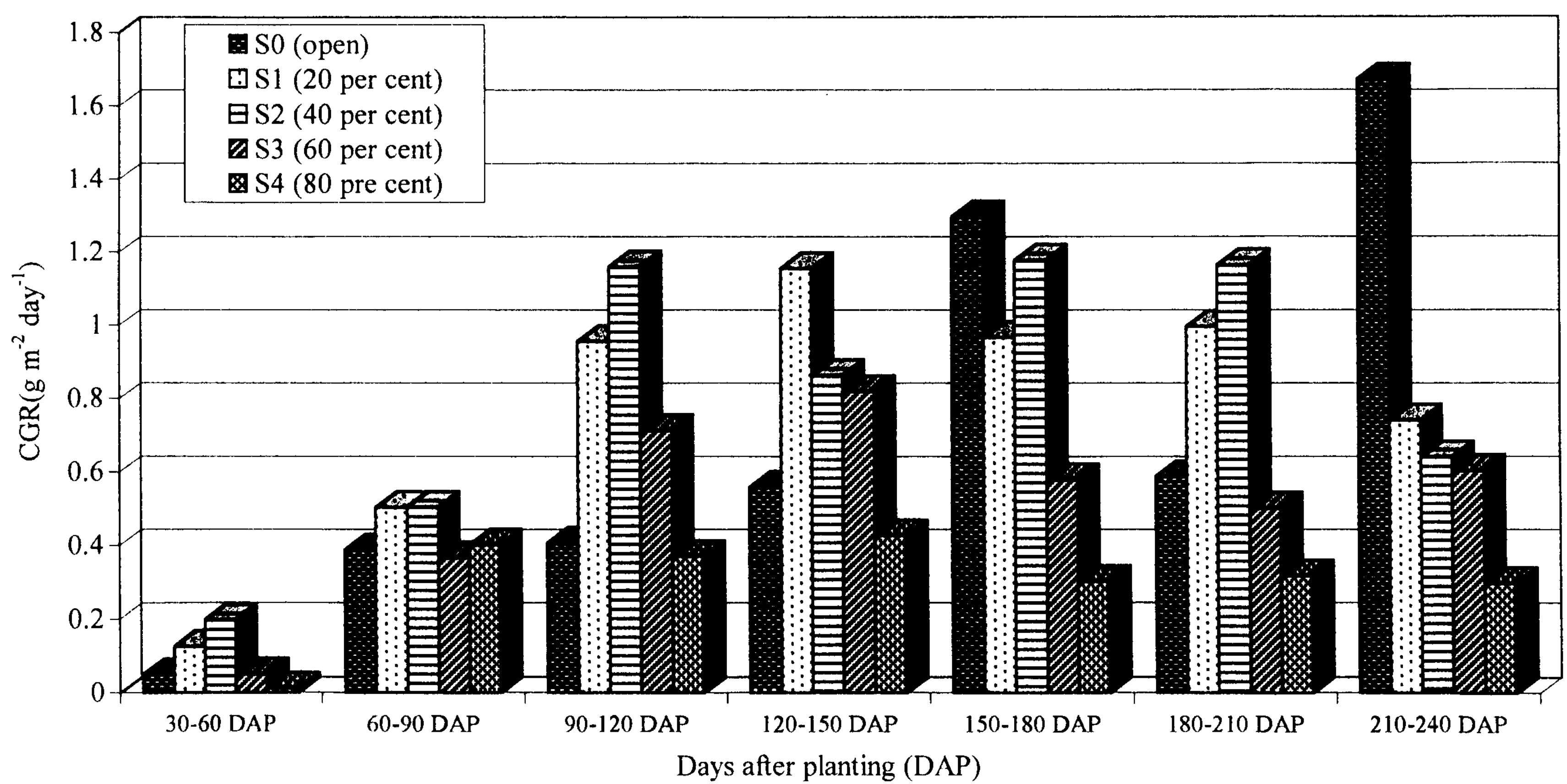


Fig. 4b Effect of shade on crop growth rate (g m^{-2} day^{-1}) during the second year



In general, different shade levels did not show appreciable difference in CGR towards the later stages of growth. However, in early growth phases (up to 150 DAP) highest CGR was observed under low shade levels (20 and 40 per cent shade). This was in accordance with the findings of Ancy (1992) and Babu (1993) in ginger. However, in turmeric highest CGR was observed under open condition compared to shaded condition (Ramadasan and Satheesan, 1980).

5.1.6.3 Relative growth rate

Relative growth rate (RGR) was inconsistent over different shade levels (Table 20a, 20b and Fig. 5a, 5b)).

Between 30 to 60 DAP, during first year, highest RGR of 0.0300 g g^{-1} day was recorded under 40 per cent which was on par with RGR under 20 per cent (0.0258 g g^{-1} day) and 80 per cent (0.0289 g g^{-1} day) shade levels. During second year, no significant variation in RGR was observed under different shade levels.

Between 60 and 90 DAP, during first year, highest RGR of 0.0400 g g^{-1} day was noticed under open condition which was on par with RGR under 20 per cent (0.0383 g g^{-1} day) and 60 per cent (0.0312 g g^{-1} day) shade levels. No significant variations in RGR was observed between 90 to 120 DAP during first year. But during second year, highest RGR of 0.0284 g g^{-1} day was observed under 40 per cent shade which was on par with RGR under 20 per cent (0.0276 g g^{-1} day) and 60 per cent (0.0253 g g^{-1} day).

Between 120 to 150 DAP, during first year, under 80 per cent shade

Fig. 5a Effect of shade on relative growth rate (g g^{-1} day) during the first year

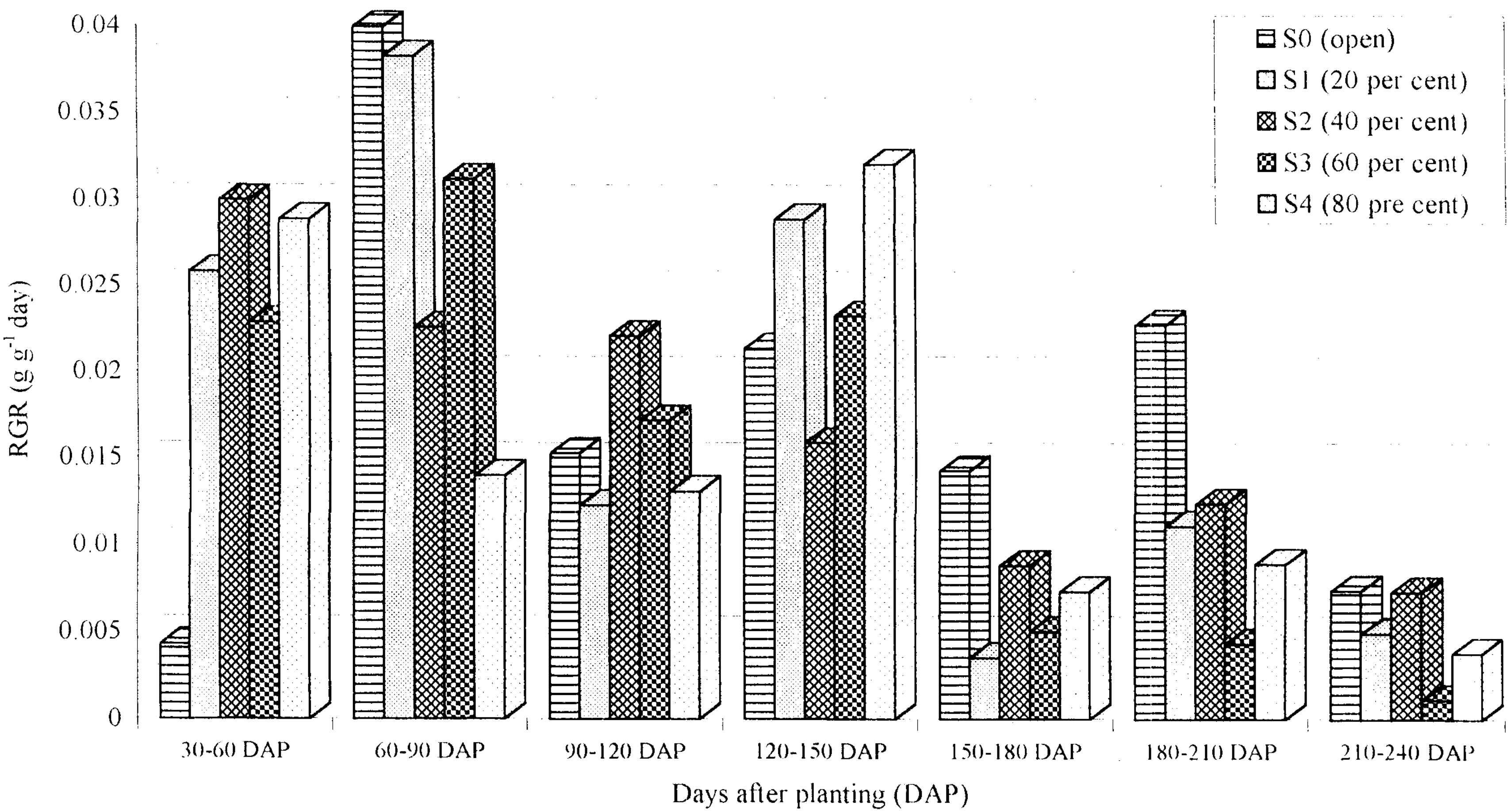
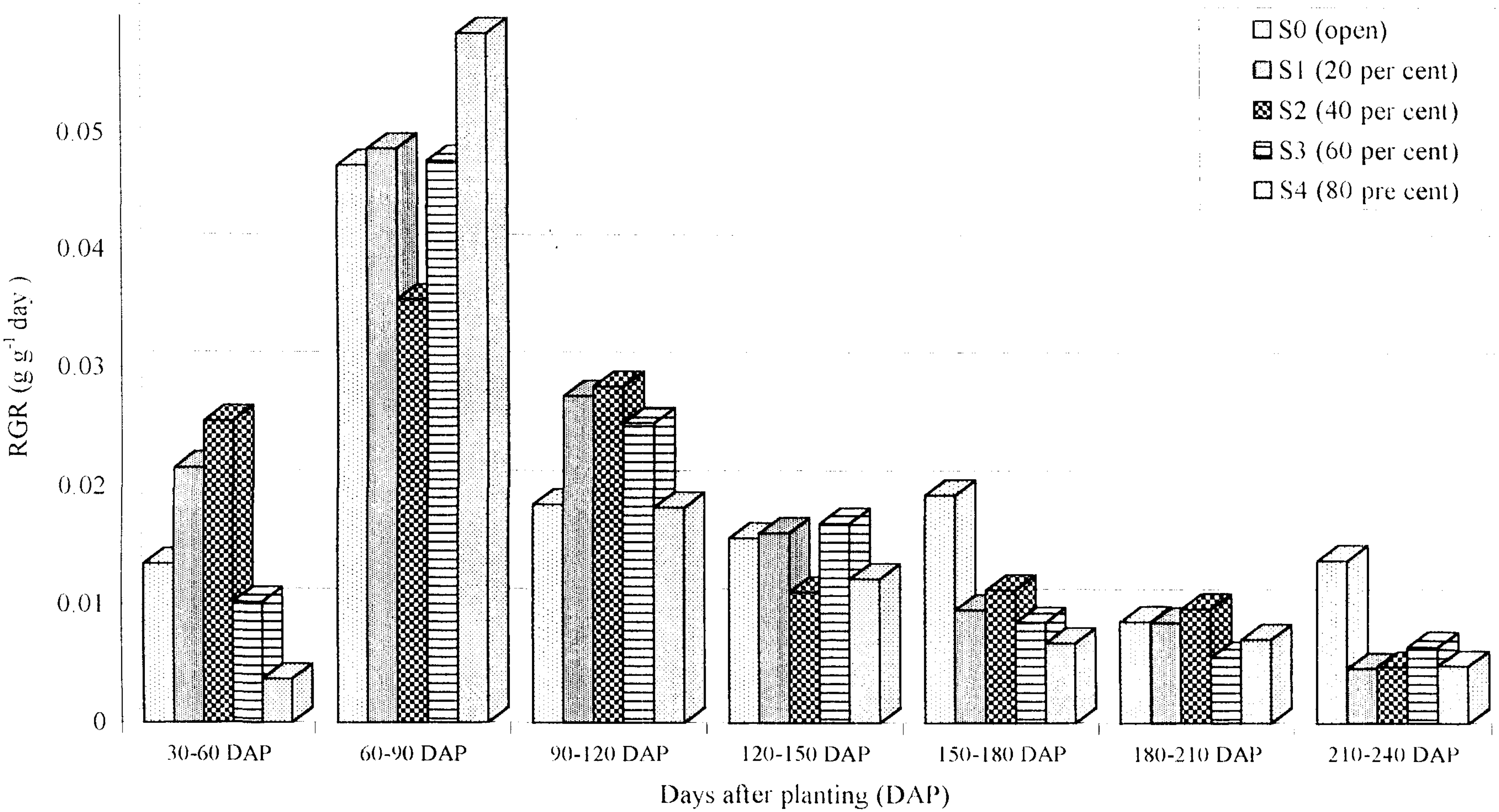


Fig. 5b Effect of shade on relative growth rate (g g^{-1} day) during the second year



recorded highest RGR of 0.0321 g g^{-1} day which was on par with RGR under 20 per cent (0.0289 g g^{-1} day) and 60 per cent (0.0233 g g^{-1} day) shade levels. Between 150 to 180 DAP, highest RGR (0.0143 g g^{-1} day) was observed under open condition which was on par with the RGR under 20 per cent (0.0088 g g^{-1} day) shade level. Between 180 to 210 DAP, during first year, highest RGR of 0.0228 g g^{-1} day was recorded under open condition. But under all other shade levels no significant variation in RGR was observed. During second year, no significant variation in RGR was noticed under all shade levels. At 210 to 240 DAP, during both the seasons, no significant variation in RGR was observed due to shade.

Higher RGR was recorded under different growth stages up to 180 DAP. During later stages of growth, decreasing trend in RGR was noticed . However, Jadhav (1987) observed a positive correlation of shade with RGR in rice.

5.1.6.4 Net assimilation rate

Net assimilation rate (NAR) varied significantly due to different shade levels (Table 21a 21b and Fig. 6a, 6b). Between 30 - 60 DAP, during first year maximum NAR was recorded under 80 per cent shade which was on par with S_1, S_2 and S_3. During second year, highest NAR was recorded under 40 per cent shade which was on par with open condition and 20 per cent shade. Between 60 - 90 DAP, during first year, NAR was highest under 20 per cent shade which was on par with NAR under open condition and 60 per cent shade. During

Fig. 6a Effect of shade on net assimilation rate (g m^{-2} day^{-1}) during the first year

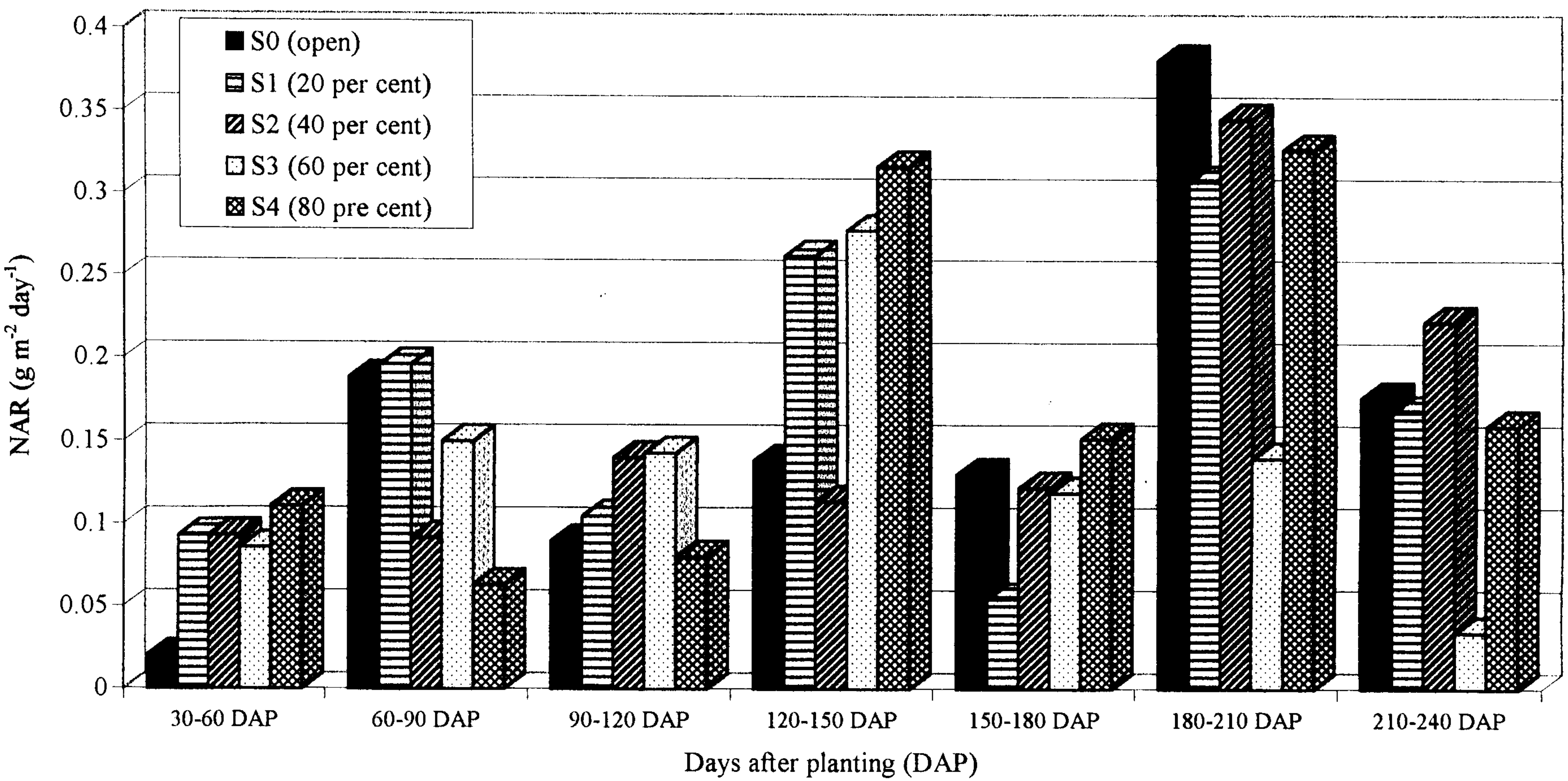
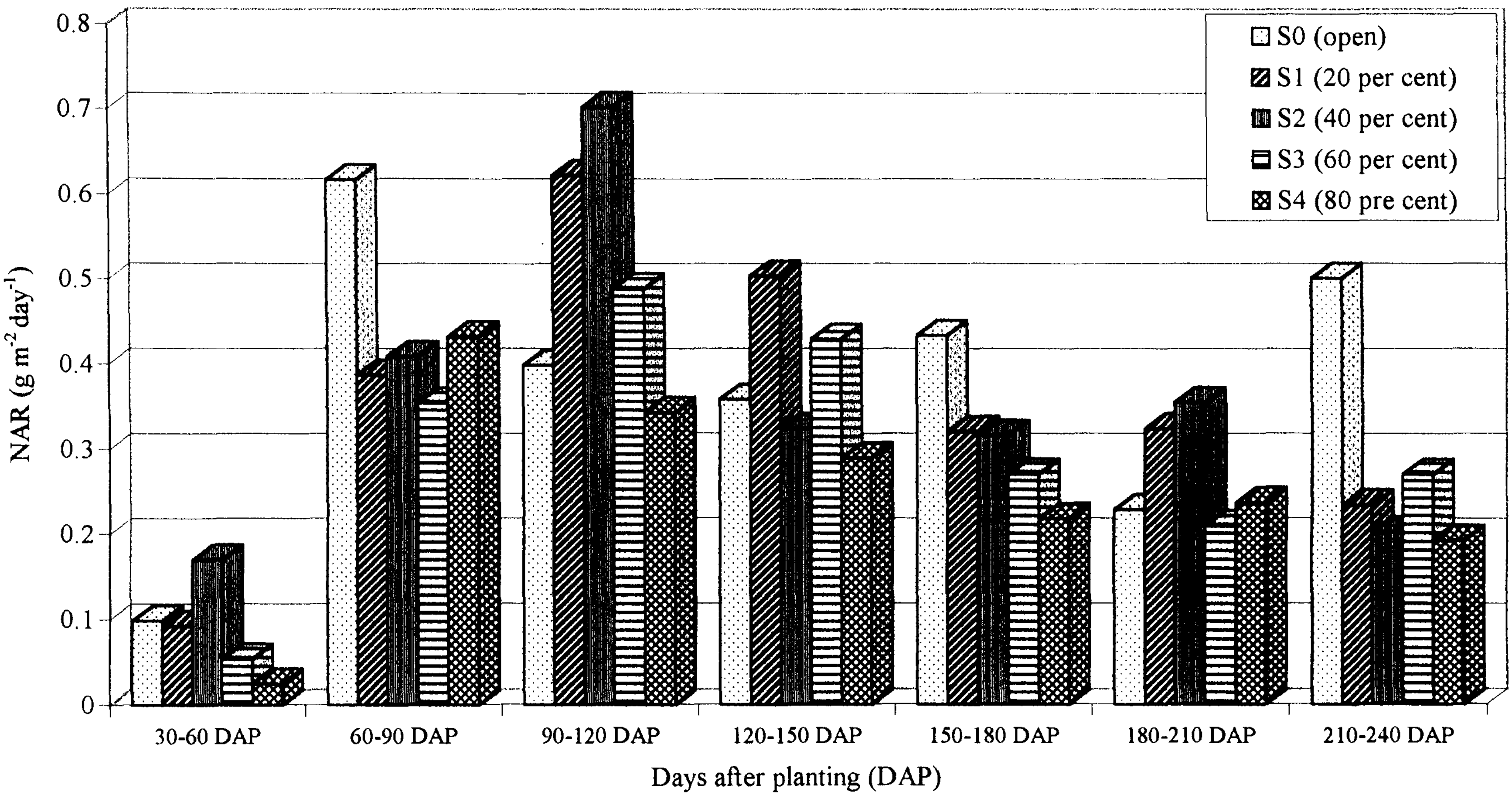


Fig. 6b Effect of shade on net assimilation rate (g m^{-2} day^{-1}) during the second year



the second year, significantly higher NAR was recorded under open condition. No significant variation in NAR was observed in all other shade levels.

Between 90 - 120 DAP, during first year, no significant variation in NAR was observed among the treatments. During the second year, highest NAR (0.7020 g m^{-2} d^{-1}) was recorded under 40 per cent shade level which was on par with NAR under 20 per cent (0.6226 g m^{-2} d^{-1}) and 60 per cent (0.4889 g m^{-2} d^{-1}) shade levels. Between 120 - 150 DAP, during first year, highest NAR of 0.3172 g m^{-2} d^{-1} was recorded under 80 per cent shade which was on par with NAR under 20 per cent (0.1047 g m^{-2} d^{-1}) and 60 per cent (0.2781 g m^{-2} d^{-1}) shade levels. The treatment did not show appreciable difference in NAR towards the later stages of growth from 150 DAP.

According to Okoli and Owasu (1975) high NAR at low shade was due to high rate of photosynthesis. A negative influence of shade on NAR was reported by Laura *et al.* (1986) in sweet potato, Ramanujam and Jose (1984) in cassava, Ramadasan and Satheesan (1980) in turmeric. Babu (1993) found that during first phase (60 - 120 DAP) the high NAR was recorded from open condition, but during second phase (120 - 180 DAP) maximum NAR was obtained from low shade level. But George (1992) reported that between 60 - 120 DAP maximum NAR was observed at 50 per cent shade in ginger. Ancy (1992) opined that NAR was significantly high at 25 and 50 per cent shade levels. However, the present study did not show influence of shade on NAR towards the later stages of growth from 150 DAP.

5.1.6.5 Leaf area duration

Different shade levels did not show appreciable difference in LAD up to 150 DAP (Table 22 a and 22 b). However, 20 and 40 per cent shade levels recorded highest LAD during early stages of growth. Between 150 - 180 DAP, during first year higher LAD of 154.09 was recorded under open condition which was on par with LAD under 40 per cent (154.09) shade. NAR under open condition (106.52) and 40 per cent shade (154.09) were on par. During the second year, highest LAD of 100.39 was recorded under 40 per cent shade which was on par with LAD under 20 per cent shade (84.39). NAR under open condition (71.27) and 20 per cent shade (84.39) were on par. Between 180 - 210 DAP and 210 - 240 DAP, during both the seasons, LAD under open condition, 20 and 40 per cent shade levels were on par.

During early stages of growth, up to 150 DAP highest LAD was recorded under 20 and 40 per cent shade. This was in accordance with the findings of Babu (1993) in ginger. But during later stages of growth LAD under open condition, 20 and 40 per cent shade levels were on par.

5.1.6.6 Leaf area index

Leaf area index (LAI) varied significantly due to different shade levels (Table 23). Up to 180 DAP, the shade levels did not show appreciable difference in LAI over periods. In general, 20 and 40 per cent shade recorded highest LAI. At 210 DAP, during first year, under 20 per cent shade highest LAI of 3.86 was recorded which was on par with LAI under open condition (3.57) and 20 per cent shade (3.56). During second year, 40 per cent shade recorded maximum LAI of 3.48 which was on par with 20 per cent shade (5.29) which was followed by open condition. At 240 DAP, LAI recorded under open condition, 20 and 40 per cent shade were on par and significantly superior to other shade levels.

In general maximum LAI was observed under open condition follewed by, 20 and 40 per cent shade levels. Up to 180 DAP relatively higher LAI was observed under low shaded conditions (20 and 40 per cent shade). Ancy (1992) reported similar results in ginger. However, during later stages of growth, it is evident that LAI under open condition, 20 and 40 per cent shade levels did not vary significantly. Open condition and low shade intensity was favourable for maximum LAI in ginger. However, higher shade levels (60 and 80 per cent) significantly reduced the LAI.

The tendency of the plants to increase the LAI under low to moderate shading was observed in the present study. This may perhaps to be a plant adaptation to expose larger photosynthetic surface under limited illumination as reported by Attridge (1990). Similar results was reported by Ravisankar and Muthuswamy (1988) and Ancy (1992) in ginger. Contrary to this, Bai (1981) found that LAI was not influenced by different shade intensities in ginger, turmeric and coleus.

5.1.6.7 Specific leaf weight

Specific leaf weight (SLW) varied significantly due to different shade levels (Table 24). During first year, highest SLW was recorded under open condition which was followed by 40 and 20 per cent shade levels. During second year, the result was same but SLW under 20 and 40 per cent shade levels were on par. During both the seasons, lowest SLW was observed under 60 and 80 per cent shade levels.

In general, up to 150 DAP, highest SLW was recorded under open condition. From 180 to 240 DAP, there was not much variations in SLW per plant due to the different intensities of shade over periods. However, under open, 20 and 40 per cent shade levels maximum SLW was recorded.

Growth efficiency is associated with leaf weight that mostly reflects leaf thickness. Thickness of leaf is now an important character in relation to the boundary layer and aerodynamic resistance. These parameters are equally involved in adaptation of a species to an environment such as temperature tolerance, drought resistance etc. Under open condition and low shade level, relatively higher leaf thickness, leaf number and leaf area were observed. This may be the reason for higher SLW under open and low shade levels. However, Syvertsen and Smith (1984) observed that, SLW were highest in full sun and lowest in 90 per cent shade in citrus.

5.1.6.8 Relative water content

Relative water content (RWC) significantly varied at different shade levels (Table 25). The maximum RWC was recorded at 80 per cent shade level during both the seasons. During first year, plants under 20 per cent shade level recorded the lowest RWC. During second year, the lowest RWC under 20 per cent shade level was on par with RWC under open condition.

During all growth stages, under 80 per cent shade, the maximum RWC was recorded. The lowest RWC was recorded under 20 per cent shade level. During second year, 20 per cent shade recorded lowest RWC which was on par with RWC under open condition. Providing shade influences the microclimate around the plant. Under shade, the water loss from plant is at a reduced rate because stomata are partially closed and the saturation deficit of the air is small.

5.1.6.9 Root : shoot ratio

Root : shoot ratio significantly varied at different shade levels (Table 26). The plants grown under open condition recorded maximum root : shoot ratio. But during second season, highest root : shoot ratio recorded under open condition which was on par with 60 and 80 per cent shade levels.

Root : shoot ratio was inconsistent over different shade levels with respect to days after planting. Plants grown under open condition showed relatively higher root : shoot ratio in almost all growth stages.

When water is a limiting factor, rooting depth is an important factor for satisfactory crop production. Under open condition, there may be moisture stress and fluctuating soil water availability, which might have reduced the growth of above ground parts and increased root growth. This resulted in high root : shoot ratio at open condition. There results are in conformity with the findings of Cripps (1971) in apple.

5.1.7 Photosynthetic rate and related parameters of ginger at 180 DAP measured using leaf chamber analyser

5.1.7.1 PAR on leaf surface

PAR on leaf surface varied significantly at 180 DAP due to shade

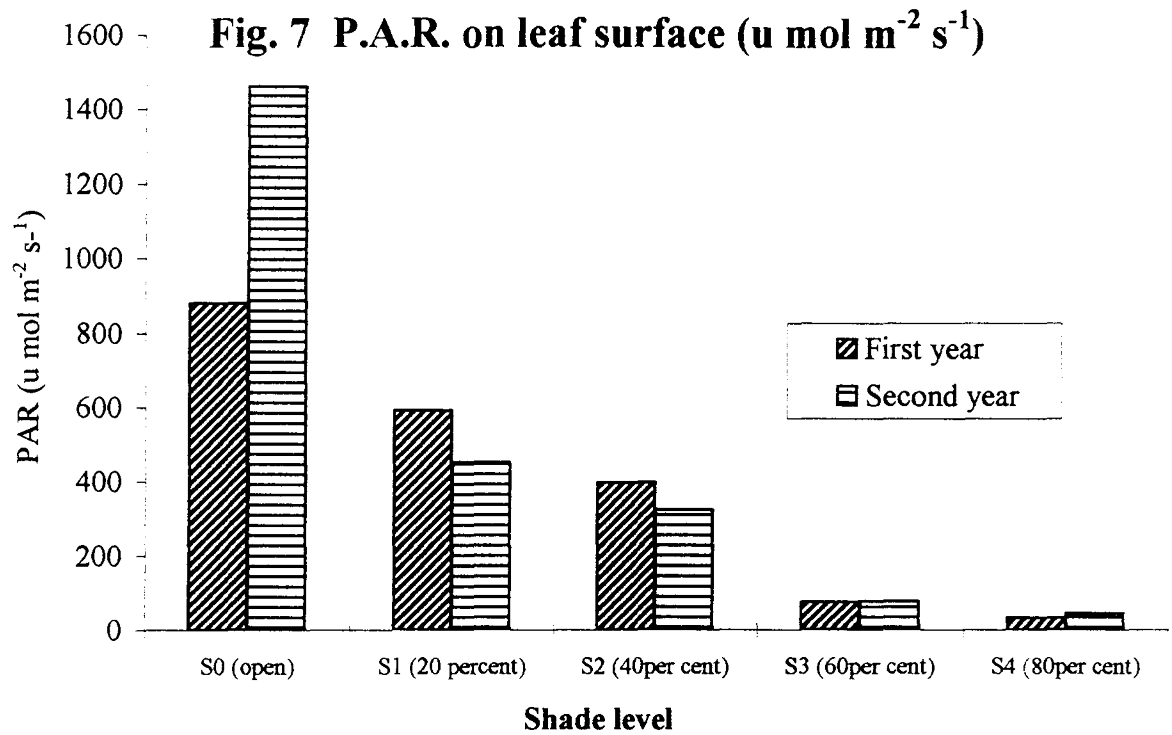


Fig. 7 P.A.R. on leaf surface (u mol m-2 s-1)
1600
1400
1200
1000
800
600
400
200
0
PAR (u mol m-2 s-1)
First year
Second year
S0 (open)
S1 (20 percent)
S2 (40per cent)
S3 (60per cent)
S4 (80per cent)
Shade level

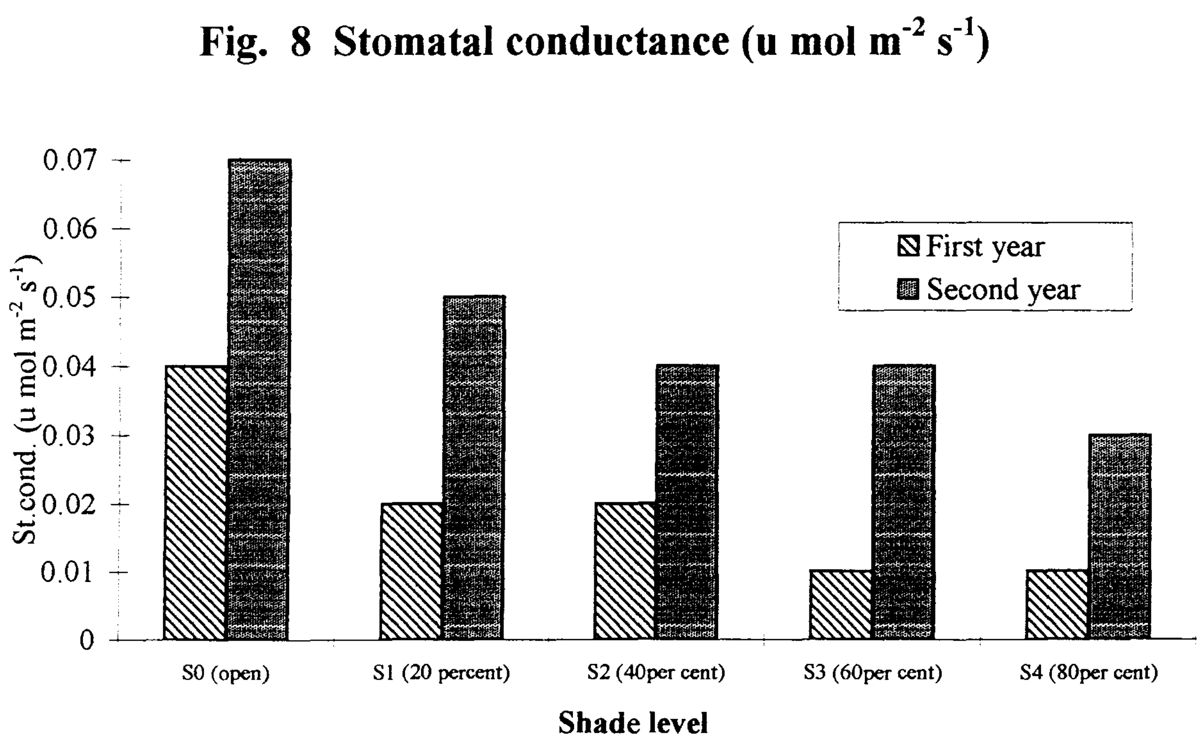


Fig. 8 Stomatal conductance (u mol m-2 s-1)
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
St.cond. (u mol m-2 s-1)
First year
Second year
S0 (open)
S1 (20 percent)
S2 (40per cent)
S3 (60per cent)
S4 (80per cent)
Shade level

(Table 27a and Fig. 7). Highest PAR of 880.75 μ mol m^{-2} s^{-1} and 1461.25 μ mol m^{-2} s^{-1} on leaf surface was recorded under open condition during first and second year respectively. During first year, PAR on leaf surface under open condition which was followed by 20 per cent shade (591.50 μ mol m^{-2} s^{-1}) and 40 per cent (397.75 μ mol m^{-2} s^{-1}) shade levels. The lowest PAR on leaf chamber was recorded under 80 per cent shade (33.00 μ mol m^{-2} s^{-1}) which was on par with PAR on leaf surface at 60 per cent (76.26 μ mol m^{-2} s^{-1}) shade levels. During second year, PAR on leaf under 20 per cent (452.00 μ mol m^{-2} s^{-1}) and 40 per cent (322.50 μ mol m^{-2} s^{-1}) shade levels were on par and superior to other shade levels. The lowest PAR on 45.25 μ mol m^{-2} s^{-1} on leaf chamber was recorded under 80 per cent shade which was on par with PAR under 60 per cent shade (76.50 μ mol m^{-2} s^{-1}).

Photosynthesis is the key to DMP and hence yield of economic organ. The rate of dry matter production in crops depends on the efficiency of the interception of photosynthetically active radiation (PAR) (Biscoe and Gallagher, 1977; Monteith, 1969). The difference in PAR on leaf surface was due to the difference in shade levels provided by the shade material and by the canopy with different foliage distribution.

5.1.7.2 Stomatal conductance

Stomatal conductance varied significantly due to different shade levels at 180 DAP (Table 27 a and Fig. 8), highest stomatal conductance of 0.04 μ mol m^{-2} s^{-1} and 0.07 μ m^{-2} s^{-1} were recorded under open condition during first year and second year respectively. During the first year stomatal conductance under 20 per cent (0.02 μ mol m^{-2} s^{-1}) shade levels was on par with the 40 per cent shade level. But during the second year, stomatal conductance under 20 per cent shade (0.05 μ mol m^{-2} s^{-1}), 40 per cent (0.04 μ mol m^{-2} s^{-1}) and 60 per cent (0.04 μ mol m^{-2} s^{-1}) shade levels were on par but the stomatal conductance under 40 per cent shade (0.04 μ mol m^{-2} s^{-1}) was on par with 60 per cent (0.04 μ mol m^{-2} s^{-1}) and 80 per cent (0.03 μ mol m^{-2} s^{-1}) shade levels.

In general, as the shade increased there would be a proportionate decrease in the stomatal conductance. Stomatal characters such as size and frequency per unit leaf area have direct correlation, with stomatal conductance. 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. Yoshida (1976) found that photosynthetic rate was highest in barely varieties with the highest stomatal frequency. From the study it is evident that the stomatal index and stomatal frequency were maximum at open condition, 20 per cent and 40 per cent shade levels. As the shade increased there was proportionate decrease in stomatal index and stomatal frequency. This may be the reason for higher stomatal conductance at open condition and low shade levels.

5.1.7.3 Stomatal resistance

Stomatal resistance varied significantly due to different shade levels (Table 27a and Fig. 9). During both the seasons, highest stomatal resistance of 155.19 μ mol m^{-2} s^{-1} and 44.93 μ mol m^{-2} s^{-1} were recorded under 80 per cent shade at first and second year respectively. Stomatal resistance under 60 per cent shade (74.54 μ mol m^{-2} s^{-1}) was on par with that under 20 per cent (57.46 μ mol m^{-2} s^{-1}) and 40 per cent (71.01μ mol m^{-2} s^{-1}) shade levels. Lowest rate of stomatal resistance was recorded under open condition and was on par with that under 20 per cent shade.

5.1.7.4 Photosynthetic rate

Photosynthetic rate varied significantly due to different shade levels at 180 DAP (Table 27a and Fig. 10). During first year, highest photosynthetic rate of 7.54 μ mol m^{-2} s^{-1} was recorded under open condition followed by photosynthetic rate of 2.51 μ mol m^{-2} s^{-1} under 20 per cent shade. Photosynthetic rate under 20 per cent (2.51 μ mol m^{-2} s^{-1}) and 40 per cent (1.80 μ mol m^{-2} s^{-1}) were on par and lowest photosynthetic rate of 0.72 μ mol m^{-2} s^{-1} was observed under 80 per cent shade which was on par with photosynthetic rate at 60 per cent (1.16 μ mol m^{-2} s^{-1}) shade.

During second year, photosynthetic rate under open condition (6.32 μ mol m^{-2} s^{-1}) and 20 per cent shade (5.61 μ mol m^{-2} s^{-1}) were on par and superior to other shade levels. Photosynthetic rate of 3.36 μ mol m^{-2} s^{-1} under 40 per cent shade was on par with the photosynthetic rate under 60 per cent shade (2.45 μ mol m^{-2} s^{-1}). The lowest photosynthetic rate of 1.86 μ mol m^{-2} s^{-1} was recorded under 80 per cent shade which was on par with photosynthetic rate under 60 per cent shade (2.45 μ mol m^{-2} s^{-1}).

Increase in photosynthetic rate was observed with increasing levels of PAR. However, the photosynthetic rate at low shade level (20 per cent) was

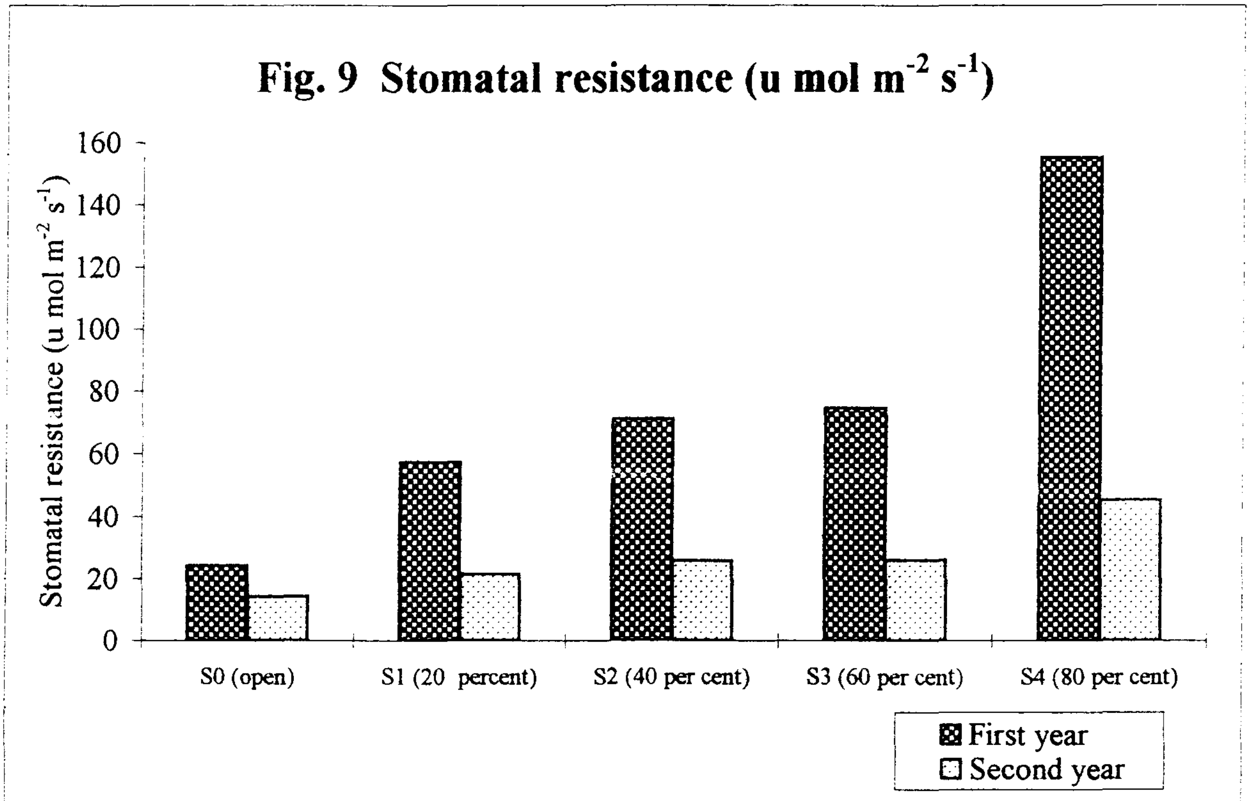


Fig. 9 Stomatal resistance (u mol m-2 s-1)
Stomatal resistance (u mol m-2 s-1)
160
140
120
100
80
60
40
20
0
S0 (open)
S1 (20 percent)
S2 (40 per cent)
S3 (60 per cent)
S4 (80 per cent)
First year
Second year

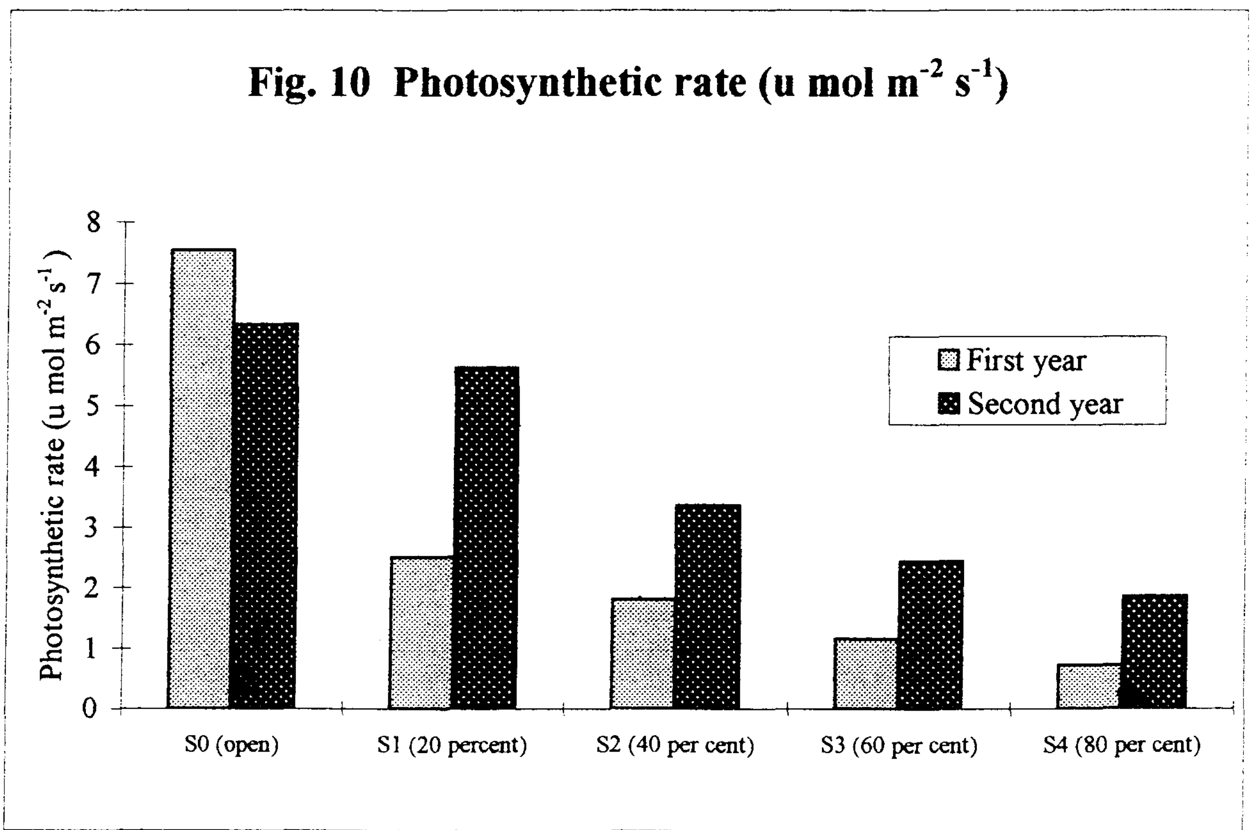


Fig. 10 Photosynthetic rate (u mol m-2 s-1)
Photosynthetic rate (u mol m-2 s-1)
8
7
6
5
4
3
2
1
0
S0 (open)
S1 (20 percent)
S2 (40 per cent)
S3 (60 per cent)
S4 (80 per cent)
First year
Second year

on par with plants grown at open condition. As the shade increase there was proportionate decrease in photosynthetic rate. The high shade intensity may perhaps reduced leaf thickness, stomatal index, stomatal frequency and stomatal conductance. This may lead to the reduction in photosynthetic rate at higher levels of shade. Ginger appeared to be efficiently utilising low light intensity for its photochemical reactions (Minoru and Hori, 1969).

5.1.7.5 Transpiration rate

Transpiration rate varied significantly due to different shade levels (Table 27b). During both the seasons, highest transpiration rate was observed under open condition. The transpiration rate of first and second year were 1.43 mol m^{-2} s^{-1} and 1.73 mol m^{-2} s^{-1} respectively. During first year, under 20 per cent shade, transpiration rate of 0.61 mol m^{-2} s^{-1} which was on par with transpiration rate under 40 per cent (0.59 mol m^{-2} s^{-1}) and 60 per cent (0.50 mol m^{-2} s^{-1}) shade levels. Lowest transpiration rate of 0.25 mol m^{-2} s^{-1} was observed under 80 per cent shade level.

During second year, transpiration rate (1.29 mol m^{-2} s^{-1}) under 20 per cent shade was on par with transpiration rate of 1.10 mol m^{-2} s^{-1} under 60 per cent shade. The transpiration rate under 60 per cent (0.76 mol m^{-2} s^{-1}) and 40 per cent (1.10 mol m^{-2} s^{-1}) were on par and the lowest transpiration rate of 0.53 mol m^{-2} s^{-1} was recorded under 80 per cent shade which was on par with transpiration rate at 20 per cent shade.

Transpiration rate was maximum when plants were grown in open condition. High light intensity increased the stomatal frequency and perhaps this might have influenced the transpiration rate. The driving force for transpiration is the gradient in water vapour beyond the boundary layer. Leaf resistance to transpiration can widely vary as environmental factors influence stomatal apertures. High rate of transpiration resulted in open and lower levels of shade may be due to high stomatal index and stomatal frequency observed in the present investigation (Table 17).

5.1.8 Biochemical aspects

5.1.8.1 Chlorophyll content

The chlorophyll 'a' content in the plant varied significantly among different shade levels (Table 28). The highest chlorophyll 'a' content was recorded at S_4 (1.42 mg g^{-1}) which was followed by S_3 (0.99 mg g^{-1}), S_2 (0.72 mg g^{-1}), S_0 (0.62 mg g^{-1}) and S_1 (0.54 mg g^{-1}). The same trend in chlorophyll 'a' content was observed during the second year.

The chlorophyll 'b' content in the plant varied significantly among the different shade levels. The highest chlorophyll was recorded at S_4 (1.38 mg g^{-1}) which was followed by S_3 (1.08 mg g^{-1}). The shade level S_2 registered a chlorophyll 'b' content of 0.76 mg g^{-1} and was on par with S_0 (0.72 mg g^{-1}). The same trend in chlorophyll 'b' content was observed during the second year.

The total chlorophyll content varied significantly among different shade levels. The highest chlorophyll (total) content was recorded by S_4 (2.80 mg g^{-1}) followed by, S_3 (2.06 mg g^{-1}), S_2 (1.48 mg g^{-1}), S_0 (1.35 mg g^{-1}) and S_1 (1.20 mg g^{-1}).

The same trend in chlorophyll (total) content was observed during second year. The increase in chlorophyll content under shade is an adaptive mechanism commonly observed in plants to maintain the photosynthetic efficiency (Attridge, 1990).

5.1.8.2 Proline content

The proline content in the plant varied significantly among different shade levels at 180 DAP (Table 28). During first year, the shade level S_0 recorded the highest proline content of 1.37 $\mu g\ g^{-1}$ which was on par with S_1 (1.28 $\mu g\ g^{-1}$). The shade level S_2 registered Proline content of 0.78 $\mu\ g\ g^{-1}$ which was on par with Proline content recorded at S_3 (0.74 $\mu g\ g^{-1}$) and S_4 (0.56 $\mu g\ g^{-1}$).

During the second year, the shade level s_0 recorded highest Proline content 1.10 $\mu\ g\ g^{-1}$ which was on par with S_1 (1.00 $\mu g\ g^{-1}$). The shade level S_2 recorded a proline content of 0.82 $\mu g\ g^{-1}$ which was on par with S_3 (0.78 $\mu g\ g^{-1}$). The lowest proline content of 0.51 $\mu g\ g^{-1}$ was recorded at the shade level S_4.

Proline accumulation has been shown to be an adaptive mechanism to stress tolerance. Low relative water content (Table 25) was recorded under 20 per cent shade and open condition. High proline content at open and 20 per cent shade levels compared to other shade levels may be due to water stress resulted by high light intensities.

5.1.9 Yield and yield components

5.1.9.1 Top yield

Top yield varied significantly due to different shade levels (Table 29). The top yield varied significantly due to the shade over different periods from 120 DAP. During all growth stages, highest top yield was observed under 20 and 40 per cent shade levels. In later stages of growth, top yield under open condition and 60 per cent shade level were on par and 80 per cent shade recorded the lowest top yield.

Shade levels (20 and 40 per cent) gave the highest top yield per plant because the number of tillers and leaves were found to be always higher under this situation. It is observed that under open condition the drying of lower leaves and drying of few initial tillers are frequently occurring. Whereas under shade levels, these chance are less, resulting in more tillers and leaves compared to open. The findings was in conformity with the observations of Ramanujam and Jose (1984), Hirota and Moritani (1980) in different crops. Similar trend was also observed in ginger (Ancy, 1992; Babu, 1993).

5.1.9.2 Fresh ginger yield

Fresh ginger yield varied significantly due to different shade levels (Table 30 and Fig. 11). The influence of shade on fresh ginger yield was significant at 150 DAP and maximum yield was recorded under 20 per cent shade during both the seasons. The same trend was observed during 180 and 210 DAP. At full maturity, the fresh ginger yield at 20 and 40 per cent shade were on par but produced significantly higher yield when compared to open condition and other levels of shade during both the seasons. In conclusion, shade levels 20 and 40 per cent produced maximum fresh ginger yield and 60 and 80 per cent shade levels exhibited yield reduction. However, open condition is found to be better than 60 and 80 per cent shade for rhizome yield.

Similar results were reported by Susan Varughese (1989), Jayachandran *et al.* (1991), Ancy (1992), George (1992) and Babu (1993) in ginger.

Zhao *et al.* (1991) observed that a range of 500 to 30,000 lx sunlight was more favourable for increased photosynthetic efficiency. If the light intensity increased beyond 30000 lx the photosynthetic efficiency decreased. He also observed that top leaves receiving full illumination are inferior with respect to photosynthetic efficiency. Better performance of crop under low light intensities than in open may be due to the fact that in open there is a threshold of illumination intensity beyond which the stomata of shade loving plants tends to close (Hardy, 1958). Assuming that this was one of the reason for shade response of crop, it may be reduced that stomata closure had a dominant influence upto the low shade 20 per cent, beyond which the availability of light for photosynthesis probably become the decisive limiting factor. Minoru and Hori (1969) found that ginger can efficiently utilize low light intensities. Under low shaded conditions, higher leaf area, bulking rate, NAR and CGR were noticed and it indicates the better performance of ginger under shaded conditions than in open. The low yield might be due to low leaf area exhibited throughout the growth period which might have reduced the total photosynthates accumulated. The data on DMP and BR showed that shading did not result in any appreciable decrease in the rate of photosynthesis and accumulation of photosynthates under 20 and 40 per cent shade level. These

Fig. 11 Effect of shade on fresh ginger yield at harvest

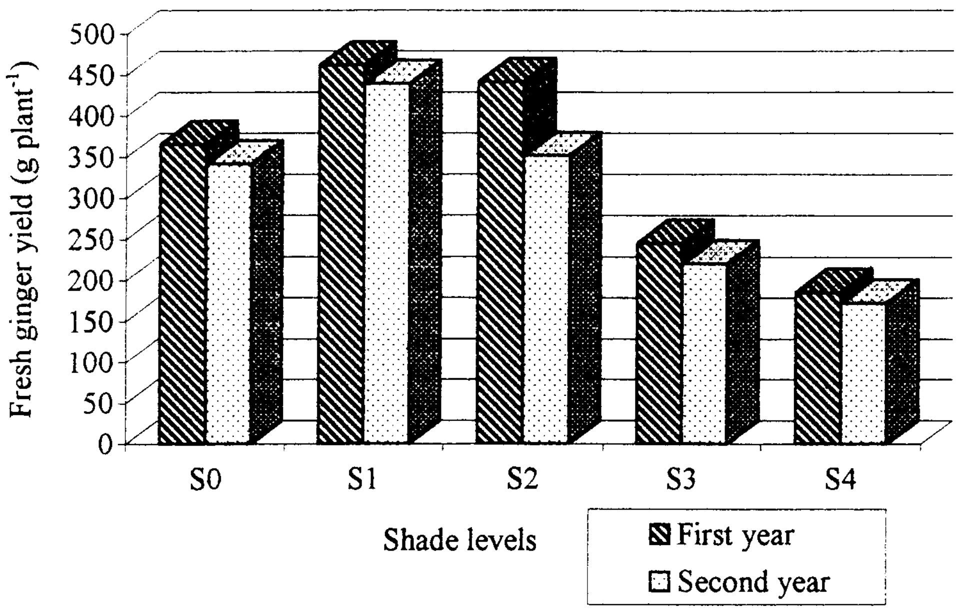
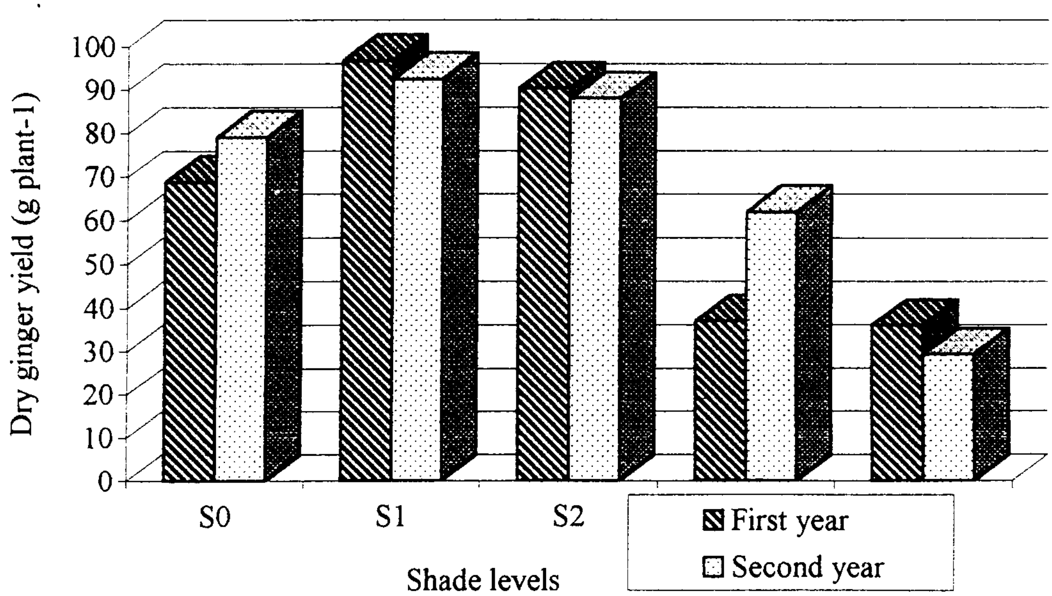


Fig. 12 Effect of shade on dry ginger yield at harvest



findings are in agreement with the observations of Ravisankar and Muthuswamy (1986), Ancy (1992) and Babu (1993) in ginger.

5.1.9.3 Dry ginger yield

Dry ginger yield varied significantly due to different shade levels (Table 31 and Fig. 12). Up to 120 DAP, not much variation in dry ginger yield was observed due to shade over periods. Between 150 to 210 DAP, highest dry ginger yield was recorded under 20 per cent shade followed by 40 per cent shade level. At full maturity, 20 per cent shade recorded 96.64 g dry ginger per plant which was on par with the yield (90.33 g) under 40 per cent shade followed by open condition (68.78 g). During second year also same trend was observed.

Clearly, the performance of the crop was much better under 20 and 40 per cent shade levels. The findings are in conformity with the observations of Ancy (1992), KAU (1992) and Babu (1993).

5.1.9.4 Bulking rate

Bulking rate (BR) significantly varied due to different levels of shade (Table 32 and Fig. 13). At 90 to 120 DAP, highest BR was observed under 40 per cent shade level which was on par with 20 per cent shade. At 120 - 150 DAP, during first year highest BR was observed under 20 per cent shade which was followed by 60 per cent shade but were par during second year. No significant variation in BR was observed at 150 to 180 DAP. During first year, between 210 - 240 DAP, no significant variation in BR was noticed among different shade levels. But during second year, maximum BR was noticed under plants grown in open condition which was on par with 20 and 60 per cent shade level. The bulking rate under 20, 40 and 60 per cent shade levels were on par during second year.

The bulking rate recorded was maximum under shade levels of 20 and 40 per cent at early growth phases (90 - 120 DAP and 120 - 150 DAP). In general, not much variation in BR at different shade levels was observed during later stages of growth. However, under open, 20 and 40 per cent shade levels maximum BR was observed.

Increased BR under low shade levels was reported by Ancy (1992) and Babu (1993). Increased BR under shade levels (20 per cent and 40 per cent) may be due to increased NAR, CGR, leaf area and efficient assimilate partitioning to rhizome. However, under intense shade BR was found to be low due to reduced photosynthetic efficiency as evident from the DMP. Similar result were also reported by Ancy (1992), George (1992) and Babu (1993) in ginger and Zara *et al.* (1982) and Roberts-Nkrumah *et al.* (1986) in cassava.

5.1.9.5 Harvest index

During early growth stages, up to 120 DAP, the effect of shade on harvest index (HI) was significant (Table 33 and Fig. 14). At 90 DAP, highest HI was recorded under 60 per cent shade which was on par with HI at 20 per cent shade. But during second year, maximum HI was recorded under open condition which was on par with HI at 80 per cent shade. At 120 DAP, highest HI was recorded under 20 per cent shade, followed by 60 per cent

Fig. 13 Effect of shade on bulking rate between 210 - 240 DAP

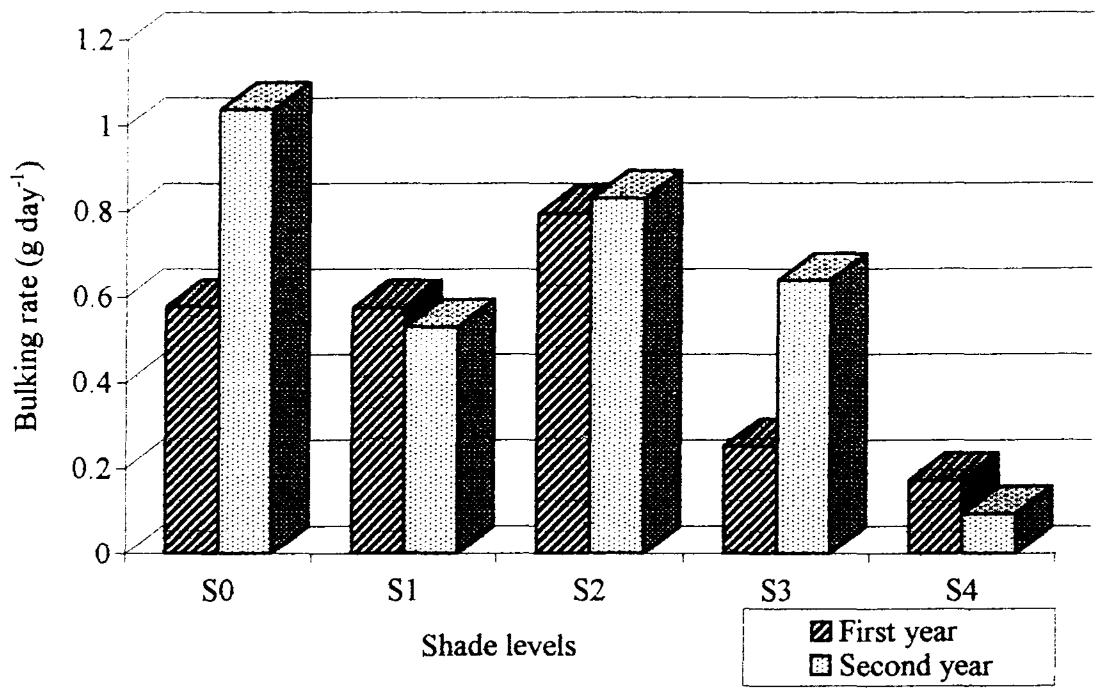
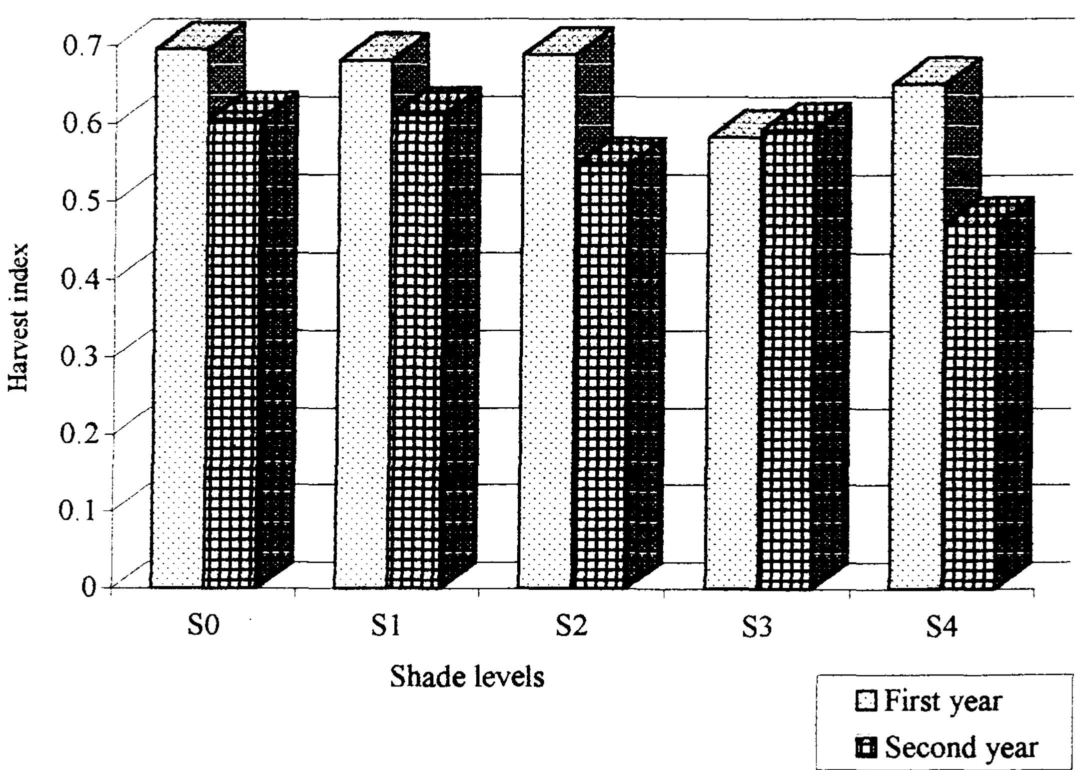


Fig. 14 Effect of shade on harvest index at 240 DAP



shade which was on par with 20 and 40 per shade levels. During second year, highest HI was recorded at 80 per cent shade, followed by HI at 60 per cent which was on par with all other shade levels.

No significant variation in HI due to shade was observed from 120 to 210 DAP. At 240 DAP, during first year no significant variation in HI among different shade levels was observed. During the second year, maximum HI of 0.611 was recorded under 20 per cent shade which was on par with HI under open condition (0.605), 40 per cent (0.546) and 60 per cent (0.591) shade levels.

The shoot dry weight and rhizome yield were found to show a decreasing trend with increasing shade intensities. As the shoot dry weight decreased there may be proportionate decrease in the rhizome yield. This may be the reason for no significant variation in HI at different shade levels.

5.1.10 Quality aspects

5.1.10.1 Volatile oil content

Volatile oil content showed an increasing trend with increasing levels of shade (Table 34). The positive influence of shade on volatile oil content with increasing shade intensity was also reported by George (1992) in ginger. Ancy (1992) found that, volatile oil content under open condition was significantly lower when compared to shade levels. The favourable effect of shade on volatile oil content was reported by George (1992), Ancy (1992), Babu (1993) and Nizam (1995) in ginger.

In both the year, 120 DAP, maximum volatile oil content was recorded under 80 per cent shade which was on par with 60 and 40 per cent shade levels. The volatile oil content under 20 per cent shade was followed by open condition. At 150 DAP, almost same trend was observed. At 180 to 240 DAP, not much variations in volatile oil content was observed due to shade over periods. In general, lowest volatile oil content was recorded under open condition during different growth stages. Though the volatile oil content under 80 per cent shade level was relatively high, the rhizome yield per plant was very low thereby the recovery of volatile oil was less. However, it is evident that the shade was favourable for the production of volatile in the rhizome.

5.1.10.2 Non-volatile ether extract

Non-volatile ether extract (NVEE) content varied significantly due to different shade levels (Table 35). During both the seasons, NVEE content under 20 and 40 per cent shade levels were found to be on par with each other and significantly superior to that under open condition and higher shade levels (60 and 80 per cent). The result was in accordance with the findings of Ancy (1992) in ginger. According to Ravisankar and Muthuswamy (1987) ginger grown in intercropped condition produced good quality rhizomes with high NVEE. Contrary to this, Babu (1993) found that highest content of NVEE was recorded from open condition followed by 25 per cent shade. George (1992) also recorded highest content of NVEE at open condition.

The NVEE content inconsistently varied over shade with respect to various days after planting. In general, at 150, 180 and 210 DAP, NVEE content at 20 and 40 per cent shade levels were on par and recorded significantly higher NVEE content compared to other levels. At full maturity, during both the seasons, 40 per cent shade registered maximum NVEE content. In general, 20 and 40 per cent shade levels were found to be favourable for more production of NVEE.

5.1.10.3 Starch content

Starch content varied significantly due to different shade levels (Table 36). During both the seasons, maximum starch content was recorded by the plants grown under 20 per cent shade which was followed by open and 40 per cent shade levels. The lowest starch content was recorded under 60 and 80 per cent shade levels.

Up to 180 DAP, not much variation in starch content was observed due to shade over periods. In general, the starch content under 20 per cent shade was significantly higher compared to open. Under higher shade levels (60 and 80 per cent shade) the starch content was observed to be low.

The starch, protein and crude fibre in the rhizome making the bulk of the dry matter (Govindarajan, 1982). This may be a reason for high dry ginger yield (Table 31) recorded under 20 per cent shade level.

5.1.10.4 Crude fibre content

The fibre content was significantly influenced by the shade levels (Table 37). During both the seasons, maximum crude fibre content was recorded under plants grown in open condition. But during second year, the crude fibre content recorded at open condition and 20 per cent shade were on par. As the shade increased there was reduction in crude fibre content.

There was not much variation in crude fibre content at different shade levels up to 180 DAP. During 210 and 240 DAP, the plants under open condition recorded maximum fibre content which was on par with 20 and 40 per cent shade levels. In general, the fibre content was maximum under open situation, which gradually reduced with intensity of shade level increased. The result was in confirmity with the observations of Ancy (1992) and Babu (1993). Contrary to this Aclan and Quisumbing (1976) reported that the fibre content of rhizome was not affected by light intensities.

In general, the quality of ginger in terms of volatile oil, NVEE, starch content were higher and the crude fibre content was less, indicating that 20 and 40 per cent shade levels were favourable for producing good quality ginger.

5.2 EXPERIMENT - II

A nutritional trial conducted under artificial shade revealed the necessity of increasing the existing fertilizer dose. The trials also revealed higher uptake of N and K under shade. Since the nutrient requirement of ginger under artificial shade was found to be higher, separate trials are necessary to evolve recommendations for intercropped ginger. So the present study, viz. the requirement of NPK for ginger in coconut garden aimed to standardise optimum dose of nutrients for ginger intercropped in coconut garden.

5.2.1 Growth characters

5.2.1.1 Height of the plants

Application of nitrogen significantly enhanced plant height at all the stages of growth, during both the years (Table 38 a and 38 b). Increased rate of nitrogen excerted no influence on plant height during both the years at 120 and 180 DAP. A progressive increase in plant height with increase in N up to 90 kg ha^{-1} in ginger was reported by Aclan and Quisambing (1976). Pushpakumari (1989) did not find any significant effect on plant height of lesser yam, tannina and elephant foot yam due to higher rates of fertilizers. Increased plant height was observed by P application at all stages of growth, during first year. Tallest plants were found at the highest level of phosphorus (100 kg ha^{-1}) application. The effect of phosphorus in enhancing the plant height was not significant at all stages of growth during second year. Application of potassium enhanced plant height only at 180 DAP during first year. However, no significant variation in plant height was observed, at 50 kg ha^{-1} and 100 kg ha^{-1} potassium.

At 60 DAP, interactions of N, P and K on plant height was not significant during both the seasons. At 120 and 180 DAP, N x P and N x K interaction on plant height was significant only during first year. At all levels of N, the effect of P in enhancing plant height was evident and maximum plant height was obtained at the highest levels of N and P. In N x K interaction, at all levels of N, the effect of K in enhancing plant height was evident and maximum plant height was obtained at the highest levels of N and K, though it was on par with 150 kg and 50 kg K_2O ha^{-1}.

5.2.1.2 Number of tillers

Significantly higher number of tillers were obtained at the highest level of N at 60 DAP during both the seasons (Table 38 a and 38 b). At 120 DAP, during first year, significantly higher number of tillers were produced at n_2 level of N. In the second year and at 180 DAP during both the seasons, N produced maximum number of tillers, though the difference between 75 kg N and 150 kg N was not significant. During 60 DAP, the levels of phosphorus had no significant effect on tillering. Application of phosphorus was found to increase tillering but no significant difference was observed between 50 kg and 100 kg P_2O_5 during first year, highest level of P produced maximum number of tillers. At 120 DAP, during first year, application of K produced maximum tillers, though the difference between 50 kg and 100 kg K_2O was not significant. The effect of K in enhancing the tiller production was significant at 180 DAP during first year and maximum tillers were recorded at the highest level.

At 60 DAP, N x P, N x K and P x K interactions on tillering was significant during both the seasons, but the effect of N, P and K in increasing the tiller production was inconspicuous. At 120 DAP, the interactions were found to be significant during first year. Under N x P interaction, maximum tillers were produced with n_2 p_2 combination. Under N x K interaction, at all levels of N, the effect of K in increasing tillering was inconspicuous. P x K interaction effect indicates that with higher levels of P the response of K was significant in enhancing tillering.

At 180 DAP, during first year, N x P and N x K interactions were same as above. Under interaction P x K, significantly higher number of tillers were produced under the combination k_2 p_2. The interactions were non-significant during second year.

5.2.1.3 Number of leaves

At 60 DAP, application of P was found to increase leaf number but no significant difference was observed at p_1 and p_2 levels (Table 39 a and 39 b). During second year, N, P and K had no effect on production of leaves. At 120 DAP, during first year, N, P and K at higher level significantly enhanced the number of leaves per plant. During second year, application of N was found to be beneficial in leaf production, but no significant differences were observed between n_1 and n_2 levels of N. Application of P at p_2 level was found to enhance the leaf production. At 180 DAP, during both years, the application of N produced maximum number of leaves, though the difference between 75 kg N and 150 kg N was not significant. Similarly P had significant effect on production of leaves but the difference between 50 kg P_2O_5 and 100 kg P_2O_5 was not significant during first year.

N x P interaction at most of the stages resulted in significantly higher number of leaves at the highest levels of N and P.

N x K interaction was non-significant during 60 DAP. At 120 DAP, significantly higher number of leaves were recorded at the highest levels of N and K during both the years. At 180 DAP, N x K interaction was non-significant during both the seasons.

P x K interaction was non-significant during 60 DAP. At 120 DAP, significantly higher number of leaves were recorded under combination n_2 p_2 during first year but the interaction effect of P x K was inconspicuous during second year. At 180 DAP, during both the years, significantly higher number of leaves were recorded under the combination n_2p_2. Under P x K interaction, during first year, at higher levels of P, potassium at k_2 level significantly influenced the leaf production. But during second year, at higher levels of P, no significant variations in leaf production was observed at k_0 and k_2 levels of K.

5.2.1.4 Leaf area

During 60 DAP, effect of N, P and its interactions were absent during both the seasons (Table 39 a and 39 b). At 120 DAP, during both the seasons, higher levels of N significantly increased the leaf area. Application of N influenced the leaf area per plant, though the difference between 75 kg N and 150 kg N was not significant at 180 DAP during both the seasons.

At 120 DAP, effect of phosphorus in enhancing leaf area was significant during first year. However, the difference between p_1 and p_2 were not significant. At 180 DAP, significantly higher leaf area was recorded at p_2 during first year.

At 120 DAP, during both the seasons, the effect of K on leaf area was absent. At 180 DAP, during first year, significantly higher leaf area was observed at k_2 level.

N x P interaction was significant at 120 DAP, during both the seasons. Maximum leaf area was recorded at highest levels of N and P. At 180 DAP also significant increase in leaf area was recorded at higher levels of N and P.

N x K interaction was significant during both the seasons at 120 DAP. At higher levels of N, the response of K was not visible. However, n_2 k_2 recorded maximum leaf area which was on par with n_2 k_0.

P x K interaction was absent at during 60 and 120 DAP. At 180 DAP, at higher levels of P the response of K was not visible.

5.2.2 Physiological aspects

5.2.2.1 Leaf area index

At 60 DAP, the influence of fertilizers on LAI were absent during both the years (Table 40 a and 40 b). At 120 DAP, during both the years, application of highest level of nitrogen (150 kg ha^{-1}) helped to increase the LAI. The application of nitrogen was found to increase the LAI but no significant difference was observed at n_1 and n_2 levels of nitrogen at 180 DAP, during both the years. Significantly higher LAI per plant was registered at 100 kg P_2O_5 ha^{-1} and 100 kg K_2O ha^{-1}.

At 120 DAP, during both the years, N x P and N x K interactions were found to be significant. A marked increase in LAI was observed at the combinations n_2p_2 and n_2 k_2. At 180 DAP, the same trend was observed.

It is evident that, higher levels of N, P and K significantly influenced the LAI during different growth stages. The interactions indicate that if N is increased there should be proportionate increase in P and K for better LAI.

5.2.2.2 Specific leaf weight

At 60 DAP, application of N significantly enhanced the SLW during both the years (Table 40 a and 40 b). However, no significant variation in SLW was observed at n_1 and n_2 levels of N. At 120 DAP, during first year, same trend was observed as above. At 120 DAP higher rates of nitrogen application significantly enhanced the CGR during both the years. Positive effect of P on CGR was significant only at 180 DAP during second the year. The difference in CGR between p_1 and p_2 were not significant. At 60 DAP, higher rates of K application significantly enhanced the CGR during both the years. At the second growth stage, the difference in CGR between k_1 and k_2 were not significant. But at final growth stage, during first year, at k_1 and k_2 levels of K recorded the same CGR.

At 60 DAP, N x K and P x K interactions were significant during first year. Significantly higher SLW was recorded at combination n_1 k_2. P x K interaction were significant during first year, highest SLW recorded for the combination p_0k_2.

At 120 DAP, N x P and N x K interactions on SLW was significant during the first year. N x P interaction in the absence of nitrogen the response of P was very much visible and maximum SLW was recorded under the combination n_0 p_2. N x K interaction, in the absence of nitrogen the response of K was very much visible.

At 180 DAP, during both the years, P x K interactions were observed. The effect of P on SLW was inconspicuous at all levels of potassium.

5.2.2.3 Dry matter production

At 60 DAP, during first year, application of N was found to be beneficial in DMP but no significant difference was observed at n_1 and n_2 levels (Table 41 a and 41 b). But during second year, application of nitrogen had no effect on DMP. At 120 and 180 DAP, during both the seasons, significantly higher DMP was recorded at highest levels of N.

No significant influence of P on DMP was recorded at 60 DAP. At 120 DAP, during first year, highest DMP was recorded at p_2 level. During second year at p_1 and p_2 levels of P significantly higher DMP was recorded but difference in DMP at p_1 and p_2 levels were not significant. At 180 DAP, during both the seasons, maximum DMP was recorded at highest levels of P.

At 60 DAP, significantly higher DMP was recorded at k_2 level of K during both the seasons. At 120 DAP, significantly higher DMP was recorded at k_2 level. But during second year, application of K had no effect on DMP. At 180 DAP, during first year, application of K at k_1 and k_2 levels recorded maximum DAP but the difference in DMP between k_1 and k_2 were not significant.

N x P interaction was significant only at 60 and 20 DAP during first year. Maximum DMP was recorded at higher levels of N and P.

N x K interactions were absent during different growth stages. P x K interactions were also absent during 60 and 120 DAP. At 180 DAP, during first year, significantly higher DMP was recorded at n_2 p_2 combination.

5.2.2.4 Net assimilation rate

The effect of treatments had no effect on NAR during first phase (Table 41 a and 41 b). However, nitrogen at n_2 level recorded the maximum NAR during both the years. At the second growth phase, during both years, significantly higher NAR was recorded at the n_2 level of N.

At the second phase (120 to 180 days) N x P interaction was significant during both the seasons. During first year, significantly higher NAR was recorded at highest level of N and P. But during second year, maximum NAR was obtained at the highest levels of N and in the absence of P, though it was on par with n_2 p_2. P x K interaction was significant only in the first year. At all levels of P the effect of K in increasing NAR was inconspicuous.

5.2.2.5 Crop growth rate

At the first and second phases (60 to 120 days and 120 to 180 days), increase in levels of N had beneficial effect on NAR (Table 42 a and 42 b). Significantly higher NAR was recorded at n_2 level of N during both the seasons. At the first phase, higher rate of phosphorus had significant effect on NAR. During first year, at highest level of P maximum values of NAR was recorded. But in the second year, the difference between p_1 and p_2 were not significant. At the second phase, during first year, application of P had significant effect on NAR but the difference between p_1 and p_2 were not significant. As regard potassium, during first year, maximum values of NAR was recorded at k_1 and k_2 levels of K.

At first phase, N x P interaction was significant during both the seasons.

At higher levels of N, the effect of K in enhancing the CGR was evident during both the years.

5.2.2.6 Relative growth rate

During both the phases (60 to 120 DAP and 120 to 180 DAP) the increased rate of nitrogen application had significant influence on RGR (Table 42 a and 42 b). Significantly higher RGR was recorded at n_2 level of N during both the seasons. At the first phase, during first year, application of P had significant influence on RGR but the difference between p_1 and p_2 were not significant. Application of K had no effect on RGR during both the phases.

Interaction between fertilizer treatments were also absent during both the phases.

5.2.3 Biochemical aspects

5.2.3.1 Chlorophyll content

Nitrogen application at higher levels significantly increased the chlorophyll 'a' content during both the years (Table 43 a and 43 b). Maximum chlorophyll 'a' content was recorded at n_2 level of N. Increased levels of P application was found to increase chlorophyll 'a' content during both the seasons. Application of K had no influence on chlorophyll 'a' content.

N x P interaction was found to be significant only during second year. At higher level of N, the effect of P in enhancing chlorophyll 'a' content was evident and maximum chlorophyll 'a' content was obtained at the highest levels N and P, though it was on par with n_2 p_1 combination. N x K and P x K interactions were absent during both the seasons.

Application of N at n_2 level significantly increased the chlorophyll 'b' content during both the years. Significantly higher level of chlorophyll 'b' content was recorded at p_2 level of P during both the seasons. At k_2 level, significantly higher chlorophyll 'b' content was recorded during both the seasons.

N x P, N x K and P x K interactions were significant during both the years. N x P interaction, significantly higher chlorophyll 'b' content was obtained under the combination n_2 p_2 levels. N x K interaction, significantly higher chlorophyll 'b' content was recorded under the combination n_2 k_2. P x K interaction, at all levels of P the effect of K in increasing chlorophyll 'b' content was inconspicuous during both the years.

Application of N at higher levels significantly increased the total chlorophyll content during both the years. The nitrogen level n_2 recorded the highest total chlorophyll content during both the years. Increased rates of P application had significant effect on total chlorophyll content and maximum increase was observed under p_2 level. Significant increase in total chlorophyll content was observed with increased rates of K and maximum total chlorophyll content was recorded at k_2 level but k_1 and k_2 were on par during first year.

N x P interaction was significant during both the years. Total chlorophyll content was maximum under n_2 p_2 combination during both the years. However, during the second year, at higher levels of N, no significant difference was observed under p_1 and p_2 levels of phosphorus. P x K interaction was significant during second year. However, in the absence of K the response of P was not visible.

5.2.4 Yield and yield components

5.2.4.1 Fresh ginger yield

Application of nitrogen significantly increased fresh ginger yield during both the seasons (Table 44a, 44b and Fig. 15a, 15b). Increase of 10.4 per cent fresh ginger yield was obtained when 150 kg ha^{-1} N was applied, compared to 75 kg ha^{-1} N. However, during the second year, 75 kg ha^{-1} and 150 kg ha^{-1} nitrogen were on par but produced significantly higher fresh ginger yield when compared to the absence of nitrogen. From the results of pooled analysis, it may be seen that by enhancing nitrogen application from 75 kg ha^{-1} (n_1) to 150 kg ha^{-1} (n_2) fresh rhizome yield increased by 0.97 t ha^{-1}. From the data on leaf area, DMP, RGR, NAR, CGR and SLW it is obvious that nitrogen exerted significant positive influence on these parameters. This in turn reveals that under intercropping situations ginger plants well supplied with N had more efficient photosynthetic activity, resulting in production of more assimilates. Combined effect of all the above factors must have favorably influenced the rhizome yield of ginger at higher levels of N. Increase in yield due to higher rates of N application was reported by several workers (Samad, 1953; Aiyadurai, 1966; Muralidharan *et al.*, 1994; Sadanandan and Sasidharan, 1979; Lee, *et. al.* 1981a; Patil and Konde, 1988; Ancy and Jayachandran, 1996). However, negative influence of increased application of N was reported by Johnson (1978).

Application of phosphorus significantly increased the fresh ginger yield. During first year, application of P was found to have effect on yield. However, no significant difference was observed between P at 50 kg ha^{-1} and 100 kg ha^{-1}.

During the second year, application of P at 100 kg ha^{-1} was found to increase the yield by 10.8 per cent than at 50 kg ha^{-1}. Increase in yield due to higher rates of P application was reported by Aiyadurai (1966). Ancy (1992) found that under shaded condition normal fertilizer dosage should be raised to 150 per cent to get good yield. From the results of pooled analysis, it may be seen that by enhancing P application, from 50 kg ha^{-1} (p_1) to 100 kg ha^{-1} (p_2) fresh rhizome yield increased by 0.94 t ha^{-1}. From the data on DMP, RGR and LAI it is obvious that P exerted significant positive influence on these parameters. This in turn reveals that under intercropping situations ginger plants supplied with higher levels of P had more efficient photosynthetic activity, resulting in production of more assimilates. Combined effect of all the above factors must have favorably influenced the rhizome yield of ginger at higher levels of P.

During first year, application of K at 100 kg ha^{-1} was found to increase the yield by 9.9 per cent than K at 50 kg ha^{-1}. During second year, also application of K was found to have effect on yield. However, no significant difference was observed between K at 50 kg ha^{-1} and 100 kg ha^{-1}. The results of pooled analysis showed that the increase in fresh rhizome yield due to enhancement of K from 50 kg ha^{-1}(k_1) to 100 kg ha^{-1} (k_2) was to the tune of 0.70 t ha^{-1}. When ginger plants intercropped in coconut garden, at higher levels of K, there was significant increase in the DMP, chlorophyll content, LAI and uptake of K. Positive influence of K application in increasing rhizome yield was reported by Singh *et al.* (1993).

N x P interaction was significant during the two years. During first year, in the absence of nitrogen, no effect for P was observed, when N applied at 75 kg ha^{-1} maximum yield was obtained at n_1 p_1 but was on par with n_1 p_2. When nitrogen was applied at 150 kg ha^{-1} maximum yield was obtained with n_2 p_2. During the second year, in the absence of N and 75 kg ha^{-1} N the response of P was not visible. But a marked increase in yield was observed at N at 150 kg ha^{-1} and P at 100 kg ha^{-1}. Results of pooled analysis revealed that, in the absence of N and 75 kg N ha^{-1}, the effect of P was not visible. When N was applied at 150 kg ha^{-1} significantly higher yield was recorded with 100 kg P_2O_5 ha^{-1}. The study revealed that for ginger intercropped in coconut gardens, N : P ratio of 1.5:1 may be ideal to get maximum fresh ginger yield.

N x K interaction was absent during both the years. However, the results of pooled analysis revealed that in the absence of N and at 75 kg N ha^{-1}, the effect of K was not visible. When N was applied at 150 kg ha^{-1}, significantly higher yield was recorded with 100 kg K_2O ha^{-1}. Therefore, when ginger intercropped in coconut garden, an N : K ratio of 1.5:1 may be ideal to get maximum fresh rhizome yield.

P x K interaction significantly influenced the green ginger yield in the second year. In the absence of P, the response of K was not visible. But highest green ginger yield was obtained under the combination 100 kg P_2O_5 ha^{-1} and 100 kg K_2 O ha^{-1}. The results of pooled analysis revealed that, when P was applied at 100 kg ha^{-1}, significantly higher yield was recorded with 100 kg K_2O ha^{-1}. Therefore, when ginger intercropped in coconut garden, P : K ratio of 1:1 may be ideal to get maximum fresh ginger yield.

Sushama and Jose (1994) reviewed the nutrition of ginger and grouped ginger as an exhausting crop and hence responded greatly to manure

Fig. 15a Effect of N, P and K on fresh rhizome yield (pooled mean in t ha^{-1})

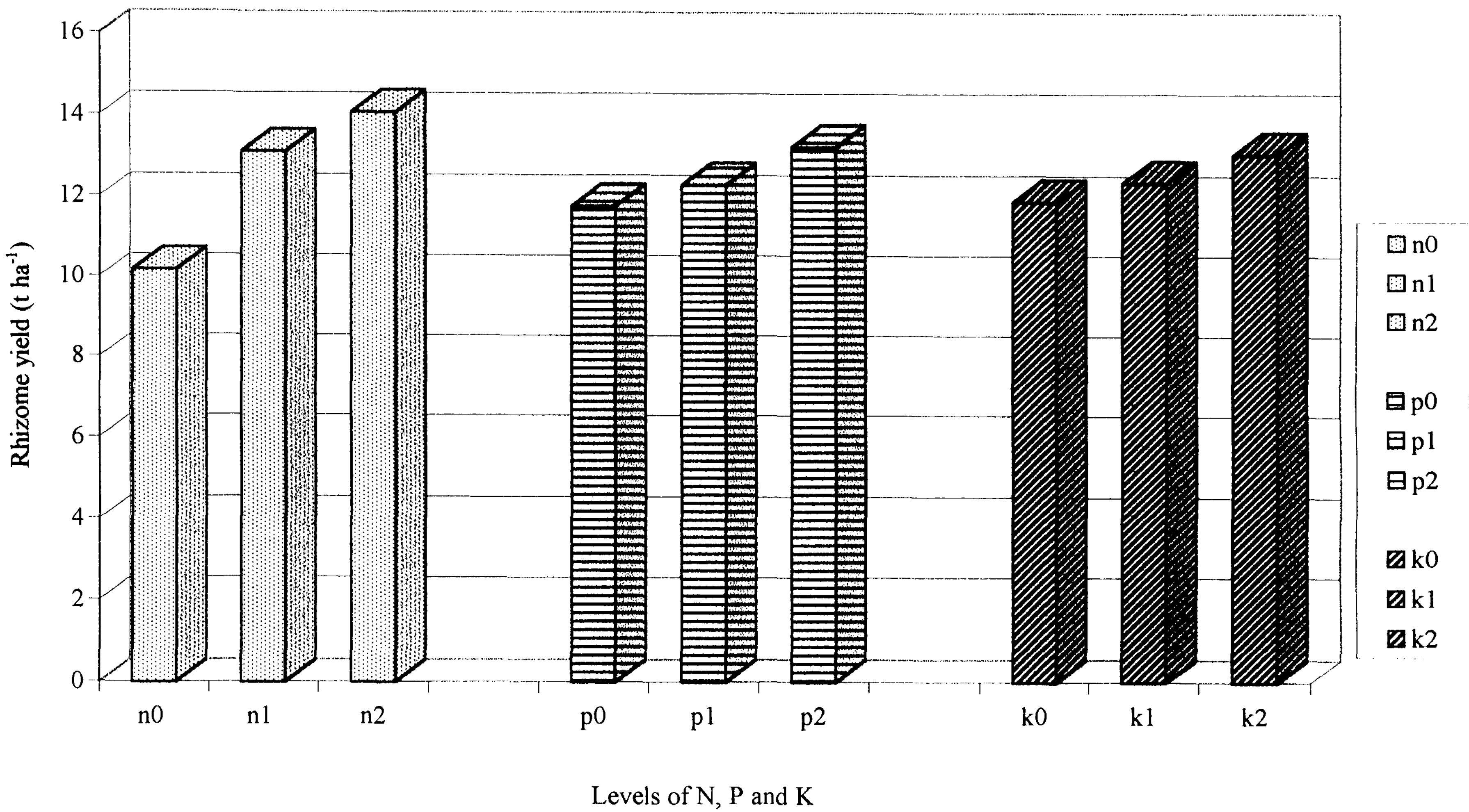
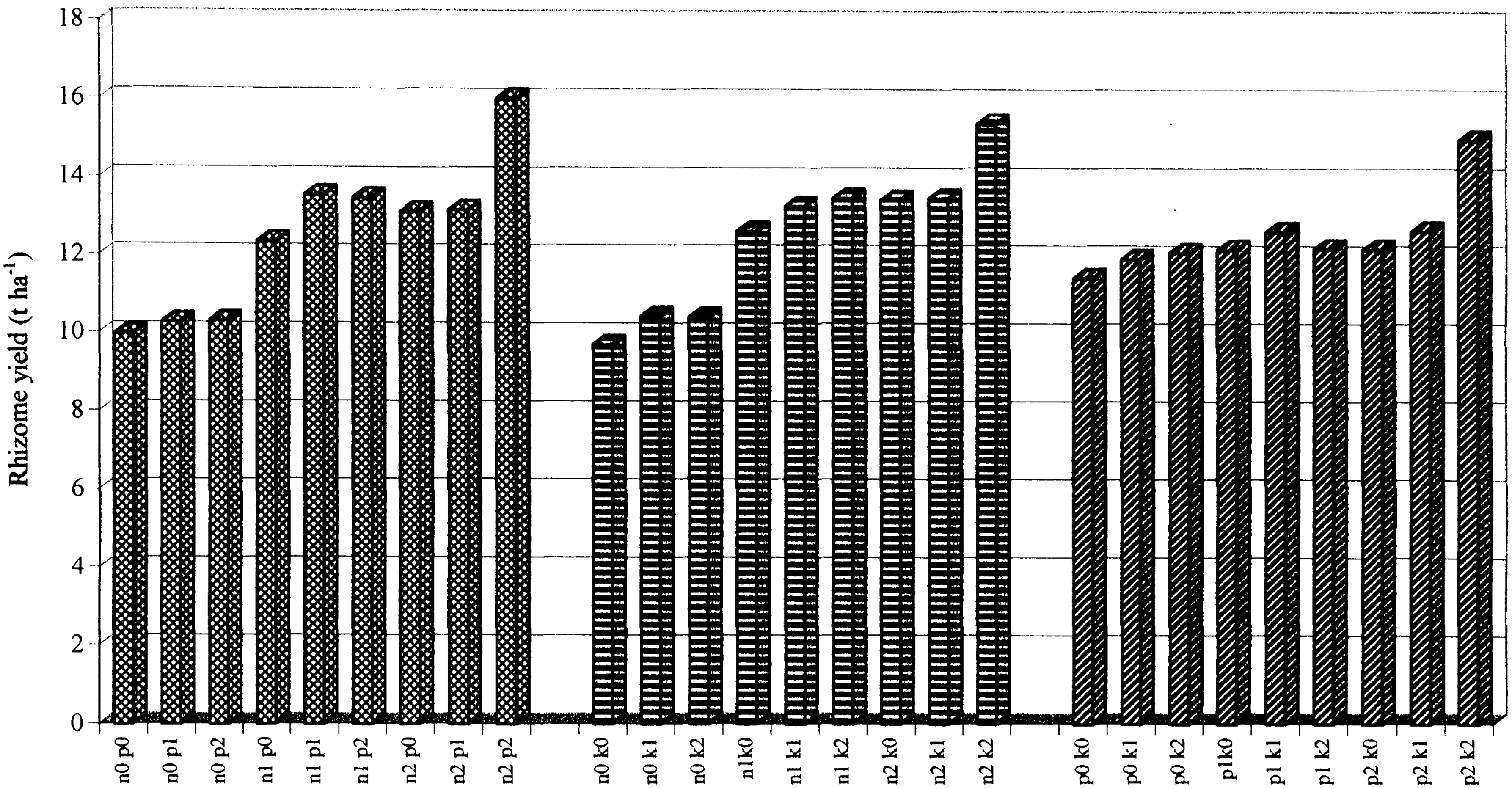


Fig. 15b Effect of N x P, N x K and P x K interactions on fresh rhizome yield (pooled mean t ha^{-1})



application. The recommended dose of NPK fertilizers in Kerala is 75 : 50 : 50 kg ha^{-1} (KAU, 1996). This recommendation was formulated based on the trials conducted at open condition. A nutrient trial conducted under artificial shade revealed the necessity of increasing fertilizer dose to 150 per cent of the existing rate (Ancy, 1992). Higher uptake of N and K under shade was reported (KAU, 1992). From the present investigation it is evident that the nutrient requirement of ginger intercropped in coconut garden may be doubled (150 :100 :100 kg N, P_2O_5, K_2O ha^{-1}) for enhancing yield.

5.2.4.2 Dry ginger yield

Dry ginger yield was significantly influenced by different levels of nutrients (Table 44 a and 44 b). Influence of nitrogen on dry ginger yield was significant during both the years. During first year, application of N at 150 kg ha^{-1} was found to increase the yield by 9.4 per cent than application of N at 75 kg ha^{-1}. During the second year, application of N was found to be beneficial in increasing dry ginger yield but no significant difference at n_1 and n_2 levels of nitrogen, was observed.

Application of P was found to have effect on dry ginger yield. However, no significant difference was observed between 50 kg P_2O_5 ha^{-1} and 100 kg P_2O_5 ha^{-1}. Phosphorus at 100 kg ha^{-1} was found to increase the yield by 11.3 per cent than application of P at 50 kg ha^{-1} . Application of K was found to increase the yield significantly during second year. However, no significant difference was observed between 50 kg K_2O ha^{-1} and 100 kg K_2O ha^{-1}.

N x P interaction was significant during both the years. During first year, in the absence of N, no effect for P was observed. When N was applied at 75 kg ha^{-1} the effect of P was visible, however no significant difference was observed between 50 kg P_2O_5 ha^{-1} and 100 kg P_2O_5 ha^{-1}. During second year, in the absence of nitrogen and at 75 kg N ha^{-1}, the response of P was not visible. But when N was applied at 150 kg ha^{-1}, significantly higher dry ginger yield was observed with 100 kg P_2O_5 ha^{-1} during both the years.

P x K interaction on dry ginger yield was found to be significant only at the second year. In the absence of K the response of P was not visible. When P was combined with 50 kg K_2O ha^{-1}, better yield was obtained at 100 kg P_2O_5 ha^{-1}. When K was increased to 100 kg ha^{-1}, maximum dry ginger yield was obtained with combination of 100 kg P_2O_5 ha^{-1} and 100 kg K_2O ha^{-1}.

5.2.4.3 Shoot dry weight

The influence of nitrogen on shoot dry weight was significant during both the years (Table 45 a and 45 b). Significantly higher shoot dry weight was recorded at n_2 level of nitrogen. Phosphorus application had significant effect on shoot dry weight during both the years. However, the difference in shoot dry weight between p_1 and p_2 was not significant. The influence of potassium on shoot dry weight was significant only at highest level of K application during both the years.

P x K interaction on shoot dry weight was significant only during second year. At higher level of P, maximum shoot dry weight was recorded at k_2 level of K.

The general trend of increase in shoot dry weight observed with increase in fertilizer treatments is in agreement with the findings of Ancy (1992) in ginger and Samed *et al.* (1956) in rice.

5.2.4.4 Harvest index

Influence of nitrogen on HI was significant only in the first year (Table 45 a and 45 b). However, no significant difference in HI was observed at n_1 and n_2 levels of N. But during second year, increased rates of nitrogen application significantly reduced the HI and lowest values were recorded at the highest level. During both the seasons, application of P and K had no effect on HI. Ancy (1992) found that under shade, HI was found to decrease with increase in fertilizer levels which might have resulted from increased top growth at higher fertilizer levels. The efficiency of translocation of assimilates of economic part was found to be decreasing with increasing fertilizer levels.

5.2.4.5 Root : shoot ratio

The effect of nitrogen on root : shoot ratio was significant during both the season (Table 45 a and 45 b). However, no significant difference in root : shoot ratio was observed between n_1 and n_2 levels of nitrogen. Phosphorus and potassium had no significant influence on root : shoot ratio.

5.2.5 Quality aspects

5.2.5.1 Volatile oil content

Different levels of N, P, K and its interactions had no significant effect on volatile oil content (Table 46 a and 46 b). No significant effect of fertilizers on volatile oil content under shade levels was reported by Ancy (1992) in ginger.

5.2.5.2 Non volatile ether extract

Different levels of N, P, K and its interactions had no effect on the NVEE content of ginger (Table 46 a and 46 b). No significant effect of fertilizers on NVEE content under shade levels was reported by Ancy (1992) in ginger.

5.2.5.3 Starch content

Significantly highest content of starch was recorded at n_2 level of nitrogen during both the seasons (Table 46 a and 46 b). Influence of P on starch content was absent during first year but significantly high starch content was recorded at p_2 level during second year. Influence of K on starch content was absent during both the seasons.

N x K interaction on starch content was significant during both the seasons. Significantly higher level of starch content was recorded at n_2 p_2 combination. All other interactions on starch content was absent during both the seasons.

5.2.5.4 Crude fibre content

Application of nitrogen at higher levels increased crude fibre content but no significant difference was observed between n_1 and n_2 levels of N (Table 46 a and 46 b). During second year, nitrogen application had no effect on crude fibre content. Interactions were absent during both the seasons. No significant effect of fertilizers on crude fibre content was reported by Aclan and Quisumbing (1976) and Ancy (1992) in ginger, Carveho *et al.* (1983) in sweet potato and Nair (1985) in lesser yam.

5.2.6 Uptake of nutrients

5.2.6.1 Uptake of nitrogen

Plant uptake of nitrogen increased with higher rates of application of nitrogen (Table 47 a and 47 b). Increase in uptake of nitrogen due to higher rates of application is a well known fact. Ancy (1992) reported that uptake of nutrients under low (25 per cent) and medium shade (50 per cent) was high in ginger and applications of fertilizers at higher levels was found to be beneficial for increasing yield. The highest leaf N content confined with the highest yield (Muralidharan *et al.*, 1994). Sushama and Jose (1994) grouped ginger as an exhausting crop and hence responded greatly to manure application.

5.2.6.2 Uptake of phosphorus

Plant uptake of P increased with higher rates of P application during both the years (Table 47 a and 47 b). Sharma and Grewal (1991) reported that N, P and K uptake by potato crop increased progressively with increase in their rate of application and the nutrient uptake was found closely linked with productivity. However, Muralidharan *et al.* (1994) found that the P leaf content did not appear to be related with the yield in ginger.

5.2.6.3 Uptake of potassium

Plant uptake increased with higher rates of K application during both the years (Table 47 a and 47 b). Significant increase in uptake of potassium with increase in dosages of nitrogen was recorded during first year. However, no significant variations in uptake of K was observed at n_1 and n_2 levels of N.

Higher K content in the leaf was found to be associated with higher yield in ginger (Muralidharan *et al.*, 1994).

5.2.7 Available nutrients in the soil

5.2.7.1 Available nitrogen

Available nitrogen content of the soil increased with higher levels of nitrogen fertilization (Table 48 a and 48 b). Such increase in available nitrogen status, consequent to nitrogen application was reported by several workers (Rajendran *et al.*, 1971, Ancy, 1992 and Babu, 1993).

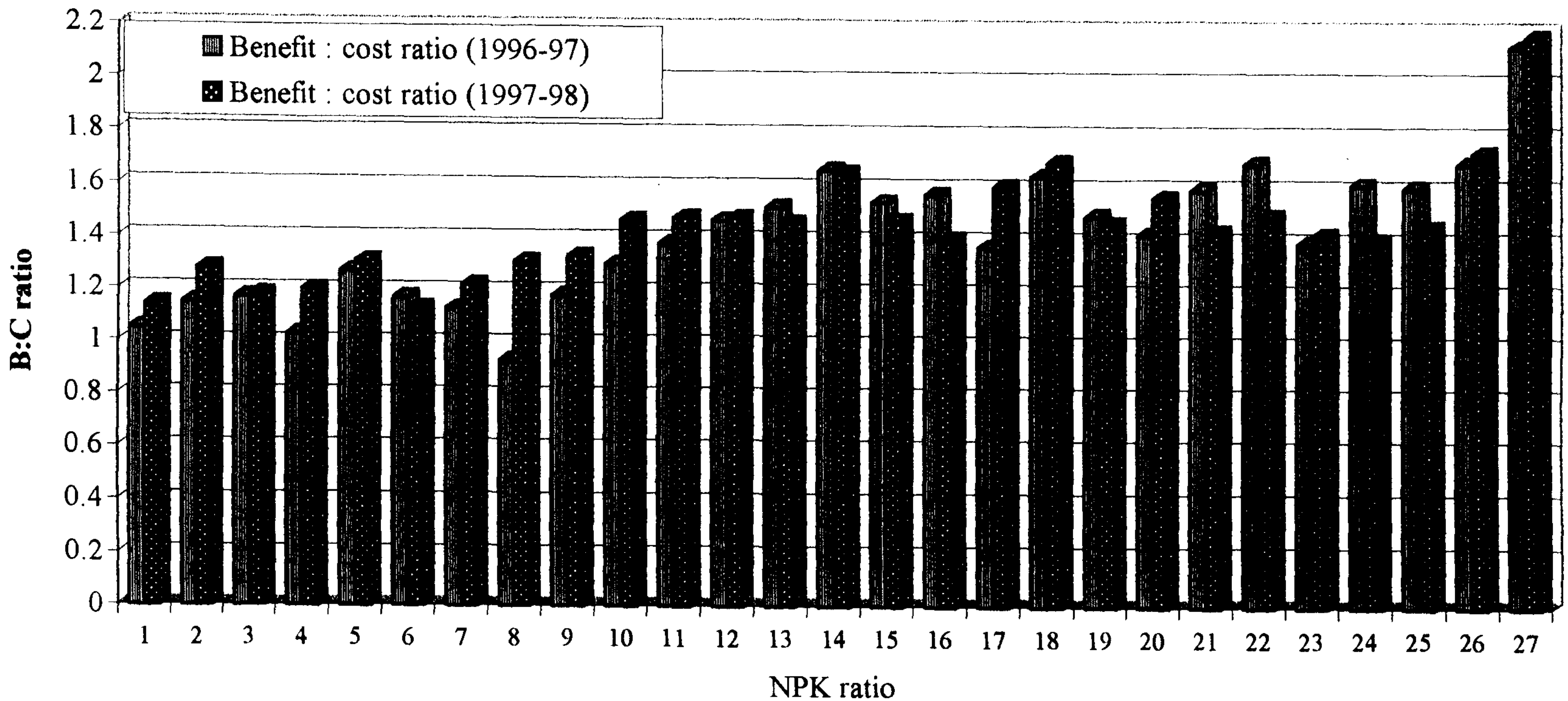
5.2.7.2 Available phosphorus

Available phosphorus content of the soil increased with highest levels of P during first year (Table 48 a and 48 b). But during the second year, there was no significant effect on different levels of P application on available P content in the soil. Potassium excerted no influence on available P in the first year. In the second year there was significant increase in available phosphorus, at k_1 and k_2 levels of K.

5.2.7.3 Available potassium

There was significant increase in available K in the soil due to higher rates of potassium application (Table 48 a and 48 b). Maximum build up of available K was found at the highest level of application. Build up of available K due to higher rates of application was observed by Kumar *et al.* (1977) in cassava. The available K status of the soil was not influenced by levels of nitrogen and phosphorus.

Fig. 16 Benefit : cost ratio of fertilizer application



(1) No fertilizers (2) 0 : 0 : 50 (3) 0 : 0 : 100 (4) 0 : 50 : 0 (5) 0 : 50 : 50 (6) 0 : 50 : 100 (7) 0 : 100 : 0 (8) 0 : 100 : 50 (9) 0 : 100 : 100

(10) 75 : 0 : 50 (11) 75 : 0 : 50 (12) 75 : 0 : 100 (13) 75 : 50 : 0 (14) 75 : 50 : 50 (15) 75 : 50 : 100 (16) 75 : 100 : 0 (17) 75 : 100 : 50 (18) 75 : 100 : 100

(19) 150 : 0 : 0 (20) 150 : 0 : 50 (21) 150 : 50 : 100 (22) 150 : 50 : 0 (23) 150 : 50 : 50 (24) 150 : 50 : 100 (25) 150 : 100 : 0 (26) 150 : 100 : 50 (27) 150 : 100 : 100

5.2.8 Economics of fertilizer application

From the economics of fertilizer application (Table 49, 50 and Fig. 16), it is evident that when ginger intercropped in the coconut garden, application of fertilizers at the rate of 150 kg N, 100 kg P_2O_5 and 100 kg K_2O ha^{-1}, produced the maximum net return of Rs. 96605.45 and Rs. 99227 during first and second year respectively. Among the fertilizer levels tried, 150 : 100 : 100 kg N, P_2O_5 and K_2O ha^{-1} gave maximum benefit : cost ratio when ginger intercropped in coconut garden.

5.3 EXPERIMENT - III

The present investigation on effect of K levels, mulching and triazole was conducted with the objectives to study the optimum potassium and mulch requirement for ginger intercropped in coconut garden. The efficacy of triazole in the improvement of yield and other desirable characters were also evaluated.

5.3.1 Growth characters

5.3.1.1 Plant height

Influence of potassium on plant height was significant only during second year at 120 DAP and the first year at 180 DAP (Table 51). During both the stages of growth maximum plant height was recorded at 150 kg N ha^{-1}.

Influence of mulch on plant height was significant only during the second year at 60 DAP and 180 DAP. At 60 DAP, increased plant height was recorded at the lowest level of mulch. However, no significant difference was observed between mulch levels, 15 t ha^{-1} and 22.5 t ha^{-1}. At 180 DAP, significantly higher plant height was recorded at mulch level 30 t ha^{-1}. Srivastava *et al.* (1969) reported the influence of various mulches on plant height.However, Babu (1993) found that under shade levels there was an increasing trend in plant height with increasing mulch levels.

Influence of triazole on plant height was significant during first year at 60 DAP. Significantly higher plant height was observed when plants were applied with triazole. However, no significant difference in plant height was observed between triazole levels 25 $\mu g\ ml^{-1}$ and 50 $\mu g\ ml^{-1}$.

K x M interaction was significant at all stages of growth. At 60 DAP, during the second year, significantly higher plant height was observed under the combination of 100 kg $K_2O\ ha^{-1}$ and 15.0 t ha^{-1} of mulch.

At 120 DAP, at lower levels of mulch the effect of K was significant in plant height. In general, at higher levels of K application, the mulch requirement can be reduced to 15 t ha^{-1} from 22.5 t ha^{-1} for higher plant height. At 180 DAP, during first year, highest plant height was observed under 100 kg $K_2O\ ha^{-1}$ and 15 t ha^{-1} of mulch. However, during second year, in the absence of K, maximum plant height was recorded at mulch level 30 t ha^{-1}.

5.3.1.2 Number of tillers

Influence of potassium on tillering was significant at difference growth stages (Table 52). At 60 DAP, during the first year, highest number of tillers were recorded at 50 kg $K_2O\ ha^{-1}$ which was on par with the tiller production at 100 kg $K_2O\ ha^{-1}$.

At 120 DAP and 180 DAP significantly higher number of tillers were produced under 100 kg K_2O ha^{-1}. But at 180 DAP, during second year, no significant difference in tiller production was observed under 50 kg K_2O ha^{-1} and 100 kg K_2O ha^{-1}.

At 60 DAP, effect of mulch on tiller production was significant during both the years. At 120 DAP, during first year, significantly higher number of tillers were observed under mulch levels 30 t ha^{-1}. At 180 DAP, effect of different levels of mulch on tillering was not observed. Jha *et al.* (1972) reported that mulch directly influenced tiller production. According to Babu (1993) increasing levels of mulch produced a significant increasing trend in tiller number. Among the treatment combinations, under 25 per cent shade, 22.50 t ha^{-1} of mulch recorded maximum tiller number. In the present investigation, tillering was not affected by different mulch levels when ginger was grown as an intercrop in coconut garden.

Triazole had no significant influence on tillering at different growth stages.

K x M interaction had no effect on tillering at difference growth stages.

5.3.1.3 Number of leaves

Influence of potassium in promoting number of leaves was significant and at 60 DAP maximum number of leaves were produced under K levels, 50 kg ha^{-1} and 100 kg ha^{-1} (Table 53). At 120 and 180 DAP, during both the seasons, significantly higher number of leaves were observed at 100 kg K_2O ha^{-1}. Ancy (1992) reported that leaf number were found to increase with increasing dose of fertilizers. The mulch and triazole had no significant effect on leaf number.

K x M interaction in promoting number of leaves per plant was significant only at 180 DAP during second year. At highest level of potassium, m_1 and m_2 levels of mulch recorded maximum number of leaves. However, no significant difference was observed between m_1 and m_2 levels of mulch. In the present study reveals that, at higher levels of K, 15 kg ha^{-1} of mulch was sufficient for obtaining maximum number of leaves.

5.3.1.4 Leaf area

Influence of potassium on leaf area was significant at 120 and 180 DAP during both the years (Table 54). At the above growth stages, significantly higher leaf area was recorded when potassium was applied at 100 kg ha^{-1}. In ginger an increasing trend in LAI with increasing fertilizer levels in shaded conditions was reported by Ancy (1992). The influence of different levels of mulch on production of leaf area was not significant during all growth stages.

Increased leaf area under reduced light intensity was reported in ginger by Ravisankar and Muthuswamy (1988), Ancy (1992), George (1992) and Babu (1993). The increased leaf area in ginger intercropped in coconut garden may perhaps be the adaptation to expose larger photosynthetic surface under limited illumination.

The positive influence of mulches on leaf area was reported by Enyl (1973) and Hulugalle *et al.* (1986) in cocoyam, Aina (1981) in maize and Jayashree (1987) in bhindi. Contrary to this, Babu (1993) observed that under open as well as under shade levels the application of higher quantities of mulch enhanced total leaf area. Significant interaction between shade and mulch levels was also observed.

Application of triazole had no significant effect on production of leaf area per plant during all growth stages.

K x M interaction on leaf area was significant only at 120 DAP during first year. Effect of potassium in increasing leaf area was evident at higher levels of mulch. Maximum leaf area was obtained at k_2 m_3 but was on par with k_2 m_2. The study reveals that, at higher levels of K, the mulch requirement can be reduced from 30 t ha^{-1} to 22.50 t ha^{-1} to obtain highest leaf area.

5.3.2 Physiological aspects

5.3.2.1 Dry matter production

Influence of potassium on DMP was significant in the first year at 120 DAP and during both the years at 180 DAP (Table 55). At all stages, significantly higher DMP was recorded at k_2 level of potassium. The positive effect of potassium in increasing DMP was reported by Bourke (1985) in sweet potato, Rajanna *et al.* (1987) in potato, Pushpakumari (1989) in greater yam. Ancy (1992) found that DMP in ginger showed a general trend of increase with increase in fertilizer dose under open and shade levels.

Application of mulch at different levels had no significant effect on DMP all stages of growth. An increase in DMP in ginger when grown as an intercrop in arecanut garden was reported by Ravisankar and Muthuswamy (1988). Susan Varughese (1989), Ancy (1992) and George (1992) observed increased DMP in ginger under shade levels. Babu (1993) observed that under all shade regimes, higher doses of mulch resulted in increased DMP. The influence of mulch for increased DMP might be due to deeper and more extensive root system, more uniform soil temperature and better physical condition in the soil (Halugalle *et al.*, 1986), which might have positively influenced for better nutrient uptake thereby enhanced photosynthesis and assimilate partitioning. However, in the present study increased application of mulch had no effect on DMP when ginger grown as an intercrop in coconut garden.

The influence of triazole on DMP was significant only at 60 DAP and during first year at 120 DAP. At 60 DAP, significantly higher DMP was recorded at triazole level 50 $\mu g\ ml^{-1}$ which was on par with 25 $\mu g\ ml^{-1}$. However, during the second year, application of triazole at 50 $\mu g\ ml^{-1}$ recorded maximum DMP which was on par with untreated plants.

K x M interaction had no significant effect on DMP at all stages of growth.

5.3.2.2 Relative growth rate

Application of potassium significantly influenced the RGR at both phases of growth (Table 56). In the first phase, significantly higher RGR was recorded at 100 kg ha^{-1} of potassium but no significant difference in RGR at 50 kg $K_2O\ ha^{-1}$ and 100 kg $K_2O\ ha^{-1}$ during the second year. At the second phase, during both the years, significantly higher RGR was recorded at 100 kg $K_2O\ ha^{-1}$ which was on par with 50 kg $K_2O\ ha^{-1}$.

The DMP was significantly influenced by the higher rate of potassium application. RGR is influenced by the physiological activity like photosynthesis, respiration and mineral uptake and metabolic balance. Increased photosynthetic efficiency at higher levels of potassium application was evident from DMP. At higher levels of potassium, increased DMP and this in turn will increase the RGR. However, in the present study increased application of potassium alone had no effect on RGR when ginger was intercropped in coconut garden.

Different levels of mulch and triazole had no effect on RGR at both the growth phases.

K x M interaction also had no significant effect on RGR in both the growth phases.

5.3.2.3 Net assimilation rate

Application of potassium significantly influenced the NAR only at first phase of growth (Table 57). However, increase in the levels of potassium had no beneficial effect on NAR. During both the years, maximum NAR was recorded in the absence of potassium

According to Ancy (1992), NAR was found to be higher under open condition and low shade levels. NAR showed positive response to fertilizer treatment under open condition and low shade levels. It may be noted that when ginger was grown as an intercrop in coconut garden, application of potassium alone had no effect on NAR.

Application of mulch had no significant effect on NAR during both the phases of growth. Babu (1993) found that the positive influence of mulch on NAR under low shade. However, Ancy (1992) and KAU (1992) reported that with increase in shade level the photosynthetically active radiation falling on the leaf surface may be less compared to open and low shade and this might have probably reflected in the NAR. In the present investigation, during the second phase (between 120 - 180 DAP), different levels of potassium, mulch and triazole application had no significant effect on NAR.

K x M interaction had no effect on NAR during both phases of growth.

5.3.2.4 Crop growth rate

Application of potassium had significant effect on CGR during both phases of growth (Table 58). In the first phase, significantly higher CGR was recorded at highest level of potassium (100 kg ha^{-1}) but no significant variation in CGR between 50 and 100 kg K_2O ha^{-1} were observed during the second year. In the second phase, significantly higher CGR was observed at 100 kg K_2O ha^{-1} during both the years.

Reduced CGR under the heavy shade was reported by many workers. Fukai *et al.* (1984) reported 50 per cent reduction in CGR in cassava when solar input was reduced up to 32 per cent. Reduced CGR under shaded situations were also reported in turmeric (Ramadasan and Satheesan, 1980), cassava (Ramanujam and Jose, 1984) and in sweet potato (Roberts Nkrumah *et al.*, 1986). Fertilizer treatments under all shade levels gave regular trend of increase in CGR. Bourke (1985) reported similar effect on CGR. Maximum CGR and increased response to nutrients in terms of CGR under 25 and 50 per cent shade levels were observed (Ancy, 1992 and Babu, 1993). In the present study, significant increase in CGR was observed at higher levels of potassium at the later stages of growth during both the years.

Different levels of mulch had no significant effect on CGR during both the phases of growth. It is observed that, application of mulch at 15 t ha^{-1} is sufficient for the better CGR.

Influence of triazole had no significant effect on CGR during both the phases of growth.

K x M interaction also had no significant effect on CGR during both the phases.

5.3.2.5 Specific leaf weight

Different levels of potassium, mulch and triazole had no significant effect on SLW during both the phases of growth(Table 59).

K x M interaction also had no significant effect on SLW during both the phases of growth.

5.3.2.6 Leaf area index

Application of potassium significantly influenced the LAI at 120 DAP and 180 DAP (Table 60). Application of potassium at higher rate (100 kg ha^{-1}) significantly increased the LAI during both the years.

In the present study, higher LAI with increase in potassium levels was observed. An increase in the LAI with increase in fertilizer levels was observed in ginger (Ancy, 1992). Leaf area index also showed the same trend as leaf number with increase in potassium levels, since the leaf number is an important factor determining the LAI. This may be the reason for increased LAI observed at higher levels of potassium application.

Different levels of mulch and triazole had no significant effect on LAI. Contrary to this, positive influence of mulches on leaf area was reported by Enyl (1973) and Halugalle *et al.* (1986) in cocoyam; Aina (1981) in maize and

Jayashree (1987) in bhindi. Under open and shade levels the application of higher quantities of mulch enhanced total leaf area (Babu, 1993). Increase in leaf area in turn enhanced the LAI of the plant. However in the present investigation different mulch levels had no significant effect on LAI.

K x M interaction had no significant effect on LAI.

5.3.3 Biochemical aspects

5.3.3.1 Chlorophyll content

Chlorophyll content of ginger was significantly influenced by the application of potassium (Table 61). Application of potassium at higher rate (100 kg ha^{-1}) significantly influenced the chlorophyll 'a' content only during the second year.

Highest chlorophyll 'b' and chlorophyll (total) contents were recorded when potassium was applied at the rate of 50 kg ha^{-1} during both the years. Increase in chlorophyll content with increase in shade intensity was reported by many workers (Susan Varughese, 1989 ; Ancy, 1992 ; Babu, 1993). Ancy (1992) observed that under shade levels, increasing levels of fertilizer produced a general trend of increase in chlorophyll content and its fractions. However, in the present investigation highest chlorophyll 'b' and chlorophyll (total) content were recorded by lower level of potassium application (50 kg ha^{-1}).

Different levels of mulch had significant effect on chlorophyll content. Significantly higher chlorophyll content was recorded when mulch applied at the rate of 22.5 t ha^{-1}. However, during first year, highest chlorophyll (total) content was recorded when mulch was applied at 30 t ha^{-1} which was on par with the mulch level at 22.5 t ha^{-1}.

According to Attridge (1990) an increase in chlorophyll content under shade is an adaptive mechanism commonly observed in plants to maintain the photosynthetic efficiency.

Present study clearly shows that the mulch requirement of ginger under intercropped condition can be reduced with out affecting the chlorophyll content of the plant since chlorophyll is one of the most important factors governing the photosynthetic efficiency of the plant.

Triazole had significant influence on chlorophyll content. But no significant variation in chlorophyll 'a' and chlorophyll 'b' contents were observed when traizole was applied at 25 and 50 $\mu g\ ml^{-1}$. Triazole applied at 25 $\mu g\ ml^{-1}$ significantly influenced chlorophyll (total) content during both the years.

The plant growth regulating effects of the triazole include increase the leaf thickness, epicuticular wax, chloroplast size, photosynthetic pigments, nucleic acid, proteins and stimulating of rooting (Fletcher *et al.*, 1986). Triazole confers drought tolerance in plants (Fletcher and Nath, 1984 ; Asare-Boamah *et al.*, 1986). Biochemical studies on the plant protective action of the triazoles indicate that under stress condition they prevent the photosynthetic pigment and proteins and maintain the efficiency of the energy transferring system. The photosynthetic rate showed a high correlation with chlorophyll content (Buttery and Buzell, 1972). Influence of triazole on chlorophyll content was observed in the present investigation.

K x M interaction had significant influence on chlorophyll content. Application of 50 kg K_2O ha^{-1} and mulch level 22.5 t ha^{-1} recorded highest content of chlorophyll 'a'. Whereas, potassium applied at 100 kg ha^{-1} and mulch levels 15.0 t ha^{-1} recorded highest chlorophyll 'a' content which was on par with application of mulch at 22.5 t ha^{-1}. The same trend was observed during second year. Significantly higher chlorophyll 'b' content was recorded when 50 kg K_2O ha^{-1} applied with 22.5 t ha^{-1} of mulch. Whereas potassium applied at 100 kg ha^{-1}, the mulch level at 15.0 t ha^{-1} recorded significantly higher chlorophyll 'b' content. The same trend was observed during the second year.

Significantly higher chlorophyll (total) content was recorded under the combination 50 kg K_2O ha^{-1} and 22.5 t ha^{-1} of mulch during both the years. However, during the first year, at 50 kg K_2O ha^{-1}, mulch levels 22.5 t ha^{-1} and 30.0 t ha^{-1} were on par and significantly superior to other levels of mulch in the production of chlorophyll (total) content. At highest level of potassium (100 kg ha^{-1}), the mulch requirement can be reduced from 30 t ha^{-1} to 15.0 t ha^{-1} for obtaining maximum chlorophyll (total) content.

The present investigation reveals that at higher levels of potassium the mulch requirement can be reduced to 50 per cent without affecting chlorophyll content, when ginger intercropped in coconut garden.

5.3.3.2 Proline content

Application of potassium had no significant effect on proline content during both the years (Table 62). Different levels of mulch had significant effect on proline content during second year. Significantly higher proline content was recorded when mulch was applied at 30.0 t ha^{-1} which was on par with the mulch level 15.0 t ha^{-1}.

Influence of triazole on proline content was significant during both the years. With an increase in the levels of triazole there was significant increase in the proline content. Plants receiving the highest level of triazole (50 μg ml^{-1}) recorded significantly higher proline content.

Biochemical studies on the plant protection action of the triazole indicate that under stress conditions they induce the stress proteins in the plants.

K x M interaction had significant influence on proline content during the first year. However, at higher levels of potassium the different levels of mulch had no significant effect on proline production.

5.3.4 Yield and yield components

5.3.4.1 Shoot dry weight

Application of potassium had significant effect on the shoot dry weight (Table 62). During first year, significantly higher shoot dry weight was recorded at 100 kg K_2O ha^{-1} which was on par with 50 kg K_2O ha^{-1}.

Ancy (1992) found that from open to 50 per cent shade, increase in fertilizer dose was found to promote shoot dry weight in ginger. However, in the present investigation revealed that, K had no significant effect on shoot dry weight. Different levels of mulch and triazole had no significant effect on shoot dry weight. K x M interaction also had no effect on top yield.

5.3.4.2 Fresh ginger yield

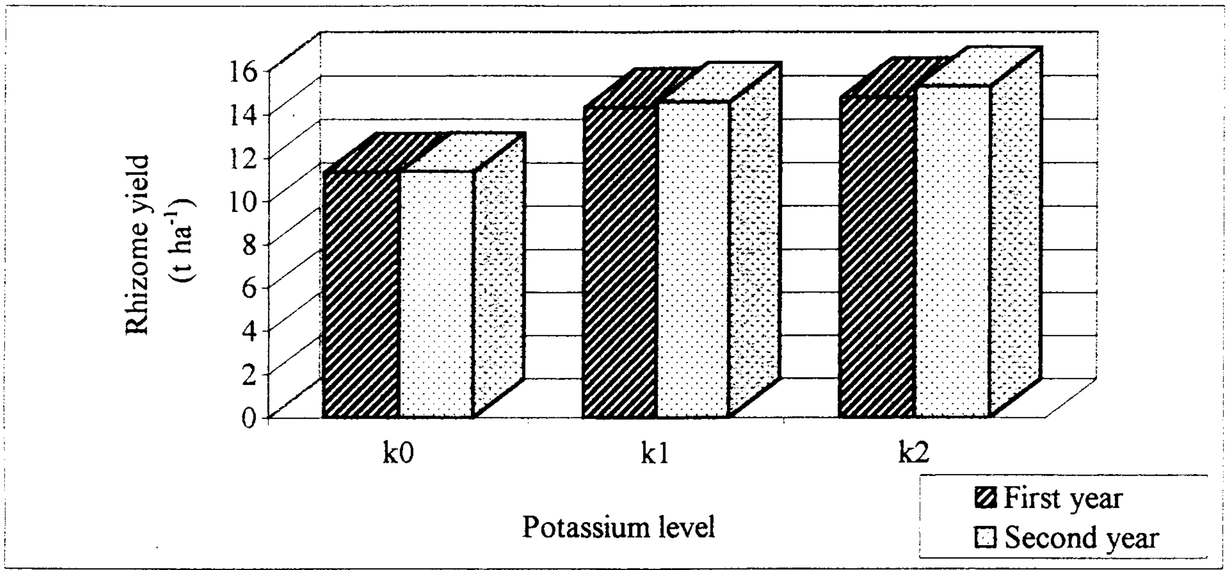
Application of potassium significantly influenced the fresh ginger yield (Table 63 and Fig. 17a, 17b). Significantly higher fresh ginger yield was recorded at 100 kg K_2O ha^{-1} which was on par with potassium at 50 kg ha^{-1}. But during the second year, significantly higher fresh ginger yield was recorded at 100 kg K_2O ha^{-1}.

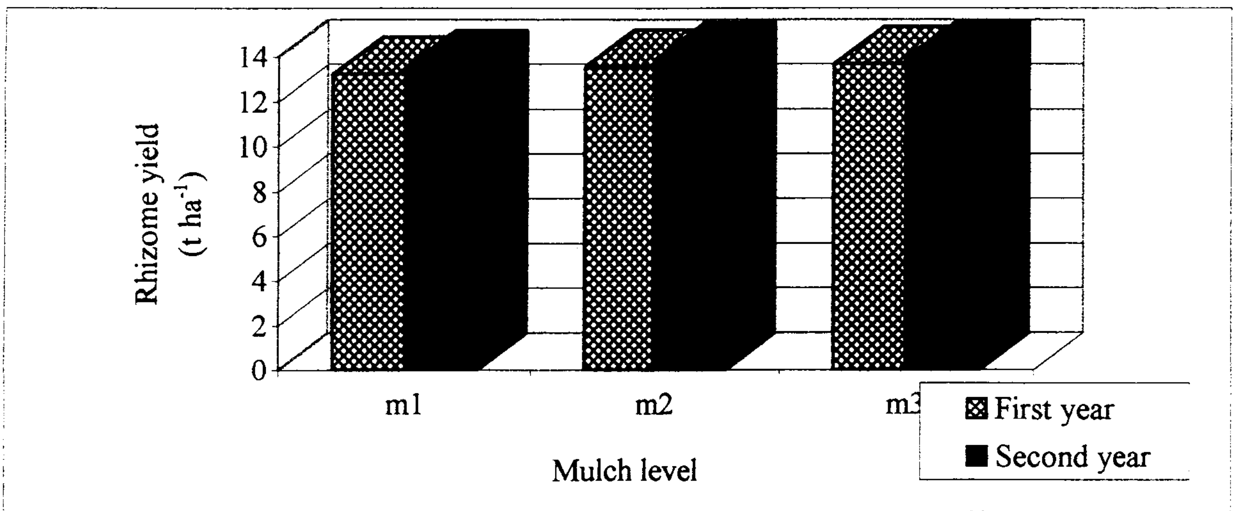
Ravisankar and Muthuswamy (1988) reported higher fresh ginger yield when ginger was grown as an intercrop. Ancy (1992) found that fertilizer treatments had a positive influence on fresh ginger yield. The role of increased dose of potassium in fresh ginger yield was evident from the present investigation.

During both the years, increased levels of mulch had no significant effect on the fresh ginger yield. For ginger, mulching is one of the important cultural operations for better growth (Jha *et al.*, 1972; Mohanty, 1977; Mishra and Mishra, 1986; Roy and Wamanan, 1988 and Korla *et al.*, 1990). Babu (1993) found that under shaded situation (25 per cent) the total quantity of leaf mulch required was 22.5 t ha^{-1} thereby a saving of 7.5 t ha^{-1} green leaves can be achieved. Present experiment reveals that the mulch requirement can be reduced to 50 per cent when ginger is intercropped in coconut garden. Influence of triazole had no effect on fresh ginger yield.

K x M interaction on fresh ginger yield was significant only at first year. In the absence of potassium, no significant difference in fresh ginger yield was observed with different levels of mulch. But in the presence of potassium, at 50 kg ha^{-1}, plants grown with 22.5 t ha^{-1} and 30.0 t ha^{-1} of mulch provided

Fig. 17a Effect of potassium (K), mulch (M) and triazole (T) on fresh ginger yield (t ha^{-1})





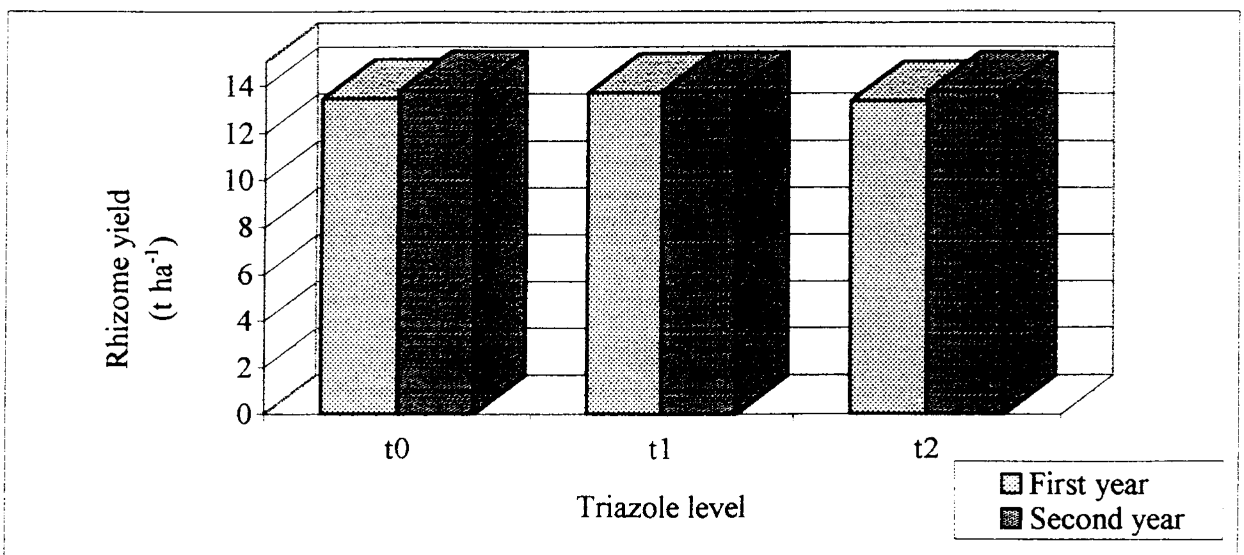
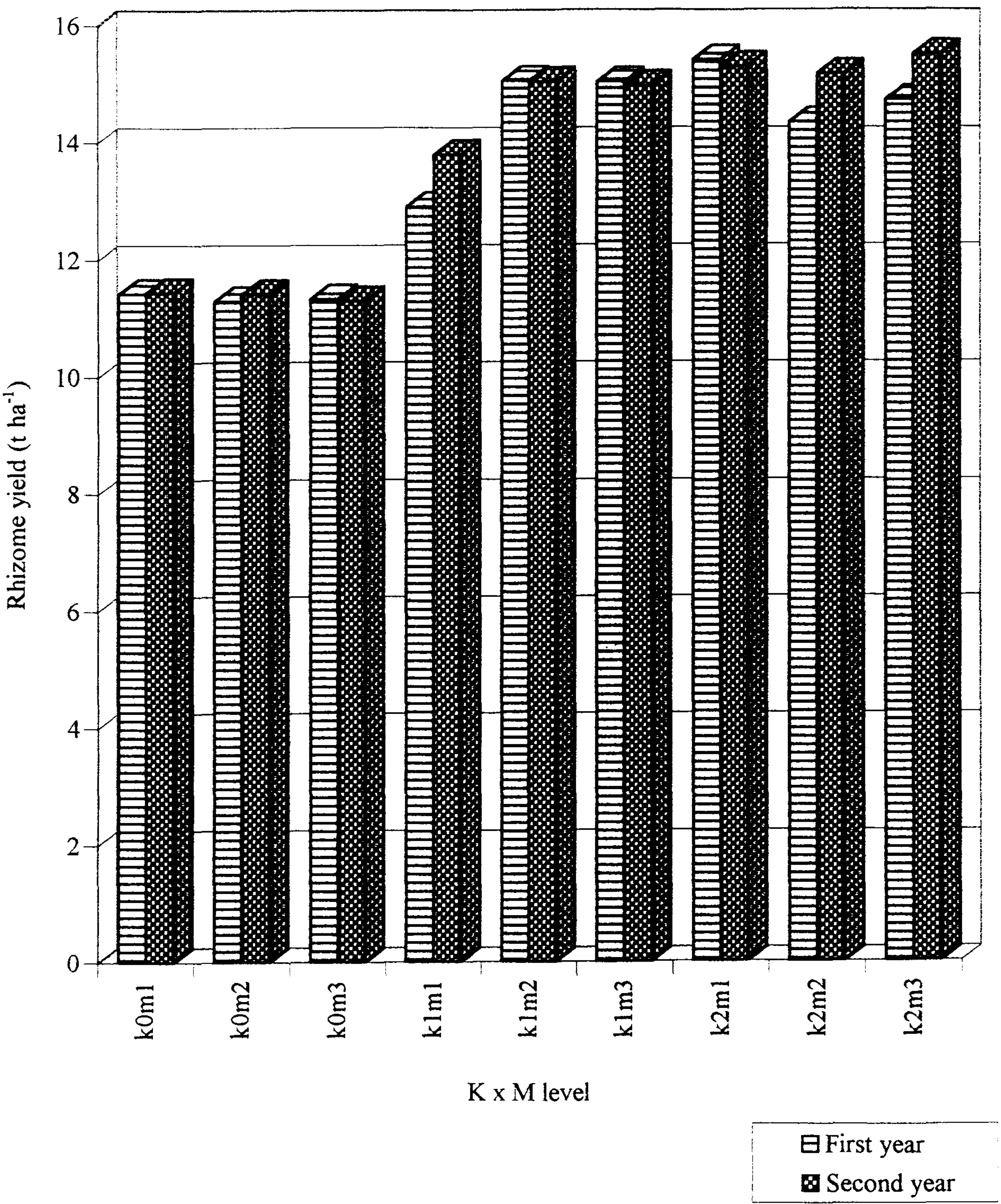


Fig. 17b Effect of potassium (K) x mulch (M) interaction on fresh ginger yield (t ha^{-1})



better yield and no significant difference in yield was observed between these two levels of mulch. However, when potassium was applied at 100 kg ha^{-1}, the mulch level 15.0 t ha^{-1} was found to be most acceptable than higher levels of mulch application.

At higher levels of potassium, the mulch requirement can be reduced to 50 per cent, when ginger is intercropped in coconut garden. The cool micro-climate under coconut palms, might have provided the favourable environment for the ginger plant under low mulch (15 t ha^{-1}) to produce ginger rhizomes on par with normal mulch (30 t ha^{-1}).

5.3.4.3 Dry ginger yield

Application of potassium had significant influence on dry ginger yield during both the years (Table 63). Application of potassium at 100 kg ha^{-1} produced significantly higher dry ginger yield of 3258.722 kg and 3367.028 kg first and second year respectively.

A general trend of increase in yield with increase in fertilizer levels was reported by several workers (Rao and Reddy, 1977 in turmeric and Pushpakumari, 1989 in greater yam). Ancy (1992) found that under 25 and 50 per cent shade, highest yield was recorded at 112.5 : 75 : 75 kg NPK ha^{-1}. This result clearly indicates that crop response to increased level of fertilizer dose is more under low shade and this may be due to the existence of an optimum soil condition and light intensity for efficient utilization of available nutrients. The shaded situation under coconut garden may be the reason for the maximum yield under highest level of potassium.

Different levels of mulch had no significant effect on dry ginger yield during both the years. The studies conducted by Babu (1993) revealed that ginger grown under shade needs only 22.5 t ha^{-1} instead of 30 t ha^{-1} for optimum yield. In the present study, no significant variation on dry ginger yield was noticed when mulch applied from 15.0 t ha^{-1} to 30 t ha^{-1}. This result clearly indicate that, when ginger is intercropped in coconut garden, the mulch requirement can be reduced to 15.0 t ha^{-1} (half of the recommended dose of 30.0 t ha^{-1}).

5.3.4.4 Harvest index

Application of potassium significantly influenced the HI of the plant during both the years (Table 64). Significantly higher HI was recorded at 100 kg K_2O ha^{-1} which was on par with 50 kg K_2O ha^{-1}. The efficiency of translocation of assimilates to economic part was found to be decreasing with increasing shade. According to Ancy (1992), fertilizer levels showed the same effect which might have resulted from increased top growth at higher fertilizer levels. The data clearly indicate that when ginger is intercropped in coconut garden, maximum HI was obtained under higher levels of potassium. Thus under shaded condition in coconut garden, ginger can efficiently utilize the potassium at higher levels and efficiency of translocation of assimilates to economic part was found to be maximum. Different levels of mulch and triazole had no significant effect on HI during both the years. K x M interaction had no effect on HI.

5.3.4.5 Root : shoot ration

The different levels of potassium, mulch and triazole and K x M interaction had no significant effect on root : shoot ratio (Table 64).

5.3.5 Quality aspects

5.3.5.1 Volatile oil

Influence of potassium on volatile oil content was significant only at first year (Table 65). Significantly higher volatile oil content was recorded at 100 kg K_2O ha^{-1}.

Ancy (1992) observed that under different shade levels the effect of fertilizer treatments on volatile oil content was found to be not significant. The effect of increased dose of potassium on volatile oil content was varied between two seasons.

Different levels of mulch had no effect on volatile oil content. Babu (1993) also observed that under shade the influence of higher levels of mulch on volatile oil content was found to be not significant.

Triazole had no effect on volatile oil content during both the years. K x M interaction also had no effect on volatile oil content during both the years.

5.3.5.2 Non-volatile ether extract

Influence of potassium on NVEE content was significant only during first year (Table 65). Significantly higher NVEE content was recorded when potassium was applied at 100 kg ha^{-1}.

Ancy (1992) and Babu (1993) observed that highest NVEE was recorded at low shade. Contrary to this, George (1992) recorded higher content of NVEE at open condition. According to Ravisankar and Muthuswamy (1987) ginger grown under intercropped condition produced good quality rhizome with high NVEE. Ancy (1992) reported that under all shade levels, effect of fertilizer treatment on NVEE was found to be non significant.

The different levels of mulch, triazole and K x M interaction had no significant effect on NVEE during both the years.

5.3.5.3 Starch content

Application of potassium significantly influenced the starch content during both the years (Table 66). Significantly higher starch content was recorded when potassium was applied at 100 kg ha^{-1} during both the years. Increase in starch content of tapioca tuber at higher levels of potassium was reported by many workers (Pushpadas and Aiyer, 1976; Nair and Kumar, 1982 and Nair, 1986). The study reveals that, when K applied at 100 kg ha^{-1}, significantly higher starch content was recorded.

The different levels of mulch, triazole and K x M interaction had no significant effect on starch content.

5.3.5.4 Crude fibre content

Application of potassium significantly influenced the crude fibre content during both the seasons (Table 66). Significantly higher crude fibre content was observed when potassium was applied at 100 kg ha^{-1} during both the years. However, application of potassium at 50 kg ha^{-1} and 100 kg ha^{-1} were on par during first year.

According to Ancy (1992) and Babu (1993) crude fibre content was maximum under open condition and it increased with increasing shade intensity. According to Ancy (1992) under shade, effect of fertilizer treatment on fibre content was found to be not significant.

The triazole, mulch and K x M interaction had no significant effect on crude fibre content.

5.3.6 Uptake of potassium

Uptake of potassium increased with higher rates of application (Table 67). Increase in uptake of potassium due to higher rates of application is reported by several workers in different crops (Pena, 1967 in taro; Sharma and Grewal, 1991 in potato and Muralidharan *et al.*, 1994 and Ancy, 1992 in ginger). The present investigation showed the same trend. The result suggests that there is the necessity of increasing dose of potassium when ginger is grown as an intercrop in coconut garden.

The effect of mulch, triazole and K x M interaction was not significant.

5.3.7 Available potassium

Available potassium status of the soil was significantly influenced by levels of potassium (Table 67). There was significant increase in available potassium in the soil due to higher rates of potassium application. Maximum build up of available potassium was found at the highest level of application Such increase in available nutrient status subsequent to their application was reported by Rajendran *et al.* (1971) in tuber crops and Ancy (1992) in ginger.

SUMMARY

SUMMARY

An investigation was undertaken at the Coconut Research Station, Balaramapuram during the years 1996-97 and 1997-98, to study the production dynamics of ginger under varying levels of shade, nutrients and triazole. The above investigation was carried out in three field experiments. In the experiment I (pot culture), production potential of ginger under open and shade levels was studied, with open condition and four levels of shade adopting CRD design with four replications. In the experiment II, the requirement of NPK for ginger in coconut garden was assessed by adopting 3^3 factorial experiment in RBD with three replications. In the experiment III, the effect of mulching, potassium and triazole levels was evaluated by adopting strip-split plot design with four replications. The salient findings are summarised below :-

EXPERIMENT - I

The plants grown under open condition registered a lower plant height and as increasing trend in plant height with increasing shade intensity was observed.

The shade levels 20 and 40 per cent was favourable for obtaining highest tiller number.

Maximum number of leaves was recorded at 20 and 40 per cent shade levels.

The plants grown under 20 and 40 per cent shade levels produced significantly higher leaf area.

Among the different shade levels, plant grown under 20 and 40 per cent shade levels recorded a maximum leaf dry weight.

Highest root length was observed under 20 and 40 per cent shade levels.

The highest root spread was resulted by providing 40 and 20 per cent shade level.

Highest root dry weight was resulted by providing 20 and 40 per cent shade levels.

Open condition and providing 20 and 40 per cent shade significantly increase the root volume.

Highest rhizome spread was resulted by providing 20 and 40 per cent shade levels and the lowest rhizome spread by 60 and 80 per cent shade levels.

From 180 DAP onwards the rhizome thickness was significantly higher by providing open condition, 20 and 40 per cent shade levels.

Maximum number of finger rhizomes was resulted by providing 20 and 40 per cent shade levels.

Maximum leaf thickness was resulted by providing open condition, 20 per cent and 40 per cent shade levels.

Stomatal index at open condition and 20 per cent shade level were on par but significantly superior to all other shade levels.

Stomatal frequency of plants at open condition, 20 and 40 per cent shade levels were on par but significantly superior to all other shade levels.

Providing 20 and 40 per cent shade levels, recorded significantly higher DMP.

In early growth phases (up to 150 DAP) higher CGR was observed under 20 and 40 per cent shade levels. Different shade levels did not show appreciable difference in CGR towards the later stages of growth.

In general, at different growth phases, significantly higher RGR was recorded at open condition, 20 and 40 per cent shade levels.

Net assimilation rate (NAR) varied significantly due to different shade levels. However, the present study did not show influence of shade in NAR towards the later stages of growth from 150 DAP.

During early stages of growth, up to 150 DAP highest LAD was recorded under 20 and 40 per cent shade levels. But during later stages of growth, no significant difference in LAD was observed in open condition, 20 and 40 per cent shade levels.

Higher LAI was observed under open condition, 20 and 40 per cent shade levels. LAI reduced significantly at higher shade levels (60 and 80 per cent).

Maximum SLW was recorded under open, 20 and 40 per cent shade levels.

Highest RWC was recorded under 80 per cent shade and the lowest RWC was recorded at open condition and 20 per cent shade levels.

The plants grown under open condition recorded maximum root : shoot ratio but during second season, open condition was on par with 60 and 80 per cent shade levels.

Highest PAR on leaf surface and stomatal conductance were recorded under open condition. As the shade increase there would be a proportionate decrease in stomatal conductance. Highest stomatal resistance was recorded under 80 per cent shade. Lowest rate of stomatal resistance was recorded under open condition and 20 per cent shade level.

Transpiration rate was maximum when plants grown at open condition. As the shade intensity increased there was a proportionate decrease in transpiration rate.

Photosynthetic rate under open condition and 20 per cent shade were on par and superior to other shade levels.

Highest chlorophyll content was recorded at 80 per cent shade level. Chlorophyll content was increased as the shade intensity increased from 20 to 80 per cent.

Highest proline content was recorded at open condition and 20 per cent shade level.

Shoot dry weight under 20 and 40 per cent shade levels were on par and significantly superior to other shade levels.

The shade levels 20 and 40 per cent recorded highest fresh ginger yield and dry ginger yield. Yield at open condition was found to be better than 80 and 60 per cent shade levels.

Bulking rate were maximum under shade levels of 20 and 40 per cent at early growth phases.

No significant variation in harvest index was observed among different shade levels.

Volatile oil content showed an increasing trend with increasing levels of shade. Maximum NVEE was recorded under 20 and 40 per cent shade levels. Higher starch content recorded at 20 per cent shade. Crude fibre gradually reduced as intensity of shade level increased.

EXPERIMENT - II

Plant height, tillering, number of leaves and leaf area were increased with higher rate of NPK application.

Leaf area index, specific leaf weight and dry matter production were increased with higher rates of NPK application. Increase in NAR, CGR and RGR due to nitrogen application was observed at 150 kg N kg ha^{-1}, but the effect of phosphorus and potassium was not evident.

Increased rate of nitrogen, phosphorus and potassium application increased the chlorophyll 'a', chlorophyll 'b' and chlorophyll (total) content of the plant.

Higher rates of nitrogen, phosphorus and potassium resulted in substantial increase in fresh ginger and dry ginger yield.

Enhancing nitrogen application from 75 kg ha^{-1} to 150 kg ha^{-1}, the fresh rhizome yield increased by 0.97 t ha^{-1}.

Enhancing P application from 50 kg ha^{-1} to 100 kg ha^{-1}, fresh rhizome yield increased by 0.94 t ha^{-1}.

Increase in fresh rhizome yield due to enhancement of K from 50 kg ha^{-1} to 100 kg ha^{-1} was to the tune of 0.70 t ha^{-1}.

When ginger intercropped in coconut gardens, N : P, N : K and P : K ratios of 1.5 : 1, 1.5 : 1 and 1 : 1 respectively were ideal to get maximum fresh ginger yield.

A general trend of increase in shoot dry weight was observed with increase in the application of fertilizers.

Increased rate of fertilizer application had no effect on HI, root : shoot ratio, volatile oil content, NVEE and crude fibre content.

Higher rates of nitrogen and phosphorus enhanced the starch content.

Higher levels of fertilizers increased the plant uptake of N, P and K.

Available N, P and K status of the soil was found to increase with levels of application of these nutrients.

The economics of fertilizer application revealed that, among the different fertilizer levels, 150 kg N, 100 kg P_2O_5 and 100 kg K_2O gave the maximum net return and benefit : cost ratio when ginger intercropped in coconut garden.

EXPERIMENT - III

Potassium application at higher rate was effective in enhancing plant height, number of tillers, number of leaves and leaf area.

Potassium nutrition at 100 kg ha^{-1} resulted in maximum DMP, RGR, CGR and LAI, but had no effect on NAR and SLW.

Potassium, mulch and triazole application was beneficial in enhancing the chlorophyll content. Mulch at 22.5 t ha^{-1} resulted in maximum chlorophyll content per plant.

Significantly higher proline content was recorded when triazole applied at 50 $\mu g\ ml^{-1}$.

Potassium nutrition was beneficial in increasing the shoot dry weight.

Higher rate of potassium (100 kg ha^{-1}) enhanced the fresh rhizome and dry ginger yield. At higher rate of K application, 15.0 t ha^{-1} mulch was sufficient for obtaining higher yield.

Higher rate of mulch and application of triazole had no beneficial effect on fresh and dry ginger yield.

Potassium at higher levels had no effect on volatile oil content and NVEE. Starch and crude fibre content increased with higher levels of potassium (100 kg ha^{-1}).

Triazole and mulch at higher levels had no beneficial effect on volatile oil, NVEE, starch and crude fibre content.

Plant uptake of K increased with higher levels of applications.

Available K status of the soil was found to increase with higher levels of potassium.

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* Originals not seen

PRODUCTION DYNAMICS OF GINGER *(Zingiber officinale* R.*)* UNDER VARYING LEVELS OF SHADE, NUTRIENTS AND TRIAZOLE

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ABSTRACT OF THE THESIS
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ABSTRACT

The experiments were conducted at the Coconut Research Station, Balaramapuram, during 1996-97 and 1997-98 to study the production dynamics of ginger under varying levels of shade, nutrients and triazole. The specific objectives were to study the production potential of ginger under open and different shade levels, to standardise optimum dose of nutrients and mulch for ginger intercropped in coconut garden and to evaluate the efficacy of triazole in the improvement of yield and other desirable characters.

The effect of shade on growth and yield contributing parameters *viz.*, tiller number, leaf number, leaf area, leaf dry weight, root spread, root volume, rhizome spread, rhizome thickness, number of rhizomes, leaf thickness, stomatal frequency, DMP and LAI under 20 and 40 per cent shade levels exhibited significant superiority in pot culture study.

In pot culture study, maximum fresh ginger yield of 450.0 and 396.3 g plant^{-1} were resulted from plants kept under 20 and 40 per cent shade levels respectively. This was 27.4 and 12.2 per cent higher compared to open condition. The dry ginger yield of 94.5 and 89.2 g plant^{-1} were obtained from plants kept under 20 and 40 per cent shade levels respectively. This was 27.8 and 20.7 per cent higher compared to open condition. However, the dry ginger yield obtained from 60 and 80 per cent shade levels were significantly lower compared to open. The shade levels 20 and 40 per cent gave the highest shoot dry weight of 48.9 and 53.6 g plant^{-1} respectively.

Volatile oil content showed an increasing trend with increasing levels of shade in pot culture study. Maximum NVEE was recorded under 20 and 40 per cent shade levels. Highest starch content was obtained from 20 per cent shade level. Crude fibre gradually reduced with increase in shade levels.

The field trial on nutrient requirement of ginger as intercrop in coconut garden revealed that, NPK application at higher levels increased plant height, tillering, leaf number, leaf area, DMP and chlorophyll content. Physiological parameters like, NAR, CGR and RGR were promoted by higher rates of nitrogen application. The results revealed that, N : P, N : K and P : K ratios of 1.5 : 1, 1.5 : 1 and 1 : 1 respectively, were ideal to get maximum fresh ginger yield.

Application of 150 kg N, 100 kg P_2O_5 and 100 kg K_2O ha^{-1} gave maximum net profit of Rs. 96605/- and Rs. 99227/- during first and second year respectively. The net profit when the existing recommendation of 75 kg N, 50 kg P_2O_5 and 50 kg K_2O ha^{-1} was Rs. 54960/- and Rs. 54730/- during first and second year respectively. Hence the study suggests that the existing recommendation (75 kg N, 50 kg P_2O_5 and 50 kg K_2O ha^{-1}) has to be doubled (150 kg N, 100 kg P_2O_5 and 100 kg K_2O ha^{-1}) for increasing the productivity of ginger intercropped in coconut garden.

Increased rate of fertilizer application did not influence the quality of the produce. Plant uptake of NPK increased with higher levels of fertilizer application.

The field experiment on mulch requirement of ginger intercropped in coconut garden showed that the rhizome yield from plots mulched with 30.0, 22.5 and 15.0 t ha^{-1} were on par. Therefore the mulch requirement of ginger intercropped in coconut garden can be reduced from 30 t ha^{-1} to 15.0 t ha^{-1}.

Application of triazole did not exhibit any beneficial effect on yield and quality of ginger.