PERFORMANCE OF SPINY CORIANDER (*Eryngium foetidum* L.) UNDER DIFFERENT SHADE REGIMES

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Thesis submitted in partial fulfillment of the requirement for the degree of

Master of Science in Horticulture

Faculty of Agriculture
Kerala Agricultural University, Thrissur

2008

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DECLARATION

I hereby declare that this thesis entitled "**Performance of spiny coriander (*Eryngium foetidum* L.) under different shade regimes**" is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar title, of any other university or society.

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ACKNOWLEDGEMENT

I wish to express my deep sense of gratitude to Dr. G.R. Sulekha, Professor, Department of Plantation crops and Spices, College of Agriculture, Vellayani and Chairman of the Advisory Committee, for her inspiring guidance, valuable advice, timely suggestions, keen interest, constructive criticism and moral support throughout my post graduate programme and preparation of thesis.

My special thanks to Dr. B.K. Jayachandran, Professor and Head, Department of Plantation crops and Spices, as a member, Advisory Committee for his valuable suggestions and critical scrutiny of the manuscript.

My sincere gratitude to Dr. B.R. Reghunath, Professor, Department of Plantation crops and Spices as a member, Advisory Committee for his constructive criticism and help rendered during the endeavour.

I am deeply indebted to Dr. Vijayaraghava kumar, Professor, Department of Agricultural Statistics, as a member, Advisory Committee for his timely help and suggestions in planning the experiment, analysis of data and its proper interpretation.

I am also thankful to Sri. C.E. Ajithkumar, Junior Programmer, Department of Agricultural Statistics for the assistance rendered during the analysis of data.

My heartfelt thanks to Dr. Roy Stephen, Professor, Department of Plant Physiology, College of Agriculture, Vellayani and Dr. Vasanthakumar, Associate Professor, Department of Plantation crops and Spices for the whole hearted help rendered during chemical analysis.

I am obligated to Dr. P.C. Jessykutty, Associate Professor, Department of Plantation crops and Spices for her valuable suggestions and help rendered

I remember with gratitude, the immense help given by my seniors, Nirmalatha, Jithesh, Surya D. Aniyan, and Nihad.

I feel strongly beholden to my affectionate and special friend Anup Ahmed.

I wish to express my sincere thanks to my classmates Vipin, Pijush Kanti Biswas, Rajani Satish, Bindu and Sheena.

I am deeply indebted to my friends Aby, Reny Jose, Pradeep, Arun Venkit, Suffair, Supin, Visakh and Om Prakash for their encouragement and help which made it possible for me to complete the study.

My sincere thanks to Mr. Sree kumar for his prompt computerized type setting and preparation of thesis.

Words fail to express my indebtedness to my father Mr. V.R. Janardhanan, mother Mrs. K.N. Retnamma, brother Mr. Salim Babu, sister Mrs. Abcina Salim for their unconditional love, moral support and encouragement without which this work would not have been a success.

I sincerely acknowledge Kerala Agricultural University for granting me the KAU Junior Research Fellowship that helped me carryout my research work.

Above all, the God Almighty for the blessings showered upon me all throughout the study.

APPU KUTTAN. J

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LIST OF ABBREVIATIONS

%	-	Per cent
@	-	At the rate of
°C	-	Degree Celsius
'	-	Minutes
Øi	-	Carbon dioxide assimilation
?	-	Leaf water potential
AGR	-	Absolute growth rate
AOAC	-	Association of Official Agricultural Chemists
B: C ratio	-	Benefit: Cost ratio
cc	-	Cubic centimeter
CD	-	Critical difference
cm	-	Centimeter
cm^2	-	Square centimeter
CO_2	-	Carbon dioxide
cv.	-	Cultivar
DW	-	Dry weight
DAP	-	Days after planting
DAS	-	Days after sowing
day^{-1}	-	Per day
et al.	-	And others
Fig.	-	Figure
FYM	-	Farm yard manure
g	-	Gram
g_l	-	Stomatal conductance
ha^{-1}	-	Per hectare
HDPE	-	High density poly ethylene
kg	-	Kilogram
kg/ha	-	Kilogram per hectare
LI	-	Environment light intensity
LAI	-	Leaf area index
m	-	Metre
m^2	-	Square metre
mg	-	Milligram
ml	-	Millilitre
mol	-	Mole
MOP	-	Muriate of potash
MAP	-	Months after planting
nm	-	Nano meter
NAR	-	Net assimilation rate
NS	-	Non significant
NVEE	-	Non-volatile ether extract
PAR	-	Photosynthetically active radiation

LIST OF ABBREVIATIONS CONTINUED

Pn_{sat}	-	Saturated rate of net photosynthesis
P_n	-	Net photosynthesis
PPFD	-	Revolutions per minute
RBD	-	Randomised block design
Rd	-	Dark respiration
RF	-	Rainfall
RGR	-	Relative growth rate
Rs	-	Rupees
s	-	Second
SE	-	Standard error
Spp.	-	Species
t	-	Tonnes
Var.	-	Variety
viz.	-	Namely
µ	-	Micro

Introduction

1. INTRODUCTION

Spiny coriander (*Eryngium foetidum* L.) belonging to the family Apiaceae is a biennial herb indigenous to Tropical America and the West Indies. It is also known as Mexican coriander or culantro. It is often mistaken and misnamed for its close relative, cilantro or leafy coriander (*Coriandrum sativum* L.).

It is increasingly becoming a crop of international trade mainly to meet the demands of ethnic populations in the developed countries of the West. Now this herb is used extensively in the Caribbean and in Asia particularly in India and Korea (Ramcharan, C. 1999). It is used mainly as a seasoning in the preparation of a range of foods, including vegetable and meat dishes, chutneys, preserves, sauces and snacks. Although used in small quantities, its pungent unique aroma gives the characteristic flavour to the dishes in which it is incorporated and this is responsible for its increasing demand among ethnic populations. It is also widely used in herbal medicines and reportedly beneficial in the treatment of a number of ailments (Wong, 1976). Though it is much utilized, it is a little understood herb.

The plant is rich in calcium, iron, carotene and riboflavin and its harvested leaves are widely used as a food flavouring and seasoning herb for meat and many other foods. Its medicinal value includes its use as a tea for flu, diabetes, constipation and fever. One of its most popular uses is in chutneys as an appetite stimulant.

It is cultivated on a small scale in homesteads and large-scale production is not popular. Its use both as a flavouring agent and herbal medicine and also as a home remedy for various ailments point towards its inclusion as an indispensable item in Kerala homesteads.

It grows naturally in shaded, moist heavy soils near cultivated areas. Under cultivation the plant thrives best under well irrigated shaded conditions. Seeking the scope for both homestead and commercial cultivation of spiny coriander in Kerala is of great relevance in the present scenario of human health care where natural medicines and flavouring materials are gaining more importance.

In Kerala, there is only a limited scope for the commercial cultivation of spiny coriander as a pure crop due to the limitation in availability of cultivable land. In order to ensure its availability, the only alternative is to incorporate these plants either in the existing cropping system or in homesteads. Both needs detailed analysis of its shade tolerance mechanism. Hence the present study, "Performance of spiny coriander (*Eryngium foetidum* L.) under different shade regimes" was undertaken with the following objectives:

1. To evaluate the adaptability and performance of spiny coriander (*Eryngium foetidum* L.) under varying levels of shade and plant population densities.
2. To study the feasibility of cultivating *Eryngium foetidum* L. under Kerala homestead conditions.

Review of Literature

2. REVIEW OF LITERATURE

Spiny coriander (*Eryngium foetidum* L.), also known as Cilantro/ Saw toothed coriander/ Mexican coriander is a member of the Apiaceae family. It is a native of Central and South America, occurring from South Mexico to Panama, Colombia, Bolivia, Brazil and Cuba to Trinidad. It has been introduced to many tropical and subtropical countries, where it is used as a substitute for leafy coriander. Leaves are harvested as and when required and used either fresh or after drying. It grows naturally in shaded, mostly heavy soils near cultivated areas. Under cultivation, the plant thrives best under well irrigated shaded conditions.

The leaves of eryngium are aromatic and used as a flavouring agent in soups, curries, stews, rice and fish dishes. Tender leaves are eaten raw or cooked as a vegetable. Leaves are also picked. It is also used in the traditional medicine of Central and South America.

For getting increased harvest of vegetable portion per unit area per unit time, there are a number of ways. The most important of them are judicious fertilization, growing selected varieties, regulation of population density (spacing), giving appropriate light intensity, better management etc.

Effect of shade and spacing on the performance of various crops, both on yield and quality aspects has been studied. Population studies and the performance of shade on the growth and vegetative yield of spiny coriander (*Eryngium foetidum* L.) are very few. There are no reports on the performance of spiny coriander under different shade regimes in India, particularly Kerala. Hence the following review traces the work of these and related aspects in other leafy, flower, fruit vegetables and spice crops.

2.1 RESPONSE OF CROP TO DIFFERENT SHADE LEVELS

2.1.1 GROWTH CHARACTERS

2.1.1.1 Effect of shade on plant height

Plant height has been reported as a character responsive to shading. Cooper (1966) noticed in tomato that the effect of shade on plant height was positive, negative or neutral depending on the time of the year and age of the plant. Shade had significant influence on the height of groundnut as reported by George (1982); in vegetable cowpea by Krishnankutty (1983) and in capsicum by Yinghua and Jianzhen (1998) and Sreelathakumary (2000).

Some workers have noticed a decidedly positive influence of shade on plant height. The general effect of shading on plants was studied by Duggar (1903) and Ross (1976) and they reported that plants under shaded conditions exhibited increased growth of main axis. Roberts and Struckmeyer (1939) observed an increase in height of plants due to shading.

Allen (1975) observed that soyabean grown under 70 percent shade grew much taller than those in light. Crockston *et al.* (1975) reported an increase in plant height in beans with increase in shade intensities. Aclan and Quisumbing (1976) reported that ginger plants grown under full sunlight were found to be shorter compared to shaded plants. According to Kulasegaram and Kathirvetpillai (1980), height of tea plant was greater under 60 percent sunlight and was least under 10 percent as compared to 30 and 100 percent. In *Mentha piperita*, plant height under 44 per cent day light was significantly greater than that under 100 or 14 per cent day light (Virzo and Alfani, 1980).

Bai and Nair (1982) observed positive influence of shading on plant height in ginger, coleus and sweet potato. According to Mullakoya (1982) maximum height was recorded under 50 percent shade and the minimum under full sunlight in guinea grass var. Mackuenii. According to Senanayake and Kirthisinghe (1983), longest shoot length in black pepper under 50 per cent light compared to 75 and 25 percent light. Varghese (1989) reported that in ginger plant height increased with increase in shade intensity from zero to 75 percent at 60 DAP only, after which plants grown at 25 percent shade had the highest plant height, whereas in turmeric, with increase in shade, plant height increased upto medium shade of 50 percent and then decreased.

Increase in plant height with increasing shade intensities in ginger were also reported by Jayachandran *et al.* (1991), Ancy Joseph (1992), Beena (1992), Babu (1993) and Sreekala (1999). Pushpa kumari and Sasidhar (1992) noticed increased vine length with increase in shade intensity in *Dioscorea alata* and *Dioscorea esculenta*. Though no significant difference was observed between shade levels with respect to plant height in turmeric, taller plants were observed at 75 per cent shade in the initial stages and 50 percent shade in the later stages (Sheela, 1992). Ginger plants grown as intercrop in arecanut plantation were significantly taller than those under open conditions when measured 200 days after planting and had significantly lower number of functional leaves and tillers per clump (Hedge *et al.*, 2000).

Greater shoot height was noticed in seven soyabean cultivars grown under shade in a coconut plantation (Babu and Nagarajan, 1993). Jung *et al.* (1994) observed that main stem length of pepper increased significantly under shaded conditions. In pepper, length of primary and secondary branches increased with decrease in light intensity from 100 to 50 percent (Devadas, 1997). In a field experiment to study response of blackgram to shade by Lakshmamma and Rao (1996) using 0, 33 and 66 percent shade, it was revealed that shading increased plant height.

In onion, tallest plants were observed in 25 percent photosynthetically active radiation (PAR) treatment and smallest plants were observed under full sunlight (Miah *et al.*, 1998). Height increase in *Asparagus racemosus* grown as intercrop in coconut gardens has been reported from KAU (KAU, 1999).

2.1.1.2 Effect of shade on girth at collar region

According to Nagaota *et al.* (1979), in general, plants grown under lower light intensities were taller, with thinner stems, particularly at higher night temperature.

2.1.1.3 Effect of shade on spread of the plant

Panikar *et al.* (1969) observed that in tobacco, length and breadth of leaves increased by 15.1 and 17.6 per cent respectively under shade as compared to unshaded plants. Pal and Jana (1999) found that plant spread increased with increasing light intensity in *Syngonium podophyllum*.

2.1.1.4 Effect of shade on number of leaves

Leaf production in plants has been found to correspond to the light levels. Scientists have reported an increase in leaf production corresponding to reduction in light level. According to Nair (1964), the production as well as the retention of leaves will be more under the shade than in the open, in peppermint. In ginger, Aclan and Quisumbing (1976) reported reduced number of leaves per plant when grown under full sunlight. According to Senanayake and Kirthisinghe (1983), maximum number of leaves in black pepper under 50 per cent light compared to 75 percent and 25 percent shade. Aasha (1986) reported that the number of leaves in open condition would be less as compared to that under shade in begonia.

According to Venkataraman and Govindappa (1987), in clove, seedlings kept under shade produced more number of leaves than those exposed to the sun. Use of plastic tunnels (protected cultivation) to protect tomato plants from cool weather and frost damage increased transpiration rate, plant height, leaf area and number of leaves (Abou-Hadid *et al.*, 1988). In *Enicostemma* *littorale,* Sharma *et al.* (1994) reported that vegetative growth (height, fresh weight, dry weight, leaf and branch number) was enhanced in the shade compared with plants grown in full sun. Number of leaves was highest under 25% shade in radish (Sarkar and Saha, 1997). In arrowroot, number of leaves was higher under intercrop compared to open space crop (Maheswarappa *et al.*, 2000). In pepper, under shaded condition, the production and retention of leaves was higher (Devadas and Chandini, 2000). More number of leaves was observed in plants grown in shade than in full light plants (Prasanta K. Patra *et al.*, 2003) in *Mentha spicata.*

Contrary to these reports, a reduction in leaf production has been also noticed with provision of shade. A decrease in number of leaves was observed in ginger at all stages by increasing the intensity of shading from zero to 75 percent (Varghese, 1989). According to Ancy Joseph (1992), maximum number of leaves per plant in ginger were recorded under 25 per cent shade at all the growth stages and the lowest number of leaves were recorded at 75 per cent shade. In ginger, Babu (1993) observed maximum leaf production under 25% shade and found it to be significantly superior to other shade levels at 120 and 180 DAP. Leaf production in ginger under open condition was found to be significantly superior compared to other shade levels (Sreekala, 1999). In sweet potato, leaf size increased as leaf number declined in response to higher shade levels, thus leaf areas were similar in all treatments (Laura et al., 1986). In cassava, Prabhakar *et al.* (1979) obtained higher number in plots where no intercrop was raised. In cassava, leaf size increased, leaf number decreased and leaf longevity increased when grown under shade in a coconut garden (Sreekumari *et al.*, 1988). The leaf number and size of leaf of Amaranthus Spp. were found to be greater at the medium level than at higher levels of shade (Simbolon and Sutarno, 1986). According to Xia (1987), *Vicia faba* plants subjected to 50 and 20 percent shade exhibited 30 per cent reduction in the number of leaves per plant.

The plants of *Centella asiatica* produced a greater number of leaves under high light than under low light (Wankher and Tripathi, 1990). Seedlings of Quercus floribunda at sunny microsites were superior in terms of number of leaves (Negi *et al.*, 1996). A field trial was conducted by El-Gizawy *et al.* (1993) in tomato to study their performance under shading (0, 35, 51 or 63%) provided by nets. They found that shading increased plant height and leaf area, but reduced leaf number and dry weight. In *Clitoria ternatea,* Sunitha (1996) reported higher number of leaves under open condition when compared to shade condition. High light intensity has increased leaf number in betel vine (Shivasankara *et al.*, 2000).

Some of the reports indicate shade as having little or no effect on leaf production in plants. Sannamarappa and Shankar (1988) reported no significant variation in leaf number of turmeric due to intercropping in arecanut.

2.1.1.5 Effect of shade on number of plants with flower shoots

Plants have been reported to respond to variation in light intensities by putting forth flowers. Shading has resulted in reduction of time taken for flowering in some plants according to a few workers. Baki (1991) observed that in tomato high temperature induced flower abscission that reduced fruit set and yield. Deepa and Anbu (1996) observed that in tomato, total number of flowers per plant ranged from 19 to 79 in summer and 170 to 2209 in rabi season under Jorhat condition. Lohar and Peat (1998) observed empty and persistent flowers without fruit set in 35/30°C temperature regime in tomato. Early flowering was noticed in black pepper at 50 percent light. Under full sunlight the vines took 94 days to flowering, while under 50 percent light it took only 84.9 days (Devadas, 1997).

More scientists have opined that shading had a negative influence upon plants when it came to flowering. Duggar (1903) pointed out that the flowers might develop on plants exposed to partial light, but generally in such cases it would be delayed considerably. Gourley (1920) observed that shaded geranium and nastrutium plants put forth only few blossoms compared to those in the open. Tomato required longer time for flower bud differentiation at low light intensities (Watanabe, 1963). In tomato, production of flowers was most successful under conditions of abundant irradiation and mild temperature regimes. In the reproductive phase, low temperature in a range of 10°C to 12°C during the early stage of flower development caused cluster bearing (Calvert, 1966).

According to Einert and Box (1968), light intensity of 75 and 50 percent during the forcing period had no effect on flower bud abortion, bloom size or forcing time of *Lillium longiflorum*. However, 50 per cent light intensity resulted in decreased number of flower buds and 75 percent had no effect on the initiation of flower buds.

Optimum growth and development of tomato occurred at (or) above 20°C (Wolf *et al.*, 1986). In tomato, Romano and Leonardi (1994) observed that days to flowering from transplanting were delayed by about few days by lower temperature i.e. 36 days in green house. In tomato, Rylski and Aloni (1994) reported that in the very early stage, flower development was highly sensitive to temperature. Nasiruddin *et al.* (1995) reported that shading delayed flowering in tomato but insignificantly only in partial shading in comparison with full exposure. Shading delayed flowering in tomato (Smitha, 2002).

Hiroi *et al.* (1970) observed that in *Aphelandra squarrosa* plants, flower bud formation was dependent on light intensity and did not occur on more shaded plants. Kaname and Fagi (1970) observed that in cucumber, 50 and 75 percent shading lowered the proportion of female flowers. In *Ilex opaca*, flower production was reduced under heavy shading i.e. 92 percent (Fretz and Dunham, 1971).

Boula *et al.* (1973) provided three different levels of shading viz. 25, 50 and 75 per cent for anthuriums. The greatest number of flowers was produced with the least shading but the flower quality was better under heavy shading. Sagi *et al.* (1979) observed flower drop under low solar radiation intensity (SRI). In *Saintpaulia ionantha* (cv. Inge), Conover and Poole (1981) found that flowering ceased when the plants were transferred to interior light levels of 0.5, 1 or 2 klx from a greenhouse at 13 klx. Plants placed under 2 klx flowered after 3 months while plants under 1 klx flowered after 6 months. Only minimal flowering occurred at 0.5 klx after nine months. In *Saintpaulia ionantha,* Kim and Sang (1982) observed that plants subjected to 75% light intensity did not flower at all, and under 25%, flowering was very poor. At 6.25 to 12.5 percent, peduncle number, florets per peduncle and flower diameter were highest.

In *Chrysanthemum* sp., Nell *et al.* (1981) found that shading reduced the number of flower heads and delayed flowering. In chilli, number of days from sowing to flowering and percentage of flower drop increased as the shade increased (Jeon and Chung, 1982). Shading delayed flowering in chilli (Sreelathakumary, 2000). A report by Mor and Halevy (1984) noted that shade caused by a dense leaf canopy reduced sprouting of the third axillary bud formation (from the top) on decapitated rose (cv. Marimba) branches in comparison to less shaded buds on branches protruding above the canopy and sparsely spaced.

Hong *et al.* (1986) reported that geranium flowered earlier at 50 per cent light than at 88 percent light. Pepper (*Capsicum annuum* L.) when grown under 50 percent light flowered earlier than at 100 percent light (Mathi and Bahadli, 1989).

2.1.1.6 Effect of shade on number of roots

In shade studies, root volume and number of roots have been found to be responsive to availability of shade.

Some studies have revealed a positive influence of shading on root growth and number. Borys *et al.* (1995) studied the response of *Chrysanthemum morifolium* to 0, 40, 50 or 60% shade. They observed that 40% shade resulted in the greatest root volume, fresh and dry weight of roots, root number and length.

At all shade levels, root volume per plant was found to be more in ginger plants grown under 80 per cent shade upto 120 DAP (Sreekala, 1999).

In contrast to these reports, many workers has reported a decrease in root production and number by shading. According to Martin and Eckart (1933), when light was partially cut off through unbleached muslin, the root volume in sugarcane decreased to about 50%. A further reduction in light intensity produced roots that were barely able to support the growth of the plants. Wong *et al.* (1985) reported that shading reduced leaf, stem, stubble and root yield, particularly in shade-tolerant species. He reported that shading increased shoot:root ratio, particularly in shade-tolerant species. *Paspalum malacophyllum* and *Paspalum wettsteinii*, two shade-tolerant grasses exhibited reduced leaf, stem, stubble and root production under low light intensity according to Wong (1991). According to Jayachandran (1992), the number of roots originating from the first daughter rhizomes in turmeric were more than from the later produced daughter rhizomes under shade.

2.1.1.7 Effect of shade on suckering / seedling

Shading does not seem to affect suckering or seedling producing capability of most plants in a positive way. But there have been isolated reports of shading leading to increase in sucker/ seedling/ tiller production in some plants. Sharma *et al.* (1994) reported that vegetative growth (height), fresh weight, dry weight and leaf and branch number were enhanced in the shade compared with plants grown in full sun in *Enicostemma littorale*.

In contrast to these reports there have been many reports of shading having an adverse or negative effect on plants' ability to put forth suckers or seedlings. Beinhart (1963) reported an increase in tillering at higher light intensities in white clover. In guinea grass (*Panicum maximum*), Mullakoya (1982) obtained maximum number of tillers in full sunlight and the lowest with 75% shade. According to Pillai (1986) there was reduction in their production in guinea grass (*Panicum maximum*) and Setaria grass (*Setaria sphacelata*) when grown under coconut shade. Senanayake and Kirthisinghe (1983) reported better production of laterals in black pepper at 50 per cent light than at 75 and 25 percent light. Wong *et al.* (1985) reported that shading reduced tiller production, particularly in shade tolerant species. In the study undertaken by Wong (1993) involving two topical grasses, *Paspalum malacophyllum* and *Paspalum wettsteinii*, under 20%, 50% and 100% light transmission, the dominating influence of shade on inhibition of tiller production was obvious in both species. Total tiller number declined with shading being the lowest in 20% light transmission in both species. According to Kephart and Buxton (1996) shading often reduces tillering of forages. Shading often reduces tillering of forages and slows the growth rate of forages. According to Nandal and Singh (2001) tiller number of fodder sorghum and oats were reduced under agro-forestry systems, due to the influence of shade.

Decrease in the number of tillers with increasing levels of shade in turmeric was reported by Varghese (1989) and Jayachandran *et al.* (1992). George (1992) reported a higher tiller production in ginger cv. Rio-de-Janeiro at 25% shade. Babu (1993) observed a higher tiller production at 120 and 180 days after planting under 25% shade in ginger cv. Rio-de-Janeiro. Sreekala (1999) reported less tiller production under higher shade intensities in ginger.

In some crops, the effect of shading on tillering or suckering was found to be insignificant. In Colocasia there was no significant reduction in tiller production with respect to increasing levels of shade (Prameela, 1990). According to Aclan and Quisumbing (1976) in ginger, tillering was not affected by shade. Beena (1992) observed no significant effect of shade on tiller production in ginger cultivars.

2.1.2 PHYSIOLOGICAL CHARACTERS

2.1.2.1 Effect of shade on Photosynthetically Active Radiation (PAR)

The growth and development of plants are influenced by solar radiation, as light energy is the main input of the photosynthetic process in green plants. (Zelitch, 1971; Yoshida, 1972; Biscoe and Gallangher, 1977; Noggle and Fritz, 1979).

In comparison with unshaded grape vines at flowering and venation, the leaves of shade grown vines (60 per cent and 30 per cent sunlight) showed significantly lower values of saturated rate of net photosynthesis (Pn_{sat}) and dark respiration (Rd), and lower light compensation (PAR_c) and light saturation points (PAR_{sat}), whereas the apparent quantum yield of CO_2 assimilation (Øi) was significantly higher. At phenological stages, the diurnal patterns of Pn (net photosynthesis), stomatal conductance to H_2O vapour (g_s) and leaf water potential (?) were positively correlated with PAR. The growth habit of shade grown vines also changed to a more open canopy, which increased the PAR trapping efficiency (Cartechini and Palliotti, 1995).

In Norway Spruce (*Picea abies*), at the saturating photosynthetically active photon flux density (PPFD), the maximum rate of CO2 uptake (P_{Nmax}) of exposed shoots (E-shoots) was 1.7 times that of the shaded shoot (S-shoots). The apparent quantum yield (a) of E-shoots was 0.9 times that of the S-shoots. A lower ability to use excess energy at high PPFD in photosynthesis was observed in the S-layer. The CO_2 and PPFD saturated rate of CO_2 uptake (PN_{sat}) of the E-shoots was 1.12 times and carboxylation efficiency (t) 1.6 times that of the S-shoots. In addition to the irradiation conditions and thus limitation by low J_a, the important limitation of photosynthesis in shade needles was due to carboxylation. This limitation of photosynthesis was accompanied by lower stomatal conductance (Sprtová and Marek, 1999).

An experiment conducted in Pune, Maharashtra, India, to study the reflected photosynthetically active radiation (PAR) under sorghum-based intercropping system revealed that generally, RPARs values were the highest during the initial stages of crop growth due to less leaf area index (LAI). Generally, RPAR increased with the increase in crop age upto 42 days after sowing (DAS) due to the increase in leaf area and LAI. RPAR values increased significantly in sole sorghum and pigeon pea than in groundnut 112 DAS. This was due to the dense canopy and small size of groundnut leaves (Singh *et al.*, 2002).

2.1.2.2 Stomatal Conductance

Stomatal conductance is measured using the steady state porometer and expressed as μ mol m^{-2} s^{-1}. Stomatal conductance has been found to vary with light levels in plants.

The minimum stomatal resistance for carbon dioxide at ambient carbon dioxide concentration varied widely from an average of 0.722 s cm^{-1} for *Circaca lutetiana*, a species which grows in shaded woodlands (Holmgren *et al.*, 1968). Net carbon dioxide assimilation (A) and stomatal conductance to water vapour (g_s) were reduced for Rhododendron plants in the 100 per cent sun regime, although few differences existed among the 69 percent, 47 percent and 29 percent sun treatments. Stomatal conductance was very sensitive to leaf to air Vapour Pressure Deficits (VPD) (Andersen *et al.*, 1991). In *Photinia fraseri*, stomatal conductance was often inversely related to light level. (Norcini *et al.*, 1991). *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). A field study conducted in Utah, USA to examine the demographic effects of associating *Cryptantha flava* with shrubs revealed that shading did not reduce stomatal conductance proportionally to photosynthesis, which led to decreased water use efficiency for plants under shrub (Forseth *et al.*, 2001).

In citrus, midday leaf temperatures and leaf to air vapour pressure differences were reduced by shading resulting in increased stomatal conductance and photosynthetic activity of shaded leaves compared to sunlit leaves (Jifon and Syvertsen, 2001). Neerakkal *et al.* (2002) reported a two times increase in stomatal conductance values at 70% shade conditions in adhathoda and alpinia.

In contrast to these reports, a reduction in stomatal conductance with increasing shade has also been observed. High light intensity during growth increased the stomatal frequency and the change in stomatal pore area per unit area of leaf is correlated with the maximum stomatal conductance. (Holmgren *et al.*, 1968; Bjorkman *et al.*, 1972, Crockston *et al.*, 1975). A four fold increase in stomatal conductance was observed for *Panicum maximum* at high intensity (Ludlow and Wilson, 1971). Atriplex leaves grown under high light intensity showed a three fold increase in stomatal conductance over leaves grown at low light intensity (Bjorkman *et al.*, 1972). Studies on cuttivar resistance to transpiration influenced by different intensities of shade (25, 30 and 75%) in tea clones revealed that there was progressive increase in cultivar resistance with increasing intensities of shade (Harikrishna and Sharma, 1980). Handique and Manivel (1987) recorded lower stomatal resistance in tea under full sun compared to leaves under shade.

In hirsute cotton, the stomatal conductance was reduced by 0.61 cms^{-1} in lower light intensity (40 per cent light intensity) as against 0.69cms' in open condition. This had resulted in reduced transpiration rate by 8.6 and 7.9 percent in 80 and 40 percent light intensity respectively (Dhopte *et al.*, 1991). Positive relationships between maximum stomatal conductance and seasonal integrated average daily quantum flux density were observed in shade intolerant *Populus tremula* and shade-tolerant *Tilia cordata*; the slope of this relationship declined with increasing soil water limitations. A negative correlation between minimum daily leaf water potential and stomatal conductance was observed, because both variables covaried with radiance. Stomatal conductance correlated positively with soil water potential in both species (Niinemets *et al.*, 1999).

A study conducted at the Lower Hantana University to examine the variation of leaf Stomatal Conductance (g_l) and Leaf Water Potential (?) in selected forest tree species under varying levels of natural shade, showed that total leaf conductance (g_e) varied significantly with tree species and shade levels. The highest g_l were observed in Semicarpus and Terminalia, i.e., 92 and 78 m mol $m^{-2}s^{-1}$, respectively. The rest of the species had significantly lower g_l values, which are between 34 and 44 m mol $m^{-2}s^{-1}$. When averaged across tree species, ge was significantly with tree species and shade levels. Swietenia and Filicium showed the lowest P values. There was a positive relationship between ? and g_l under all three shade levels. However, the relationship was strongest ($r^2 = 0.764$) under open conditions and became weaker with increasing shade ($r^2 = 0.531$ and 0.363 under medium and full shade, respectively (Costa *et al.*, 2000).

In Norway Spruce (*Picea albies*), at the saturating photosynthetically active Photon Flux Density (PPFD), the maximum rate of CO_2 uptake (PNmax) of exposed shoots (E-shoots) was 1.7 times that of the shaded shoots (S-shoots). This limitation of photosynthesis in shaded shoots was accompanied by lower stomatal conductance (Sprtová and Marek, 1999). Sreekala (1999) reported that there is a tendency of ginger plants to decrease the stomatal conductance with increase in shade levels.

Also, reports exist stating that shading had little or no effect on stomatal conductance in plants. *Acuba japonica* (Thumb). cv. variegata were exposed under conditions of full sun and shade over two years. Two days after treatment initiation, net CO_2 assimilation was proportional to light level, although stomatal conductance to water vapour was not influenced by shading (Andersen *et al.*, 1991). Dewelle *et al.* (1978) measured the difference in stomatal conductance and carbon dioxide assimilation and noted that they do not show a direct correlation. Neerakkal *et al.* (2002) reported no significant difference among plants grown under open and shade conditions in Strobilanthes.

2.1.2.3 Effect of shade on chlorophyll content

Chlorophyll content has been found to either increase or decrease in response to shading in most plants. According to Priestly (1929), the chloroplasts in leaves would undergo changes in position according to the differences in light intensity. It was pointed out that in leaves of plants grown under low light intensities the plastids were limited in number and they were arranged at right angles to the light rays and were larger in size, thus increasing the area of light absorption.

Most scientists have quoted positive effect of shading on chlorophyll contents in plants. According to Clark (1905) certain optimum intensity of light was found to be necessary in plants for chlorophyll production. He found that direct sunlight of high intensity was resulting in destruction of chlorophyll. Shirley (1929) reported that shaded leaves generally enhanced the chlorophyll level per unit weight. Seybold and Egle (1937) observed an increase in chlorophyll 'b' content under low light intensity. Gardner *et al.* (1952) and Bjorkman and Holmgren (1963) observed that the concentration of chlorophyll per unit area weight of leaf increased with decreasing light intensities until the intensity was so low that it hazarded the survival of plants.

An increase in chlorophyll content with increase in shade levels was reported by Evans and Murray (1953), Guers (1971) and Okali and Owasu (1975) in cocoa. Shade plants generally have a higher chlorophyll content than the sun plants (Copper and Qualls, 1967; Bjorkman, 1968). An increase in chlorophyll content with increase in shade levels were reported by Frydrych (1970) in bean; Moon and Pyo (1981) in Chinese cabbage, Sorenson (1984) in winged bean, Singh (1994) in okra and French bean, El-Gizawy *et al.* (1993) in tomato and Sreelathakumary (2000) in chilli. Similar trend was noticed in crops like black gram, groundnut, red gram (George, 1982) and groundnut and hybrid napier (Singh, 1994). Misra *et al.* (1968) reported increased chlorophyll contents in leaves of shaded bougainvillaea plants. Reduction in chlorophyll a/b ratio in shade-grown plants was less than in sun-grown plants (Lewandowska and Jarvis, 1977) in picea.

Increase in chlorophyll content with increasing shade levels was reported in tea (Ramaswamy, 1960; Venkataramani, 1961), cotton (Bhatt and Ramanujan, 1975), tobacco (Anderson *et al.*, 1985); pepper (Vijayakumar *et al.*, 1985). In the case of fruit crops also studies revealed that there was an increase in chlorophyll content with increase in shade intensities as reported by Tsankov *et al.* (1976) in grapes and Radha (1979) in pineapple.

Lower chlorophyll a/b ratios are typical of shade ecotypes and may enable more efficient absorption of light under shade conditions due to the difference in the absorption spectra of chlorophyll 'a' and 'b' and the variance in light quality in the under story (Boardman, 1977, Young and Smith, 1980). Lukyanova and Domanskaya (1977) found that in *Hedera taurica* and *Euonynymus japonicus*, chlorophyllase activity increased and the chlorophyll content decreased as the light intensity increased. The lower chlorophyll content in sun leaves maybe attributed to the decomposition of chlorophyll under intense light intensities. Priessel *et al.* (1980) observed that in *Codiaeum variegatum* var. pictum, increased light generally reduced chlorophyll and carotenoid contents, but did not affect anthocyanin content.

Shading in coleus significantly influenced the content of total chlorophyll, chlorophyll 'a' and 'b' and their contents went on increasing with increasing shade levels. The chlorophyll content of leaves was found to be significantly influenced by shade and the contents of total chlorophyll and its components were found to be increased by shading upto 50 and 75 percent in colocasia (Bai, 1981).

Ramanujan and Jose (1984) found that the cassava leaves grown under low light (6000 lux) recorded higher concentration of total chlorophyll per unit leaf weight. They also observed that low light favoured the concentration of chlorophyll 'b' and thus the ratio of chlorophyll 'a' to chlorophyll 'b' was reduced significantly.

Nii and Kurowia (1988) studied the anatomical changes including chloroplast structure in peach leaves under different light conditions and found that chlorophyll content per unit leaf area per dry weight increased with shading. Shade leaf chloroplasts (10 and 25% of full sun) were larger and rich in thylakoids, while sun leaf chloroplasts (50 and 100% of full sun) showed poorly stacked grana.

Ravisankar and Muthuswamy (1988) observed higher content of total chlorophyll and its components in ginger in two-year and six-year old arecanut plantations compared to those grown in pure stand in the open. The increase in chlorophyll content under shade conditions is an adaptive mechanism commonly observed in plants to maintain the photosynthetic efficiency (Attridge, 1990). Sreekala (1990) reported that in ginger there is a general increasing trend in chlorophyll content with increasing shade levels.

Shaded plants often develop higher total chlorophyll content on weight basis (Muthuchelian *et al.*, 1989). The total chlorophyll content in the leaves of unshaded plants of black pepper were found to be 44% less than the contents present in the shaded leaves (Vijayakumar and Mammen, 1990). Higher light intensities have a damaging effect on chlorophyll, both on weight as well as area basis according to Naidu & Swamy (1993) in pongamia and Liang *et al.* (1995) in Japanese beech. Chlorophyll and cartenoid content of leaves of pepper were found to be increasing with increasing shade (Yinghua and Jianzhen, 1998). Summary report of ICAR Ad-hoc scheme on shade studies on content based intercropping situation conducted from 1988 to 1991 at Vellanikkara, indicated an increase in chlorophyll of turmeric due to shading (KAU. 1992). Total chlorophyll and its components increased steadily with increased levels of shade in turmeric at 135 DAP (Sheela, 1992).

The chlorophyll contents of tea shoots grown under the shade trees were significantly higher than those from unshaded plots (Mahanta and Baruah, 1992). Fahl *et al.* (1994) reported that chlorophyll a and b, protochlorophyll and total leaf chlorphyll contents increased in shade grown plants compared to those in full sun light.

In stokes aster, as environment light intensity (LI) declined, plants had more chlorophyll per unit dry weight (DW), a higher chlorophyll 'b' chlorophyll 'a' ratio, less leaf, area, and a lower root: shoot ratio (Callan and Kennedy, 1995). Leaves of shade grown grape vines had higher contents of chlorophyll (Cartechini and Palliotti, 1995).

In shade grown plants of *Andrographis paniculata*, plants had more chlorophyll per unit dry weight (Pratima, 1998). The chlorophyll 'a', 'b' and carotenoid content were higher when arrowroot was grown under shade compared to open (Maheswarappa *et al.*, 2000). Similar trend was reported by Singh (1988) in potato, Prameela (1990) in colocasia and Valenzuela (1990) in cocoyams. Taro and tannia responded to shading with a significant increase in chlorophyll content per unit area of leaf (Johnston and Onweueme, 1998).

Contrary to these reports, some scientists have noticed a negative effect of shading on chlorophyll content in some crops, (Einert and Box, 1968) observed that in *Lilium longifolium*, leaf chlorophyll content was highest under full sunlight at the time of initiation and directly proportional to light intensity. Sharma and Sen (1971) observed maximum chlorophyll in Solanum nigrum when grown under continuous illumination. Higazy *et al.* (1975) noticed that the concentration of total chlorophyll as well as its components 'a' and 'b' decreased by increasing shade intensity in cowpea. An inverse relationship of shade and chlorophyll content had been reported in peanut (Rao and Mittra, 1988).

Shading has also been found to be insignificant in the case chlorophyll production by some scientists. Instances where the chlorophyll content was unaffected by shading were observed in crops like chickpea (Pandey *et al.*, 1980) and kiwi fruit (Grant and Ryng, 1984). Chlorophyll content was not affected by shade treatments in sweet potato (Bai, 1981) and spinach (Moon and Pyo, 1981). Chlorophyll a: b ratios were similar across both sun and shade levels for *Vinca major* L. (Demming and Adams, 1992).

2.1.3 GROWTH ANALYSIS

2.1.3.1 Effect of shade on Leaf Area Index (LAI)

Shading has been reported to have a profound influence on leaf area index of plants. Increase in total leaf area results in higher leaf area index (Russell, 1961). Lazenby (1906) noticed increased leaf area in the case of salad crops such as tomato, cabbage and lettuce under shaded conditions. Leaf area increase consequent to shading has also been reported by Porter (1937), Nagaota *et al.* (1979), El-Gizawy *et al.* (1993), El-Abd *et al.* (1994), Heuvelink and Marcaelis (1996) and Paez *et al.* (2000) in tomato plants. Vinson (1923) studied the effects of shading on geranium and reported largest leaf area under shaded conditions. Leaf area per plant of red clover was found to increase under conditions of moderate shading. Panikar *et al.* (1969) observed an increase of 15.1 and 17.6 per cent in the length and breadth of leaves in tobacco under shade as compared to unshaded plants.

High LAI had been reported under intercropping system by several scientists (Lin *et al.*, 1981; Reddy and Willey, 1981; Mandal *et al.*, 1986). Mullakoya (1982) reported that leaf area decreased with increasing light-intensities in guinea grass. The maximum leaf area was recorded in 75 percent shade level. Ramanujan *et al.* (1984) observed that LAI of cassava increased with increase in shade intensity.

Sorenson (1984) observed higher LAI with high shade intensity in winged bean. Gratani *et al.* (1987) found that leaf area of sun leaves (upper layer) was lower than that of shade ones within Beech crown. In Satsuma mandarin orange, reduced light intensity increased LAI. Ravisankar and Muthuswamy (1988) revealed that in ginger a high LAI was noticed when grown as an intercrop in six year old arecanut plantations. Increased leaf area in shade grown plants was due to leaf expansion as well as increased leaf number (Singh, 1988). According to Pushpa kumari (1989), maximum LAI was recorded at 50 percent shade in greater yam and at 25 percent shade in lesser yam, tannia and elephant foot yam.

Plants grown under shaded situation produced more leaves and leaf area and this is an adaptation to expose larger photosynthetic surface under limited illumination (Attridge, 1990). Valenzuela (1990) reported greater LAI in shade grown cocoyams compared to sun grown plants. Wilson *et al.* (1980) found an increase in the proportion of green leaf of a *Paspalum notatum* pasture under trees compared with that in the open pasture. These findings support earlier work using artificial shade (Wong and Wilson, 1980) as well as tree shade (Cameron *et al.*, 1989).

Ancy Joseph (1992) reported an increase in leaf area index with increase in shade intensity in ginger. LAI in ginger was significantly lower under open condition compared to shade levels in all growth stages. In ginger, minimum leaf area was noted in plants grown under open condition (Sreekala, 1999). In forage grasses, response to reduced light (shade) include larges leaves with fewer mesophyll cells and stomata per unit leaf area, intercellular air space, higher leaf area ratio (LAR), and reduced specific leaf weight (SLW) (Kephart *et al.*, 1992). According to Babu (1993), in ginger, maximum leaf area was produced under 25 percent shade and minimum under open condition at 120 and

180 DAP. Rodriguez – Montero (1997) reported that shading in *Dioscorea alata* resulted in larger leaves.

Yinghua and Jianzhen (1998) reported increased leaf area index in capsicum with increasing shade. In pepper, LAI increased when light intensity was reduced from 100 to 50 percent (Devadas and Chandini, 2000). Maheswarappa *et al.* (2000) noticed greater LAI in shade grown cocoyams compared to sun grown plants. Shade plants of tannia had significantly larger leaves (Johnston and Onwueme, 1998). LAI showed significant variation between the treatments and was higher under 20 percent and 40 percent shade levels compared to open and further increase in shade levels resulted in a LAI, which was on par with open in turmeric (Sreekala and Jayachandran, 2001). Total leaf area of shade plants was higher in comparison with full sunlight plants in *Mentha spicata* (Prasanta K. Patra *et al.*, 2003).

Contrary to these reports, a negative trend has been noticed in some crop with respect to LAI upon shading. In Bird's foot trefoil, there was a decrease in leaf area under conditions of moderate shading. (Mckee, 1962). Beinhart (1963) reported that decreased light intensity resulted in lower leaf area in clover. The optimum LAI depends not only on the arrangement of leaves within the canopy but also on the light intensity that the canopy receives. Growth will be slow in periods of low light intensity (Bleasdale, 1973).

Negative trend was also observed by Bhatt and Ramanujam (1975) in cotton; Palis and Bustrillos (1976) in sorghum; Tarila *et al.* (1977) in vegetable cowpea; Patterson (1980) in cogon grass; Ramadasan and Satheesan (1980) in turmeric; Bai (1981) in sweet potato; George (1982) in groundnut and blackgram; Krishnankutty (1983) in bhendi, amaranthus, clusterbean and vegetable cowpea; High light has been reported to increase LAI in pepper (Mathai, 1983). According to Pillai (1986), LAI decreases under shade situation in Guinea grass (*Panicum maximum*) and Setaria grass (*Setaria sphacelata*). Total leaf area in cardamom increased as the light intensity increased (Sulikeri, 1986). Ajithkumar (1999) observed an increase in LAI up to 40 percent shade and thereafter a decline in 60 and 80 percent in ginger. Leaf area was significantly reduced in tree species grown in 20 percent and 40 percent shade conditions compared to open condition (Netshiluvhi, 1999). High light intensity increased leaf area in betel vine (Shivasankara *et al.*, 2000). In *Clitoria ternatea*, LAI was more in open condition when compared to shade condition (Reshmi, 2001).

Shading has been reported to be of not much significance when it comes to LAI in plants by some scientists. Bai (1981) reported that leaf area index of ginger, turmeric and coleus was not influenced by different intensities of shade. Similar report by George (1982) in cowpea has illustrated the same point.

2.1.3.2 Effect of shade on Net Assimilation Rate

Net Assimilation rate (NAR) refers to the change in dry weight of the plant per unit leaf area per unit time. Shading has been found to have a profound effect on net assimilation rate of plants.

Some reports indicate a positive correlation between shading and net assimilation rate. An increase in NAR with increasing shade intensities was reported in sweet potato and coleus (Bai, 1981). A positive trend i.e. an increase in NAR with increase in shade intensity was reported in cocoyams (Valenzuela, 1990). Ravisankar and Muthuswamy (1987) reported a significant negative correlation of NAR with light intensity in ginger raised in arecanut garden.

In contrast to these reports some workers have indicated a negative correlation between shading and net assimilation rate. Blackman and Wilson (1951), Newton (1963) and Coombe (1966) reported a positive correlation in crop plants between NAR and irradiance. NAR was maximum under open condition in barley according to Kamet (1959). Shading reduced NAR more at the beginning of the experiment than at later stages in potato (Nosberger and Humphries, 1965). In chickpea (Pandey *et al.*, 1980) noticed a decrease in NAR with increasing shade intensity. Similar results were reported in blackgram, cowpea and groundnut by George (1982). Ramanujam et al. (1984) observed that the NAR of cassava grown under was reduced significantly when compared to those plants grown under normal light. Similar decrease in NAR with shade was reported by Ramanujam and Jose (1984) in cassava, Laura *et al.* (1986) and Roberts-Nkrumah *et al.* (1986) in sweet potato. Low light intensities induced reduction in NAR in cucumber (Smith *et al.*, 1984), *Paspalam conjugatum* (Ipor and Price, 1992), chilli (Sreelathakumary, 2000) and ragweed *Parthenium* sp. (Pandey *et al.*, 2003). George *et al.* (1998) found that open condition was significantly superior to shading in ginger.

Ancy Joseph (1992) found that the NAR under 25 and 50 per cent shade levels were significantly high in ginger with a drastic decrease under heavy shade. Beena (1992) found significant difference in NAR between shade levels at both 60 and 120 DAP. The highest value of NAR was observed at 50 percent shade in ginger. George (1992) revealed a significant difference in NAR between shade levels at both 60 and 120 DAP in ginger. Highest values were observed at 50 per cent shade. Babu (1993) found that in ginger during the first phase (60-120 DAP), the highest NAR was obtained from 25 percent shade level. NAR was maximum under open condition in radish (Sarkar and Saha, 1997). Sreekala (1999) reported that shade level beyond 20 percent showed less NAR in ginger. According to Pushapa kumari and Sasidharan (1992) open grown plants recorded maximum NAR at harvest in lesser yam.

Jung *et al.* (1994) revealed that shaded plants of pepper had considerably low NAR during flowering and early fruit development stages compared to exposed plants. Yinghna and Jianzhen (1998) reported that NAR of pepper was highest under 30 percent shade. A low rate of NAR under shade was reported in *Clitoria ternatea* (Reshmi, 2001).

Shading has also been found to be insignificant in its effect on NAR in some plants. Several reports indicated that NAR was not influenced by increase in shade intensity in crops like cocoa seedlings (Gopinathan, 1981), ginger and turmeric (Bai, 1981) *Mentha arvensis* (Duriyaprapan and Britten, 1982), Greater yams (Pushpa kumari and Sasidharan, 1992) and ginger (Ajithkumar, 1991) In turmeric, no significant difference on NAR was observed between shade levels, cultivar and shade × cultivar interactions both at 120 and 180 DAP (Sheela, 1992).

2.1.3.3 Effect of shade on Relative Growth Rate

Relative Growth Rate (RGR) is the rate of increase in dry weight per unit time and is expressed as g $m^{-2}day^{-1}$ Multiple regression analysis identified water potential and stomatal conductance as the factor, which contributed most to the observed variation of absolute biomass gain and relative growth rate (Costa and Rozana, 2000).

Evans and Murray (1953) recorded greatest relative growth rate at a light intensity between 30 to 60 per cent of full daylight in cocoa plants. Paez *et al.* (2000) reported that RGR increased at all growth intervals under shade in tomato.

In contrast to these reports, a reduction in RGR values with an increase in shade was also observed. According to Okoli and Owasu (1975), RGR were maximal for cocoa plants grown under medium shade. In sweet potato, RGR tended to define with increasing shade and lowest values were recorded in 73 per cent shade (Roberts-Nkrumah *et al.*, 1986). Muthuchelian *et al.* (1989) reported that in woody legume tree species (*Eythrina variegata* Lam.), seedlings grown under shade resulted in lower RGR compared to sun plants.

A decrease in RGR in shade-tolerant compared to light demanding tree species was reported by Mori *et al.* (1990). Shaded plants of pepper had considerably lower RGR during flowering and early fruit development stages compared to exposed plants (Jung *et al.*, 1994). Shade levels 60 and 80 per cent recorded low values of RGR in ginger plants during all stages except between 60-90 DAP (Sreekala, 1999).

Studies on the effect of artificial shading on growth of *Trema micrantha* seedlings revealed that shading for 60 days caused decrease in relative growth rate by reductions in net assimilation rate rather than leaf area ratio (Valio, 2001). Pandey *et al.* (2003) observed lower RGR in ragweed Parthenium in winter compared to summer stands.

Reports of shade having no effect on RGR in plants also exist. Murata (1961) reported that RGR was practically free from the influence of solar radiation as long as the level of radiation was above one third of full incident radiation.

2.1.3.4 Effect of shade on Absolute Growth Rate

AGR of sun light plants was observed to be more than that of the shade plants in *Mentha spicata* (Prasanta K. Patra *et al.*, 2003).

2.1.4 YIELD

2.1.4.1 Effect of shade on total herbage yield (fresh weight)

Yield as a parameter was found to be highly responsive to shading in crop plants by many workers. Fresh or dry weight of biomass, as the case maybe, was observed to decrease rather than increase with shading. However there are some exceptions.

Blackman and Wilson (1951) reported that the ability of plants to tolerate shade depends on the efficiency of total dry matter production. Monteith (1969) observed that the maximum amount of dry matter produced by a crop was strongly correlated with the amount of light intercepted by its foliage. Of the various environmental factors, the light is one that has much influence on the growth and productivity of the plant. Hanada (1991) found that covering crops with plastic net or non-woven fabrics increased the yield of vegetables both in tropical and sub-topical areas. The yield increase was found to be the combined result of shading, suppression of increase in soil temperature and conservation of soil moisture. Soil temperature at a depth of 5cm was found to be lower by as much as 6^0C under cover with a shading intensity of more than 67% comported to control and this produced an underground environment more suitable for root growth.

Some scientists reported positive effect of shading on fresh matter production in crop plants. According to Bai (1981), colocasia did not show any marked decrease in yield with increase in shade upto 50 per cent of full sunlight. Highest yield of ginger under low light intensity of about 25 percent shade was also reported by Bai and Nair (1982). Ravisankar and Muthuswamy (1988) recorded that fresh rhizomic yield increased when ginger was grown as an intercrop in arecanut plantation. Babu (1993) reported that the green ginger yield obtained from all shade levels (25, 50 and 76 per cent shade) were significantly superior to open condition. El-Aidy (1986) found higher yield in tomato plants grown under shade than those in the open field, but this trend could be reduced by increasing shade with 40 per cent shade being the best. El-Gizawy *et al.* (1993) found increased number of fruits per plant and total yield in tomato. Highest yields were obtained under 35% shading. To study the effect of shade in tomato, four shade treatments ranging from 1:1 (1 row of tomato: 1 row of maize) to 4:1 (4 rows of tomato: 1 of maize) were tried. The treatment 1:1 proved significantly effective for fruit set, number of fruits per plant and yield (Sharma and Tiwari, 1993).

In a study to find out the radiation stress on the therapeutic yield and biomass production in *Nerium oleander* and *Urginea indica*, the highest biomass production, harvest index and therapeutic yield in *N.oleander* and therapeutic yield of *U.indica* were obtained at radiation stress (120 lx) A moderate light intensity (60 lx) resulted in the highest biomass production and harvest index in *U.indica* (Pal and Gupta, 1991). Jayachandran *et al.* (1992) revealed that the yield of turmeric at 25 per cent shade was on par with that under open condition.

Warren and Anderson (1994) observed that marketable yield of bell pepper from plots shaded with spam bonded polypropylene row overhead covers were equal to or greater than those from other treatments. Yinghua and Jianzhen (1998) reported highest yield in pepper when under 30 per cent shade. Shade tree cover of 23-38 per cent had a positive effect on yield of coffee plants but production may decrease under shade cover of more than 50 per cent (Soto-Pinto *et al.*, 2000).

Most scientists reported a decrease in yield with increase in shade levels. According to Curme (1962), fruit set and yield of tomato were positively influenced by increased levels of incident sunlight. Habfield (1968) reported that the yield of the tea bush is limited by excessive leaf temperature in unshaded conditions and by low light intensity in shaded condition. In potato, shading at the beginning of tuber initiation reduced the rate of tuber formation and growth while shading during the early stages had no effect on the number of tubers though it reduced the final yield (Gracy and Holmer, 1970). Sagi *et al.* (1979) observed that in tomato, reduced fruit set under low solar radiation intensity. Arora *et al.* (1983) reported that plant survival in the field and yield per plant in tomato were higher in non-shaded plots and to the smothering effect to the shade plants. *Xanthosoma sagittifolium* and *Colocasia esculentum* showed enhanced ability to survive stress condition when grown under shade but only with a low yield of edible materials (Caesar, 1980). Moon and Pyo (1981) reported highest fresh weight at 35 percent shade in Chinese cabbage, lettuce and spinach beyond which the performance was poor than those in full sunlight. In cocoa, under light limited environment, pod yield was low (Field and Mooney, 1983; Hirose, 1988; Nair *et al.*, 1996)

Shen and Seely (1983) reported that light intensity decreased plant fresh and dry weight but did not affect the leaf nutrient content. Smith *et al.* (1984) found that tomato yields were best under 15 per cent shade than 40 per cent shade and open. Watson *et al.* (1984) found that the green fodder yield of Marshall rye grass (*Lolium multiflorum*) reduced as the shade increased. Studies conducted in 4 sweet potato cultivars showed that fresh weight of the tuber was not affected in 25 per cent shade but in 55 per cent shade, values were noticeably lower and in 73 per cent shade tuberisation was almost completely suppressed in all cultivars. The responses were resulted from slower tuber growth in 55 per cent shade and from delayed tuber initiation and slower tuber growth in 73 per cent shade (Laura *et al.*, 1986).

Roberts-Nkrumah *et al.* (1986) pointed out that fresh weight of the tuber in 50 per cent shade was markedly lower and little tuberisation occurred in 75 per cent shade. Rylski and Spigelman (1986) investigated the effect of different levels of shading (0, 12, 26 and 47 per cent) on yield of capsicum under higher solar radiation during summer and winter. Shading inhibited the development of laterals shoots on the main stem of plant below the first flower. The changes in plant development due to shading affected fruit set, number of fruits per plant, fruit location on the plant, fruit development and yield. The lateral shoots, which developed under high light intensity, provided 25 per cent of the total yield whereas; only a few fruits were picked from lateral shoots of plants under low light intensity. The lowest number of fruits per plant was obtained under 47 per cent shading. Under shading, individual fruits were larger and had a thicker pericarp. The highest yield of high quality fruits was obtained with 12 and 26 percent shade.

The cardamom clumps under medium light and high light weighed significantly more as compared to clumps grown under low light (Sulikeri, 1986). In groundnut, shading at maturity did not reduce yield, though yield was affected by shading during flowering, pegging and filling stage (Rao and Mittra, 1988). In tannia, highest yield was recorded under 25 percent shade with an almost equal yield at 50 per cent shade (Pushpa kumari, 1989). In turmeric, a shade intensity increase was the cause for a steady decrease in rhizome yield (Varghese, 1989). According to Jayachandran *et al.* (1991), ginger c.v Rio-de-Janeiro is a shade loving plant and produced higher yield under 25 per cent shade and comparable yield with that of open and under 50 percent shade. However, shade intensity beyond 50 per cent decreased the yield.

Shade studies on tropical crops viz. colocasia, coleus, cowpea, brinjal, amaranthus, cluster bean, bhendi and sweet potato were conducted in KAU under 0, 25, 50 and 75 per cent shade levels (Nair, 1991). In all these crops, the yield was highest in open (zero percent shade) and declined with increasing shade levels. In a study to find out the effect of shade on yield of *Aralia continentalis* Kitag, a medicinally valuable herb found in far east Russia, Ostrogradskii and Chernyshev (1992) reported that plants growing in the open produced significantly greater amounts of above and below ground parts than plants growing in the shade of oak trees. In the first and second year, in plants in the open, the above ground mass was greater than that below ground but in the third year the opposite was true. Jung *et al.* (1994) reported that pepper plants set smaller fruits in proportion to the degree of shading.

Sale (1973) and Singh (1988) reported that fresh and dry weights of potato were maximum under full sunlight. When tomato crop was grown in glass house, the single fruit size and fruit number were effected by season largely through direct effects of solar radiation on crop photosynthesis and glass house air temperature (Cockshull and Ho, 1995). Sarkar & Saha (1997) reported that fresh and dry weights of radish were higher under open conditions. Shukla *et al.* (1997) reported the effect of subabul canopy on yield of vegetable like chilli, brinjal, cauliflower and okra. Yield of all vegetables was significantly lower when grown under shade than in open. Lower leaf fresh weight and dry weight was observed in shade grown plants by Johnston and Onwuemet (1998). Both fresh and dry yields of onion were highest under full sunlight (Miah *et al.*, 1998).

Insignificance of shading with respect to fresh matter production was also reported. Aclan and Quisumbing (1976) observed no significant difference in rhizome yield among ginger plants grown under full sunlight, 25 percent and 50 percent shade. But heavier shading of 75 percent reduced the yield.

2.1.4.2 Effect of shade on dry weight of total biomass

Photosynthetic efficiency and biomass production of crop plants are positively correlated with total leaf area of the plant (Russell, 1961). The effect of light intensity on dry matter production has been well established (McWhorter and Jordon., 1976).

Shirley (1929) and Gardner *et al.* (1952) reported that generally with increasing light intensities there would be an increase in the percent dry matter in trees. In black pepper, 50% percent light enhanced dry matter production (Senanayake and Kirthisinghe, 1983; Seneviratne *et al.*, 1985). Dry weight of leaves was more in sun light than in the shade plants, and so were the fresh weight too in *Mentha spicata* (Prasanta K. Patra *et al.*, 2003).

2.1.5 CHEMICAL ANALYSIS

2.1.5.1 Effect of shade on oil content

Shade has been reported to influence oil content in crop plants. Ohasi (1962) noticed charges in the content of essential oils with differences in temperature at different stages of plant development in Japanese mint. Plants synthesize organic compounds during their metabolic processes when they grow. The nature and amount of these chemical substances vary according to the agro-climatic conditions and growth stage of the plant (Chopra *et al.*, 1958). Light regimes received by plant determines the productivity and quality of its produce. The active principles maybe present in plant parts like cortical region, bark, stem, leaves, flowers, fruits, seeds etc. The main groups of phytoconstituents of therapeutic significance is classified as carbohydrates, glycosides, tannins and phenolic compounds, lipids, volatile oils, resin and resin combinations and alkaloids (Handa and Kapoor, 1999).

Positive effects of shading on oil content in plants have been reported. Gupta (1964) carried out studies in this respect and reported that the shade dry herb contains 4 percent (w/w) of oil against 3% in the sun dry hay in Japanese mint. An (1982) studied the effect of light intensity on groundnut and observed that shade increased the oil content of fruits. The quality of products of tea, coffee, cinchona and rauvolfia was found to be improved under shade conditions (Feng, 1982). Ginger cultivar, Rio de Janeiro grown as an intercrop in a six year old arecanut plantation recorded highest volatile oil and non-volatile ether extract (NVEE) contents followed by those grown in two year old plantations compared to those grown in the open as a pure crop (Ravisankar and Muthuswamy, 1987).

In ginger, George (1992) found an increase in volatile oil content with increase in shade intensity and the highest value recorded was under 75% shade. Babu (1993) found that in ginger, volatile oil content showed an increasing trend with increasing levels of shade. Lowest contents of volatile oil were in 25% shade, which was on par with open. Boldo (*Peumus boldus* Mol.) leaves grown in the shade had higher essential oil and alkaloid contents than those in full sunlight (Vogel *et al.*, 1996). Under open condition, citronella contains citronellal 43.6%, isopulegol 2.3%, cirtronellol 14.4% geraniol 19.7%, elemol 3.5%, caryophyllene oxide 4%, under shade condition citronellal 40.6%, isopulegol 0.1%, citronellol 14.1%, geraniol 22.7%, elemol 4.1%, caryophyllene oxide 4%. Under open condition, palmarosa contains linalool 1.5%, gevaniol 81.6%, geranu acetate 9.3% under shade condition contain linalool 1.7%, genaniol 83.8%, geranyl acetate 8.8% (Ima, 1998).

Shading has also been reported to have an adverse effect with respect to oil content in plants. Graded shade levels of 20,47,63,80 and 93 percent were found to have little effect on quality parameters of soyabean viz, oil and protein content of seeds except at 93 percent shade where the portion content was the highest and oil content was the lowest (Wahua and Miller, 1978). Ginger showed a steady decrease in the oleoresin content upto 50 percent level of shade (Varghese, 1989). Ancy Joseph (1992) recorded the highest volatile oil content under 25 percent shade followed by that under 50 percent shade. The reduction in oil content of menthol mint due to intercropping with onion observed particularly in first harvest needs further investigation. It is likely that a change in canopy composition of mint due to shading of leaves is primarily responsible for the decline in oil content (Kothari *et al.*, 1996)

Menthol mint is a long day plant and flowers during summer season in India. Flowering was more profuse in plants grown in the open than those raised under shade. The higher proportion of flowers in plants cultivated in the open resulted in higher concentration of menthone and lower percentage of menthol in their oil as the flower oil is rich in menthone, but poor in menthol (Rao *et al.*, 2000).

2.1.5.2 Effect of shade on Non-Volatile other Extract (NVEE)

Reports indicate that NVEE content in plants is responsive to shading. Some scientists have noticed a positive effect of shading on NVEE content in plants. But an overwhelming number of reports indicate otherwise.

A negative effect of shading on NVEE contents has been noticed especially at higher shade levels. Ancy Joseph (1992) found that NVEE content under 25 and 50 percent shade was on par with each other and significantly superior to that under zero and 75 percent shade. According to Beena (1992), an increase in volatile oil content was seen in ginger with increase in shade intensity, but the content of oleoresin was higher under open and 25 percent shade than under intense shade. The content of oleoresin under open and 25 percent shade was higher than under intense shade level (George, 1992).

2.1.6 ECONOMICS OF CULTIVATION

Ancy Joseph (1992) found that the gross and net returns were maximum by growing ginger under low shade. The shade in the decreasing order of benefit: cost ratio was 25, 50, 0 and 75 percent. According to Palanikumar (2004), yield of mint was the highest under 25 percent shade condition, which ultimately recorded the highest income.

2.2 RESPONSE OF CROP TO DIFFERENT SPACINGS.

2.2.1 GROWTH CHARACTERS

2.2.1.1 Effect of spacing on plant height

Plant height has been reported as a character responsive to spacing. Decidedly positive effect of spacing on plant height has been reported by some scientists. Lawande *et al.* (1986) observed more plant height with increased row spacing in cabbage. Pandey *et al.* (1992) and Garcia *et al.* (1992) noticed increased plant height with wider row spacing in garlic. According to Deka and Shadeque (1993), in garlic, plant height increased with wider row spacing. These findings are in accordance with the results obtained in garlic by Singh *et al.* (1995), Naruka (2000) and Naruka & Dhaka (2001). Sharma *et al.* (1995) noticed that in sprouting broccoli (*Brassica oleracea* var. italica), wider spacing led to taller plants. Bhati (1988b) in coriander and Bhati (1988a) in fenugreek observed the same phenomena. Bhama (1991) noticed taller plants with wider spacing in *Solanum viarum*. Spacing had significant effect on the height of *Solanum khasianum* as reported by Sundharaiya *et al.* (2003). Pundir and Porwal (1999) reported that, in chilli, maximum plant height was recorded under widest spacing. Rajeswara Rao *et al.* (1998) had observed taller plants with increased row spacing in lemon grass. Sharma (2001) noticed an increasing trend in plant height with every ascending level of spacing in Chinese cabbage. Ponnuswamy and Sundarraiya (2003) reported in palmarosa (*Cymbopogan martinii*) that significantly higher plant height was obtained with wider spacing. According to Ramachandra *et al.* (2003), patchouli (*Pogostemon patchouli* Pellet.) plants grew taller at wider spacing.

Close spacing has also been reported to contribute to increase in height of plants by Kamalanathan & Thamburaj (1970) and Srinivasan *et al.* in tomato, Shanthi & Balakrishnan (1989) and Muthuramalingam *et al.* (2001) in aggregatum onion, Muni Ram *et al.* (1990) in Egyptian henbane, Das *et al.* (1992) and Karaman (1999) in black cumin, Gandhikumar & Vijayakumar (1996) in davana, Maya *et al.* (1996) in sweet pepper, Krishnamoorthy *et al.* (2000) in ajowan, Hore *et al.* (2004) in ginger, Kizil and Toncer (2005) in nigella, Pakkiyanathan *et al.* (2004) in ashwagandha and Kandiannan and Chandaragir (2006) in turmeric.

Some scientists have reported the insignificant effect of spacing on plant height. Peneva (1969) and Hoeven *et al.* (1975) in chrysanthemum observed no effect of spacing on plant height. Rajanna & Khalak (1991) found no significant influence of spacing on plant height in zinnia. Similarly, Jandial & Saini (1987), Khurana *et al.* (1990) and Sharma & Rastogi (1992) saw no influence of spacing on height of plants in cauliflower. Sharma & Peshin (1994) observed the same in sweet pepper.

2.2.1.2 Effect of spacing on spread of the plant

Viswanathan *et al.* (1993), in a study on patchouli, observed plant spread to increase with wider spacing. According to Ramachandra *et al.* (2003), wider spacing resulted in greater spread of the plant in patchouli.

2.2.1.3 Effect of spacing on number of leaves

Leaf production in plants has been found to correspond to plant population densities.

Scientists have reported an increase in leaf production with wider spacing. Rajanna and Khalak (1991) observed more number of leaves at wider spacing in zinnia.

Janardhan *et al.* (1993) recorded higher number of leaves at wider spacing in onion. Muthuramalingam *et al.* (2001) reported that in aggregatum onion, wider spacing accounted for higher number of leaves. Kanwar *et al.* (1993) noticed that in squash melon, planting at wider spacing resulted in significantly more number of leaves. Similar trend was noticed by Gandhi kumar & Vijaya kumar (1996) in davana, Pakkiyanathan *et al.* (2004) in ashwagandha.

Contrary to these reports, Maheswarappa *et al.* (2001) observed that in galangal, closer spacing gave higher number of leaves.

Some of the reports indicate spacing as having little or no effect on leaf production in plants. Deka and Shadeque (1993) noted the insignificance of spacing with respect to number of leaves put forth by the plant in garlic. Singh *et al.* (1995), Naruka (2000) and Naruka & Dhaka (2001) reported that there was no significant difference in the number of leaves per plant under different spacings in garlic. Sasidhar *et al.* (1997) in turmeric and Hore *et al.* (2004) in ginger reported the absence of significance for spacing with regard to leaf production.

2.2.1.4 Effect of spacing on number of plants with flower shoots

Plants have been reported to respond to variation in spacing by putting forth flowers. Arora & Saini (1976), Narayana Gowda (1985) and Narayana Gowda & Jayanthi (1988) reported an increase in flowering percentage with increase in spacing in China Aster. Rajanna & Khalak (1991) reported increased number of flowers per plant in zinnia at wider spacing.

The relative insignificance of spacing with regard to flowering has also been widely reported. Pall & Padda (1972) and Bhardwaj (1991) in onion found no importance for spacing with respect to flowering. Similar trend was noticed by Muthuramalingam *et al.* (2001) in aggregatum onion. Sharma & Rastogi (1992) noted that spacing had no significant effect on flowering in cauliflower.

2.2.1.5 Effect of spacing on number of roots

The general effect of spacing on plants was studied by Donald (1962) and reported that as the planting density increases, the number of roots produced also increases.

2.2.2 PHYSIOLOGICAL CHARACTERS

2.2.2.1 Effect of spacing on chlorophyll content

Chlorophyll content has been found to either increase or decrease in response to spacing in most plants. Positive effect of spacing on chlorophyll content in plants has been quoted by most scientists. According to Dimri & Lal (1997), in tomato, chlorophyll content was highest under the wider spacing. Higher chlorophyll contents with wider spacing was noticed by Bhati (1988b) in coriander and in fenugreek (1988a). Similar trend was observed in garlic by Naruka (2000) and Naruka & Dhaka (2001). Mahesh kumar & Rawat (2002) reported the significant positive effect of spacing on chlorophyll content in cabbage, with an increase in chlorophyll content with wider spacing.

Contrary to these reports, Garg *et al.* (2001) and Burman *et al.* (2002) reported more chlorophyll content at closer spacing in moth bean.

2.2.3 GROWTH ANALYSIS

2.2.3.1 Effect of spacing on Leaf Area Index (LAI)

Leaf Area Index is described as the size of assimilatory apparatus of plant stands (Watson, 1947). Spacing has been found to have a significant influence on the leaf area index of plants.

Positive effect of spacing on leaf area index has been reported by Diaz and Manrique (1995) in field beans. Here, leaf area index increased with increase in spacing. Craufurd (1996) observed that in cowpea, maximum leaf area indices were noted as the row spacing increased.

Most scientists have noticed closer spacing to increase leaf area index. Shrivastava *et al.* (1996) observed in onion that maximum leaf area index was noted at the closest spacing. Similar trend was noticed in cardamom by Korikanthimath *et al.* (1998), in galangal by Maheswarappa *et al.* (2001), in pepper by Aliyu (2002) and in turmeric by Kandiannan & Chandaragir (2006).

2.2.3.2 Effect of spacing on Net Assimilation Rate (NAR)

Spacing has been found to have not much of an influence on the net assimilation rate of plants. However, Aliyu (2002) reported that, in black pepper, NAR increased with an increase in plant population density.

Heath and Gregory (1938) reported that NAR was relatively constant for a wide range of species. According to Shrivastava *et al.* (1996), in onion, spacing did not influence NAR significantly.

2.2.3.3 Effect of spacing on Relative Growth Rate (RGR)

Contrasting reports have been found on the effect of spacing on RGR of plants. Khare (1985) and Shrivastava *et al.* (1996) reported that RGR increased with increase in spacing in onion. In stark contrast to this report, Blackman (1968) and Aliyu (2002) noted that in pepper, an increase in RGR was observed with an increase in plant density.

2.2.3.4 Effect of spacing on Absolute Growth Rate (AGR)

Donald (1962) studied the general effect of spacing on plants and observed that AGR of plants decreased with increase in planting density. Austin *et al.* (1976), Laing *et al.* (1983) and Saxena *et al.* (1983) produced reports contradicting this and noted maximum AGR values at closer spacing.

Insignificance of the effect of spacing on AGR in plants was brought out by Shrivastava (1996) in onion.

2.2.4 YIELD

2.2.4.1 Effect of spacing on total herbage yield (fresh weight)

Yield as a parameter was found to be highly responsive to spacing in crop plants by many workers.

Nievwhof (1969), Janseen (1983) and Sande and Jaurissen (1986) reported that in knol khol, fresh weight increased with wider row spacing. A decrease in fresh weight with closer spacing was noted in cabbage by Lawande *et al.* (1986). Similar trend was observed in Chinese cabbage by Sharma (2001). Dimitrov (1960) and Narasimraju (1979) observed greater fresh yield with wider spacing of plants. Gowde *et al.* (1983) noted that, in bell pepper, wider spacing gave significantly higher yield. In chilli, Pundir & Porwal (1999) reported that widest spacing recorded maximum fresh weight. Balayan *et al.* (1990) observed increased fresh yield with increased spacing in celery. Bhati (1988) and Jat *et al.* (1996) noted that yield in coriander was highest at the widest row spacing.

Contrary to these reports, closer spacing has been found to give greater results by some scientists. Higher fresh weight at closer spacing was noted by Khadir *et al.* (1989), Lal (1996), Malik & Bhattacharya (1996) and Mahesh kumar & Rawat (2002) in cabbage. Dharmatti & Kulkarni (1988), Sharma & Peshin (1992), Shrivastava *et al.* (1993) and Maya *et al.* (1996) reported that sweet pepper gave higher yield at closer spacing. According to Aliyu (2000), in pepper, closer spacing gave greater yield. Korikanthimath *et al.* (1998) noted in cardamom that higher planting density gave higher yields. Gowde *et al.* (1979) in lucerne, Malik & Bhattacharya (1996), Parmar *et al.* (1999) in cabbage, Maheswarappa *et al.* (2001) in galangal, Man Singh *et al.* (2003) in bergamot mint, Ramachandra *et al.* (2003) in patchouli, noticed an increase in fresh yield with closer spacing.

2.2.4.2 Effect of spacing on dry weight of total biomass

Spacing has been noticed having a negative effect on dry yields by scientists. However, some contradictory reports have also been published. Arslan (1994), Telci (1995), Das *et al.* (1992), Geren *et al.* (1997), Ghosh *et al.* (1981) and Kizil & Toncer (2005) reported in nigella that a wider row spacing gave maximum yield. Singh & Singh (1970), Randhawa & Gill (1985), Vogel (1987), Ahmed *et al.* (1988), Sharma & Prasad (1990) and Krishnamoorthy *et al.* (2000) observed in ajowan, an increase in yield with wider spacing. Pundir and Porwal (1999) noted in chilli, an increase in yield with wider row spacing. Chaudhary (1999) in cumin and Sharma & Prasad (1990) in fennel recorded higher yields at wider spacing.

In contrast to these reports, an increase in dry yield with closer spacing has been noted by Mohan kumar *et al.* (1973) in galangal, Burman *et al.* (2002) in moth bean, Prakash Rao (1983) and Gandhi kumar & Vijayakumar (1996) in davana, Rajanna & Khalak (1991) in zinnia, Ahmed *et al.* (1988), Singh & Neopaney (1993) and Hore *et al.* (2004) in ginger, Pandey *et al.* (1999) in mango ginger, Maheswarappa *et al.* (2001) in kacholam and Kandiannan & Chandaragir (2006) in turmeric.

2.2.5 CHEMICAL ANALYSIS

2.2.5.1 Effect of spacing on volatile oil

Spacing in general has been reported to have no influence over oil content in plants. However, Katoch *et al.* (1978), Singh & Nand (1979) and Man Singh *et al.* (2003) observed that oil content in herb was significantly increased under wider row spacing in bergamot mint. According to Kizil & Toncer (2005), in nigella, highest oil rate was obtained at widest spacing.

Contrary to these reports, spacing at closer intervals has also been reported to increase oil yields. Faroda (1972) and Burman *et al.* (2002) found that closer row spacing yielded more oil in moth bean. Bhadoria & Chauhan (1994) in cluster bean and Gupta & Kumar (1995) in *Brassica campestris* var. toria have observed closer spacing yielding more oil. Rao *et al.* (1998) in lemon grass and Ponnuswamy and Sundarraiya (2003) in palmarosa, noted an increase in oil yield with closer spacing. Vishwanathan *et al.* (1993) and Ramachandran *et al.* (2003) in patchouli noticed an increase in oil with closer spacing.

Many scientists have reported the insignificant effect of spacing on oil content in plants. Bhati & Shaktawat (1994) in coriander, Damato *et al.* (1994) in Florence fennel and Krishnamoorthy *et al.* (2000) in ajowan noted no effect of spacing on oil content. Gandhikumar & Vijayakumar (1996) reported that spacing had no influence on oil content in davana.

2.2.6 ECONOMICS OF CULTIVATION

Spacing has been found to have a significant effect on crop yields, and hence on the benefit: cost ratio of cultivation. Wider row spacing in garlic facilitated greater returns according to Naruka & Dhaka (2001). In contrast, Prakash *et al.* (2000) in cauliflower and Sharma & Chandra (2002) in cabbage, reported that closer spacing netted higher returns.

According to Chaudhary (1999), in cumin, no significant influence of spacing was on the net returns of the crop.

Materials and Methods

PLATE 1: LAY OUT OF THE EXPERIMENTAL PLOT

3. MATERIALS AND METHODS

The study entitled 'Performance of spiny coriander (*Eryngium foetidum* L.) under different shade regimes' was conducted at the College of Agriculture, Vellayani, Thiruvananthapuram, Kerala during the period from May 2006 to February 2007.

The details of the materials used and methods adopted for the study are presented in this chapter. The work was carried out in two phases viz.,

1. Preparation of uniform planting material.
2. Cultural trial of the plant under different shade regimes.

3.1 PHASE 1: PREPARATION OF UNIFORM PLANTING MATERIAL

In phase 1 of the experiment, sufficient number of seedlings were purchased from a nursery at Neyyattinkara in Thiruvananthapuram district and multiplied in the Department of Plantation crops and Spices, College of Agriculture, Vellayani to facilitate the laying out of the experiment.

3.2 PHASE 2: CULTURAL TRIAL OF THE PLANT UNDER DIFFERENT SHADE REGIMES

3.2.1 Experimental site

The field experiment (Plate 1) was conducted at the Instructional Farm, College of Agriculture, Vellayani, which is located at 8 ˚5' North latitude, 76 ˚ 9' East longitude and at altitude of 29m above sea level. Area No: 4 of the instructional farm was chosen for this purpose.

3.2.2 Soil

The soil of the experimental site is red loam belonging to Vellayani series, which comes under the order Oxisol.

3.2.3 Climate

The climate of the experimental site is humid tropical.

3.2.4 Weather

Weather parameters like temperature, relative humidity and rainfall during the period of study are presented in Appendix 1.

3.3 EXPERIMENTAL DESIGN AND LAYOUT

The experiment was laid out in Random Block Design with five replications. Separate design was used for three shade levels.

The lay out plan is shown in Fig 1.

Table 1: Treatment (three shade levels and four spacing) Illustration

Shade levels:

S_1 - 25% shade

S_2 – 50% shade

S_3 – 75% shade

Spacings:

T_1 – 10 × 15 cm (120 plants per plot)

T_2 – 15 × 15 cm (80 plants per plot)

T_3 – 20 × 15 cm (60 plants per plot)

T_4 – 30 × 15 cm (40 plants per plot)

Number of treatments – 12

Plot size – 120 cm × 150 cm.

FIGURE 1

S_1 (25%)

S_1T_1	**S_1T_2**	**S_1T_4**	**S_1T_3**
S_1T_1	**S_1T_2**	**S_1T_3**	**S_1T_4**
S_1T_2	**S_1T_1**	**S_1T_4**	**S_1T_3**
S_1T_2	**S_1T_1**	**S_1T_3**	**S_1T_4**
S_1T_1	**S_1T_3**	**S_1T_2**	**S_1T_4**

S_2 (50%)

S_2T_3	S_2T_1	S_2T_2	S_2T_4
S_2T_4	S_2T_2	S_2T_1	S_2T_3
S_2T_4	S_2T_1	S_2T_3	S_2T_2
S_2T_1	S_2T_3	S_2T_2	S_2T_4
S_2T_2	S_2T_3	S_2T_4	S_2T_1

S_3 (75%)

S_3T_2	S_3T_1	S_3T_3	S_3T_4
S_3T_1	S_3T_4	S_3T_3	S_3T_2
S_3T_4	S_3T_1	S_3T_3	S_3T_2
S_3T_1	S_3T_3	S_3T_2	S_3T_4
S_3T_2	S_3T_3	S_3T_1	S_3T_4

3.4 SEASON

The field experiment was conducted from May 2006 to February 2007.

3.4.1 Nursery

Five hundred seedlings were planted in nursery beds of size 100×150cm and allowed to multiply vegetatively to get sufficient number (4500) of uniform seedlings for transplanting to the main site for the experiment.

3.4.2 Main field preparation and planting

The land was thoroughly prepared by digging and leveling and beds of size 120×150 cm were made 20cm apart. Seedlings were planted at four population densities of 10×15cm, 15×15cm, 20×15cm and 30×15cm. High Density Poly Ethylene (HDPE) shade nets of appropriate mesh size were used for providing the required shade requirements of 25%, 50% and 75%.

3.4.3 Application of manures and fertilizers

Manures and fertilizers were applied as per recommendations for leafy coriander (J.S. Pruthi, 2001). Uniform cultural practices were given.

3.4.4 Irrigation

Field was irrigated once in two days.

3.4.5 Weeding

Periodical weeding was done and the plots were kept weed free.

3.5 OBSERVATIONS

3.5.1 Biometric observations:

The following observations were taken at monthly intervals. Observations of ten plants selected at random from each replication were taken and the average values were worked out.

3.5.1.1 Plant height

The height of the plant was measured from the base of the plant to the tip of the longest leaf and was expressed in centimeter.

3.5.1.2 Girth at collar region

Girth at collar region was measured using a thread and was expressed in centimeter.

3.5.1.3 Spread of the plant

Spread was obtained by taking the product of the distance between the terminal parts of the largest branches on both planes and expressed in square centimeters.

3.5.1.4 Number of leaves

For each experimental plot, the total number of leaves of the observational plants was counted and the average number recorded.

3.5.1.5 Number of plants with flower shoots

For each experimental plot, the total number of plants with flower shoots was counted and percentage recorded.

3.5.1.6 Number of roots

For each experimental plot, the total number of major roots of the observational plants was counted at the time of final harvest and the average number recorded.

3.5.4.7 Suckering / Seedling

Throughout the duration of the crop, periodical surveillance was conducted to see whether the plants put forth any suckers or seedlings as the case may be and recorded.

3.5.5 Physiological characters

The following physiological characters were recorded:

3.5.5.1 Photosynthetically Active Radiation (PAR)

Photosynthetically Active Radiation (PAR) in shaded conditions was measured using Steady State Porometer (? T) and expressed as μ mol $m^{-2}s^{-1}$.

3.5.5.2 Stomatal conductance

Stomatal conductance was measured using the Steady State Porometer and expressed as μ mol m^{-2} s^{-1}.

3.5.5.3 Chlorophyll content

The chlorophyll content was estimated by the following method prescribed by Starnes and Hadley (1965). A representative sample of 25 mg was weighed and leaf tissues were then ground with 10 ml of 80% acetone using a pestle and mortar. The homogenate was centrifuged at 3000 rpm for 10 minutes. The supernatant was collected and was made upto 25ml with 80% acetone. The OD value of the extract was measured at 663 and 645 nm using 80% acetone as the blank in the spectrophotometer. The amount of pigments was calculated using the following formula and expressed in mg. of pigments g^{-1} of fresh leaf.

Chlorophyll a = [12.7 (OD at 663) – 2.69 (OD at 645)] × v/w × 1000 mg g^{-1}.

Chlorophyll b = [22.9 (OD at 645) – 4.68 (OD at 663)] × v/w × 1000 mg g^{-1}.

Total Chlorophyll = [20.2 (OD at 645) + 8.01 (OD at 663)] × v/w × 1000 mg g^{-1}.

Where,

v – volume (cc)

w – weight (g)

3.5.6 Growth analysis

The following growth analyses were conducted at bimonthly intervals:

3.5.6.1 Leaf Area Index (LAI)

Leaf area was calculated by tracing the area of the leaf on the graph sheet and Leaf Area Index (LAI) was worked out as per the method suggested by William (1946).

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

3.5.6.2 Net Assimilation Rate (NAR)

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) modified by Buttery (1970) was used for calculating NAR and expressed in g^{-2} day^{-1}.

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

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

3.5.6.3 Relative Growth Rate (RGR)

Relative Growth Rate (RGR) is the rate of increase in dry weight per unit time expressed as g m^{-2} day^{-1}. Relative growth rate was calculated as per the method of Blackman (1919).

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

where W_1 and W_2 are total dry weight per plant at time t_1 and t_2 respectively.

3.5.6.4 Absolute Growth Rate (AGR)

Absolute Growth Rate (AGR) gives an idea of daily growth rate. AGR was worked out by the formula suggested by Briggs *et al.* (1920) and expressed as g day^{-1}.

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

where W_1 and W_2 are total dry weight per plant at time t_1 and t_2 respectively.

3.5.6 Yield

The following parameters were measured at the time of harvesting:

3.5.7.1 Number of marketable harvests

Standard size was fixed for harvesting the marketable leaves. When the plants produced marketable size of leaves (25cm length and 6cm breadth at the central region) they were harvested and frequent harvestings were carried out till they produced inflorescence.

3.5.7.2 Total herbage yield (fresh weight)

Fresh weight of leaves from individual harvests was recorded and from the total fresh weight of each observational plant, total herbage yield was computed in grams per plot.

3.5.7.3 Dry weight of total biomass

Plants from each treatment plot were uprooted, first dried in shade and then dried in hot air oven at 70 – 80 ° C. Dry weight of each plant was recorded and average value was taken as dry matter yield and expressed in grams per plot.

3.5.7 Chemical analysis

3.5.8.1 Volatile oil (%)

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

PLATE 2: FULL GROWN PLANT OF *Eryngium foetidum*

PLATE 3: PLANT WITH INFLORESCENCE

PLATE 4: LEAVES ATTAINED MARKETABLE SIZE

3.5.8.2 Non-Volatile Ether Extract (NVEE)

Non-Volatile Ether Extract (NVEE) was estimated at monthly intervals from 120 days after planting by Soxhlet distillation method (A.O.A.C, 1975) and expressed as percentage on dry weight basis.

3.5.8 Storage studies

3.5.9.1 Drying and storing

The leaves were dried under room temperature and also oven dried and stored to study shelf life.

3.5.9.2 Cold storage

Representative samples of freshly harvested leaves from each treatment were bagged in polythene covers and kept in refrigerator to study shelf life of the crop under cold storage and observations recorded periodically.

3.5.9.3 Storage under ambient temperature

Representative samples of each treatment comprising of freshly harvested leaves were stored under ambient temperature in room condition and observations were recorded periodically.

3.6 INCIDENCE OF PESTS AND DISEASES

Throughout the duration of the crop, periodical surveillance was conducted for detection of pests and diseases.

3.7 ECONOMICS OF CULTIVATION

The economics of cultivation was worked out based on the cost of cultivation and the prevailing market price of the crop. In computing the cost involved, different variable cost items like planting materials and labour charges were considered at the prevailing market rate during 2006-'07.

The net income and benefit cost ratio was calculated as follows:

Net Income (Rs.ha^{-1}) = Gross income – Total Expenditure

$$\text{Benefit cost ratio} = \frac{\text{Total Income}}{\text{Total Expenditure}}$$

3.8 STATISTICAL ANALYSIS

The data recorded were subjected to analysis of variance technique as applied to RBD (Cochran and Cox, 1965) and the significance was tested by F-test (Snedecor and Cochran, 1967). Separate analysis for each shade level and pooled analysis taking all shade levels together were carried out. Critical difference (CD) at 5% level of significance was provided wherever the effects were found to be significant.

Results

4. RESULTS

An investigation was conducted at the College of Agriculture, Vellayani to assess the performance of spiny coriander under different shade regimes from May 2006 to February 2007. The data collected were statistically analysed and the results of the experiment are presented in this chapter.

4.1 BIOMETRIC OBSERVATIONS

4.1.1 Growth Characters

4.1.1.1 Plant height

The data presented in Table 1 (a) – 1 (e) shows the effect of three levels of shade on plant height at four spacing (population densities).

At 1 MAP, under individual analysis, none of the four spacings (10 × 15cm, 15 × 15cm, 20 × 15cm and 30 × 15cm) showed significant difference for plant height at three levels of shade (25%, 50% and 75%). However, the treatment S_3T_2 (75% shade, 15 × 15cm) recorded the highest value for plant height (13.13cm) and S_1T_1 (25% shade, 10 × 15cm) recorded the lowest (9.99cm). Pooled analysis of data [Table 1(**a**)] showed the three levels of shade exhibiting significant difference for plant height. The highest value for plant height was observed under 75% shade (12.65cm) where as the lowest (10.26cm) was observed under 25% shade. Population density (T_1, T_2, T_3 and T_4) and the shade × population density interaction were found to have no significant difference for plant height values.

Analysis of the three individual experiments revealed that, at 2 MAP, the four population densities showed significant difference between each other only under the S_1 (25%) shade level. Here, T_4 (30 × 15cm) spacing was observed to be the most responsive (14.65cm). A similar trend was observed at 3 MAP, 4 MAP and 5 MAP upon individual analysis.

Overall analyses of data [Table 1(b)] showed significant variation among the three levels of shade for plant height at 2 MAP. The highest value for plant height was observed under 75% shade (16.26cm) whereas the lowest (13.7cm) was observed under 25% shade. Plant population density (T_1, T_2, T_3 and T_4) and the shade × population density interaction effect exhibited no such variation and their values for plant height were found to be on a par with each other.

Analyses combining the effect of shade levels [Table 1(c)] showed that, at 3 MAP, shade levels had significant variation for plant height among them whereas plant population density and the interaction effect of shade × population density had no statistically significant variation. The highest value for plant height was observed under S_3 (18.64cm) and the lowest was observed under S_1 (16.86cm).

Pooled analyses of data [Table 1(d)] showed the three levels of shade (25%, 50%, 75%) to have significant difference with respect to plant height 4 MAP. With an increase in shade, a corresponding increase in plant height was observed. Highest value for plant height was observed under S_3 (19.42cm) and the lowest under S_2 (17.79cm). The plant population density (T_1, T_2, T_3 and T_4) and the shade × population density interaction effect values for plant height were observed to be not significantly different from each other.

Overall analyses of data [Table 1(e)] showed that there was significant difference between the values for plant height under different shade intensities 5 MAP. There was no such significant variation for plant height values among plant population densities and shade × population density interaction effect. The highest value for plant height (20.27cm) was observed under S_3, whereas the lowest was observed under S_2 (18.58cm) with S_1 showing an intermediate value of 18.88cm (Fig.2).

Table 1(a). Effect of different levels of shade and spacing on height of plant (cm) in *Eryngium foetidum* at 1 MAP

	T_1	T_2	T_3	T_4	MEAN (SHADE)	CD
S_1	9.99	10.10	10.64	10.30	10.26	NS
S_2	12.02	11.65	11.21	10.95	11.46	NS
S_3	12.25	13.13	12.50	12.73	12.65	NS
MEAN (SPACING)	11.42	11.63	11.45	11.33		

POOLED ANALYSIS

SHADE	0.918
SPACING	NS
SHADE × SPACING	NS

NS – Non-Significant

Table 1(b). **Effect of different levels of shade and spacing on height of plant (cm) in *Eryngium foetidum* at 2 MAP**

	T_1	T_2	T_3	T_4	MEAN (SHADE)	CD
S_1	12.51	13.28	14.37	14.65	13.7	1.52
S_2	15.28	14.76	14.41	13.80	14.55	NS
S_3	15.58	16.62	16.80	16.04	16.26	NS
MEAN (SPACING)	14.45	14.89	15.19	14.83		
POOLED ANALYSIS						
SHADE	1.25					
SPACING	NS					
SHADE × SPACING	NS					

NS – Non-Significant

Table 1(c). Effect of different levels of shade and spacing on height of plant (cm) in *Eryngium foetidum* at 3 MAP

	T_1	T_2	T_3	T_4	MEAN (SHADE)	CD
S_1	14.60	16.03	17.82	19.00	16.86	2.537
S_2	17.77	17.21	16.84	16.21	17.01	NS
S_3	18.19	19.04	18.74	18.56	18.64	NS
MEAN (SPACING)	16.85	17.43	17.80	17.92		
POOLED ANALYSIS						
SHADE	1.355					
SPACING	NS					
SHADE × SPACING	NS					

NS – Non-Significant

Table 1(d). Effect of different levels of shade and spacing on height of plant (cm) in *Eryngium foetidum* at 4 MAP

	T_1	T_2	T_3	T_4	MEAN (SHADE)	CD
S_1	15.86	17.30	18.80	20.10	18.01	2.514
S_2	18.44	17.96	17.76	17.02	17.79	NS
S_3	18.98	19.80	19.46	19.44	19.42	NS
MEAN (SPACING)	17.76	18.35	18.67	18.85		

POOLED ANALYSIS

SHADE	1.355
SPACING	NS
SHADE × SPACING	NS

NS – Non-Significant

Table 1(e). Effect of different levels of shade and spacing on height of plant (cm) in *Eryngium foetidum* at 5 MAP

	T_1	T_2	T_3	T_4	MEAN (SHADE)	CD
S_1	16.70	18.24	19.26	21.34	18.88	2.445
S_2	19.12	18.68	18.48	18.04	18.58	NS
S_3	19.46	20.72	20.14	20.78	20.27	NS
MEAN (SPACING)	18.42	19.21	19.29	20.05		
POOLED ANALYSIS						
SHADE	1.344					
SPACING	NS					
SHADE × SPACING	NS					

NS – Non-Significant

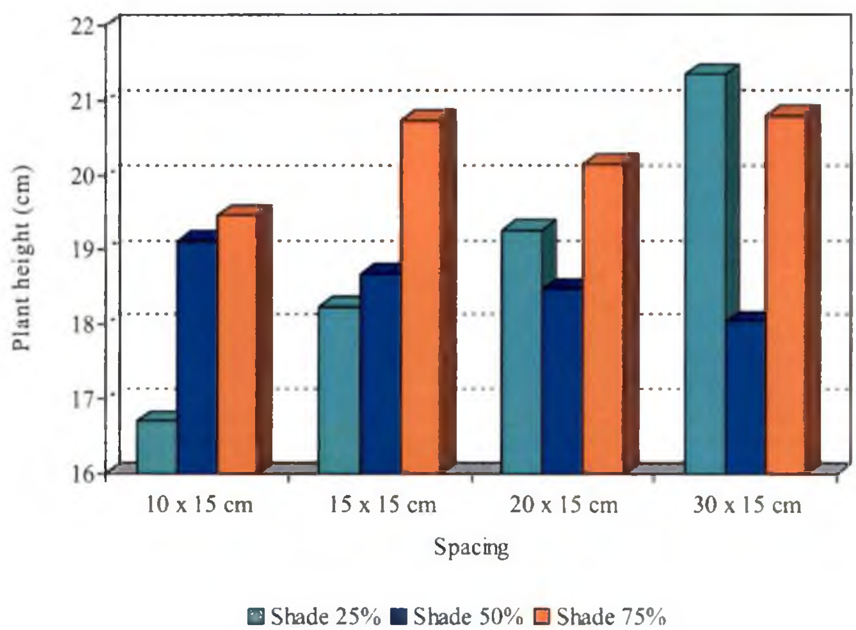

Fig. 2. Effect of different levels of shade and spacing on height of plant (cm) in *Eryngium foetidum* at 5 MAP

4.1.1.2 **Girth at collar region**

Table 2 (a) – 2 (e) shows the effect of shade on stem girth at four plant population densities.

At 1 MAP, individual analysis showed significant difference among the four spacings (10 × 15cm, 15 × 15cm, 20 × 15cm and 30 × 15cm) under S_1 (25%) and S_3 (75%) shade levels. T_2 (15 × 15cm) and T_3 (20 × 15cm) spacing were found to be the most responsive under S_1 and S_3, with stem girth values 1.44cm and 0.85cm, respectively. Upon pooled analysis of data, shade and the interaction effect of shade × population density were revealed to have significantly different values for stem girth at 1 MAP, whereas there was no such significant variation among stem girth values of the four plant population densities. The highest stem girth value of 1.37cm was observed under S_1 (25%) shade level, which was on a par with S_2 (1.33cm) and significantly higher than S_3 (0.85cm). Under T_1 (10 × 15cm) spacing, S_2 (1.24cm) gave the highest stem girth, whereas S_3 (75%) recorded the lowest value of 0.76cm. This trend was seen repeated for T_2, T_3 and T_4 spacing.

At 2 MAP [(Table 2(b)], four population densities showed significant variation for stem girth only under S_3 (75%) shade level, according to individual analysis performed. Here, the spacing T_3 (20 × 15cm) showed the highest value (1.42cm), whereas T_1 (10 × 15cm) recorded the lowest (1.16cm). Overall analysis showed that shade and the interaction effect of shade × population density recorded significant variation with respect to stem girth values. With increase in shade level, stem girth was seen to decrease. S_1 (25%) showed the highest value (2.15cm), whereas S_3 (75%) registered the lowest (1.30cm). Under T_1 (10 × 15cm) spacing, S_2 (50%) shade level recorded the maximum stem girth value of 1.72cm, which was on a par with S_1 (1.67cm), and significantly higher than S_3 (1.16cm). At T_2 (15 × 15cm) spacing, S_1 (25%) shade level registered the maximum stem girth value of 2.37cm, whereas S_3 (75%) shade level recorded the minimum of 1.30cm. Similar trend was observed for T_3 and T_4 spacing.

Table 2(a). Effect of different levels of shade and spacing on stem girth (cm) in *Eryngium foetidum* at 1 MAP

	T_1	T_2	T_3	T_4	MEAN (SHADE)	CD
S_1	1.22	1.44	1.42	1.40	1.37	0.048
S_2	1.24	1.36	1.36	1.36	1.33	NS
S_3	0.76	0.85	0.91	0.90	0.85	0.076
MEAN (SPACING)	1.07	1.21	1.23	1.22		

POOLED ANALYSIS

SHADE	0.074
SPACING	NS
SHADE × SPACING	0.288

NS – Non-Significant

Table 2(b). Effect of different levels of shade and spacing on stem girth (cm) in *Eryngium foetidum* at 2 MAP

	T_1	T_2	T_3	T_4	MEAN (SHADE)	CD
S_1	1.67	2:37	2.30	2.26	2.15	NS
S_2	1.72	2.21	2.19	2.20	2.08	NS
S_3	1.16	1.30	1.42	1.33	1.30	0.088
MEAN (SPACING)	1.51	1.96	1.97	1.93		

POOLED ANALYSIS

SHADE	0.149
SPACING	NS
SHADE × SPACING	0.333

NS – Non-Significant

Table 2(c). **Effect of different levels of shade and spacing on stem girth (cm) in *Eryngium foetidum* at 3 MAP**

	T_1	T_2	T_3	T_4	MEAN (SHADE)	CD
S_1	2.27	3.20	3.15	3.06	2.92	0.109
S_2	2.36	2.93	2.93	2.84	2.76	NS
S_3	1.56	1.65	1.87	1.74	1.70	0.114
MEAN (SPACING)	2.06	2.59	2.65	2.54		

POOLED ANALYSIS	
SHADE	0.217
SPACING	0.485
SHADE × SPACING	0.839

NS – Non-Significant

Table 2(d). Effect of different levels of shade and spacing on stem girth (cm) in *Eryngium foetidum* at 4 MAP

	T_1	T_2	T_3	T_4	MEAN (SHADE)	CD
S_1	3.17	3.82	4.11	4.23	3.83	0.170
S_2	2.95	3.27	3.58	3.65	3.36	NS
S_3	2.75	3.11	3.26	3.33	3.11	NS
MEAN (SPACING)	2.06	3.40	3.65	3.73		

POOLED ANALYSIS	
SHADE	0.445
SPACING	NS
SHADE × SPACING	NS

NS – Non-Significant

Table 2(e). Effect of different levels of shade and spacing on stem girth (cm) in *Eryngium foetidum* at 5 MAP

	T_1	T_2	T_3	T_4	MEAN (SHADE)	CD
S_1	3.66	3.83	4.26	4.42	4.04	0.384
S_2	4.81	4.81	4.70	4.81	4.78	NS
S_3	4.88	4.96	5.03	5.31	5.05	NS
MEAN (SPACING)	4.45	4.53	4.66	4.84		

POOLED ANALYSIS

SHADE	0.377
SPACING	NS
SHADE × SPACING	NS

NS – Non-Significant

At 3 MAP [(Table 2(c)], analysis of the three separate experiments revealed that the four plant population densities (10 × 15cm, 15 × 15cm, 20 × 15cm and 30 × 15cm) registered significantly different values for stem girth under S_1 (25%) and S_3 (75%) shade levels. Here, T_2 (15 × 15cm) and T_3 (20 × 15cm) gave the highest values 3.20cm and 1.87cm, respectively and T_1 (10 × 15cm) spacing recorded the lowest under both shade levels (2.27cm and 1.56cm). Combined analysis revealed shade, population density and the interaction effect of shade × population density as registering significant difference for stem girth values. With increase in shade intensity, stem girth was found to be decreasing. S_1 (25%) shade level showed the best response (2.92cm), whereas S_3 (75%) recorded the worst (1.70cm). T_3 (20 × 15cm) spacing was observed to record the highest value of 2.65cm, whereas T_1 (10 × 15cm) recorded the lowest of 2.06cm. Under T_1 (10 × 15cm) spacing, S_2 (50%) shade recorded the highest stem girth value of 2.36cm, whereas S_3 (75%) recorded the lowest (1.56cm). At T_2 (15 × 15cm) spacing, S_1 (25%) shade level registered the maximum stem girth value of 3.20cm, whereas S_3 (75%) recorded the minimum (1.65cm). This trend was repeated for T_3 and T_4 spacing.

At 4 MAP [(Table 2(d)], according to the analysis of data pertaining to separate experiments conducted over different shade levels, significant variation among the four plant population densities for stem girth values was observed only under S_1 (25%) shade level. Here, T_4 (30 × 15cm) spacing recorded the highest value of 4.23cm, whereas T_1 (10 × 15cm) recorded the lowest (3.17cm). Analysis combining the effects of shade levels revealed significant difference among the three shade levels for stem girth, whereas plant population density and the interaction effect of shade × population density recorded no such phenomena. S_1 (25%) shade level registered the highest value for stem girth (3.83cm) and the values were observed to decrease with increase in shade intensity.

At 5 MAP [(Table 2(e)], individual analysis of data indicated significant difference among stem girth values only for S_1 (25%) shade level, where T_4 (30 × 15cm) recorded the highest value of 4.42cm. Pooled analysis showed that an increase in shade (25%, 50% and 75%) yielded a corresponding increase in stem girth. Highest stem girth value was seen under S_3 (5.05cm) whereas the lowest was under S_1 (4.04cm). Plant population density / spacing (T_1, T_2, T_3 and T_4) and shade × population density interaction effect were found to be non-significant.

4.1.1.3 Spread of the Plant

The effect of three levels of shade at four population densities is shown in Table 3 (a) – 3 (e).

Individual analysis of data revealed the plant spread values of the four population densities (10 × 15cm, 15 × 15cm, 20 × 15cm and 30 × 15cm) to be on a par under the three levels of shade (25%, 50% and 75%) throughout the period of study. However, treatments S_1T_4 (25% shade, 30 × 15cm), S_2T_4 (50% shade, 30 × 15cm) and S_3T_2 (75% shade, 15 × 15cm) consistently recorded the maximum values for spread of the plant under S_1 (25%), S_2 (50%) and S_3 (75%) shade levels respectively, throughout the length of the study period.

Combined analyses of data [Table 3(a)] showed the three levels of shade to have significant difference among them for spread of the plant at 1 MAP. With an increase in shade intensity (25%, 50%, 75%), a corresponding increase in spread of the plant was observed. Highest value for spread of plant (302.61 cm^2) was observed under S_3 (75%shade) and the lowest value (218.16cm^2) under S_1 (25% shade). Spacings / population densities (T_1, T_2, T_3 and T_4) and the shade × population density interaction effect were revealed to have no significant difference for plant spread.

Overall analysis of data furnished in the Table 3(b) indicated that there was a significant difference for plant spread values among the three levels of shade at 2 MAP. A corresponding increase in plant spread was observed with increase in shade. Maximum value for plant spread (354.40cm^2) was observed under S_3 (75% shade) and minimum (262.86cm^2) was seen under S_1 (25% shade). Spacing / population density (T_1, T_2, T_3 and T_4) and the interaction effect of shade × population density exhibited no significant difference for spread of plant at 2 MAP.

Analyses combining the three shade levels [Table 3(c)] revealed shade as showing significant difference for spread of the plant at 3 MAP. With increase in shade intensity (25%, 50%, 75%), a corresponding increase in plant spread was observed. The highest value for plant spread was observed under S_3 (388.82cm^2) and the lowest was recorded under S_1 (289.67cm^2). Population density / spacing (T_1, T_2, T_3 and T_4) and the shade × population density interaction effect were found to be non-significant with respect to spread of the plant at 3 MAP.

Pooled analysis of data [Table 3(d)] showed significant variation among plant spread values under the three levels of shade (25%, 50% and 75%) at 4 MAP. Corresponding increase in plant spread was observed with increase in shade intensity. Highest value for plant spread was under S_3 (434.21cm^2) and the lowest was recorded under S_1 (319.70cm^2). There was no significant difference between the values of plant spread at 4 MAP for population density / spacing (T_1, T_2, T_3 and T_4) and the interaction effect of shade × population density.

Overall analyses of data [Table 3(e)] recorded significant variation among plant spread values for the three levels of shade at 5 MAP. With increase in shade, an increase in spread of the plant was observed. Highest value for spread of the plant at 5 MAP (484.21cm^2) was seen under S_3 (75% shade) (Fig 3.) and lowest value (384.64cm^2) was recorded under S_1 (25% shade).

Table 3(a). Effect of different levels of shade and spacing on spread of the plant (cm^2) in *Eryngium foetidum* at 1 MAP

	T_1	T_2	T_3	T_4	MEAN (SHADE)	CD
S_1	174.48	191.58	242.00	264.58	218.16	NS
S_2	255.20	245.14	236.12	266.90	250.84	NS
S_3	274.50	325.38	308.84	301.74	302.61	NS
MEAN (SPACING)	234.70	254.03	262.30	277.70		

POOLED ANALYSIS

SHADE	38.75
SPACING	NS
SHADE × SPACING	NS

NS – Non-Significant

Table 3(b). Effect of different levels of shade and spacing on spread of the plant (cm^2) in *Eryngium foetidum* at 2 MAP

	T_1	T_2	T_3	T_4	MEAN (SHADE)	CD
S_1	212.92	233.98	289.10	315.46	262.86	NS
S_2	309.60	300.98	286.40	321.18	304.50	NS
S_3	324.04	377.72	359.38	356.46	354.40	NS
MEAN (SPACING)	282.18	304.22	311.64	331.03		

POOLED ANALYSIS

SHADE	44.22
SPACING	NS
SHADE × SPACING	NS

NS – Non-Significant

Table 3(c). Effect of different levels of shade and spacing on spread of the plant (cm^2) in *Eryngium foetidum* at 3 MAP

	T_1	T_2	T_3	T_4	MEAN (SHADE)	CD
S_1	235.36	260.76	318.14	344.42	289.67	NS
S_2	339.40	331.60	314.24	349.32	333.65	NS
S_3	358.68	410.92	395.02	390.66	388.82	NS
MEAN (SPACING)	311.16	334.42	342.46	361.46		

POOLED ANALYSIS

SHADE	46.34
SPACING	NS
SHADE × SPACING	NS

NS – Non-Significant

Table 3(d). Effect of different levels of shade and spacing on spread of the plant (cm^2) in *Eryngium foetidum* at 4 MAP

	T_1	T_2	T_3	T_4	MEAN (SHADE)	CD
S_1	263.42	287.90	351.52	375.90	319.70	NS
S_2	375.50	368.18	344.90	388.34	369.23	NS
S_3	406.06	456.04	439.26	435.48	434.21	NS
MEAN (SPACING)	348.32	370.70	378.56	399.90		

POOLED ANALYSIS

SHADE	49.37
SPACING	NS
SHADE × SPACING	NS

NS – Non-Significant

Table 3(e). **Effect of different levels of shade and spacing on spread of the plant (cm^2) in *Eryngium foetidum* at 5 MAP**

	T_1	T_2	T_3	T_4	MEAN (SHADE)	CD
S_1	342.34	344.58	415.94	435.72	384.64	NS
S_2	423.86	419.50	394.64	430.56	417.14	NS
S_3	456.74	510.00	482.92	487.18	484.21	NS
MEAN (SPACING)	407.64	424.69	431.16	451.15		
POOLED ANALYSIS						
SHADE	51.69					
SPACING	NS					
SHADE × SPACING	NS					

NS – Non-Significant

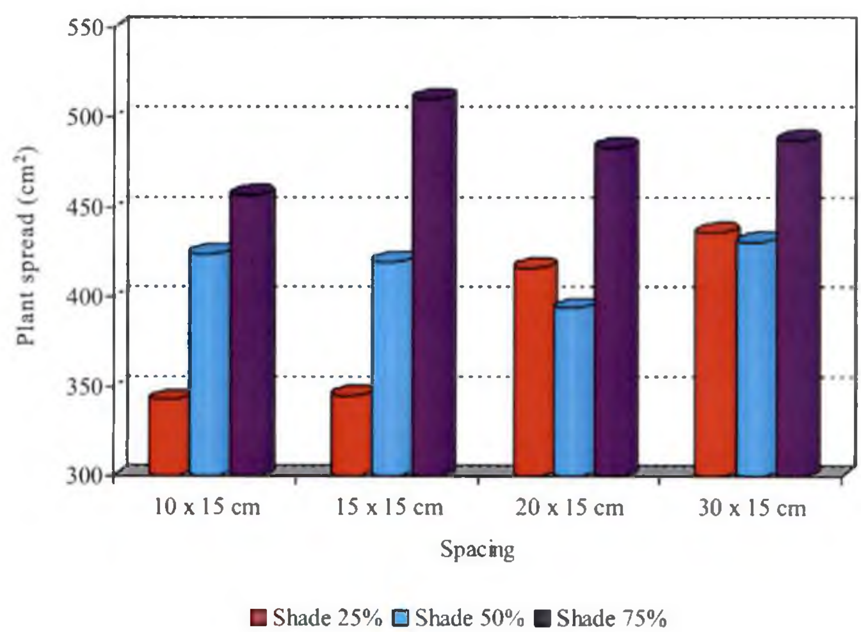

Fig. 3. Effect of different levels of shade and spacing on spread of the plant (cm) in *Eryngium foetidum* at 5 MAP

4.1.1.4 Number of Leaves

The data presented in Table 4 (a) – 4 (e) shows the effect of three levels of shade at four population densities on the number of leaves per plant.

Individual analysis of data showed no significant variation among the four plant population densities for number of leaves of the plants under S_1, S_2 and S_3 levels of shade for the first three months of study. But, at 4 MAP, plants grown under S_1 (25%) shade level registered significant variation for the number of leaves per plant, with T_4 (30 × 15cm) spacing recording the maximum number of plant leaves (12.90). At 5 MAP, plant population densities exhibited significant difference for the number of leaves per plant under all three levels of shade. Here, treatments S_1T_4 (25% shade, 30 × 15cm), S_2T_4 (50% shade, 30 × 15cm) and S_3T_3 (75% shade, 20 × 15cm) recorded the highest number of leaves per plant.

The analysis combining the shade levels [Table 4(a), Fig. 4] revealed that, at 1 MAP, significant difference existed among the values for the number of leaves per plant of the three shade levels. An increase in the number of leaves was observed with an increase in shade. Highest value for number of leaves (7.19) was seen under S_3 (75% shade) and the lowest number of leaves (5.67) was observed under S_1 (25% shade). Plant population density / spacing (T_1, T_2, T_3 and T_4) and the interaction effect of shade × population density recorded no significant variation among the number of leaves per plant values at 1 MAP.

Combined analyses of data [Table 4(b)] showed that there existed a significant difference among the three levels of shade with regard to the number of leaves per plant at 2 MAP. With an increase in shade level (25%, 50% and 75%), a corresponding increase in the number of leaves was recorded. (Fig. 5) Highest number of leaves (10.1) was found under S_3 (75% shade) where as the lowest number of 8.17 was recorded under S_1 (25% shade). Both population density / spacing and the interaction effect of shade × population density were found to be non-significant with respect to the number of leaves per plant.

Overall analysis of data furnished in Table 4(c) indicated three levels of shade exhibiting significant difference for the number of leaves at 3 MAP. Increase in shade intensity (25%, 50% and 75%) was observed to increase the number of leaves at 3 MAP (Fig. 6). Maximum number of leaves (13.32) was seen under S_3 (75% shade) whereas minimum (10.26) was observed under S_1 (25% shade). Plant population density / spacing (T_1, T_2, T_3 and T_4) and the shade × population density interaction effect were observed to be non-significant at 3 MAP.

Table 4(d) depicts the pooled analysis of data indicating the three shade levels to have significantly different number of leaves per plant at 4 MAP. An increase in shade intensity led to a corresponding increase in the number of leaves. Maximum number of leaves (14.99) was seen under S_3 (75% shade) and the minimum (12.13) was recorded under S_1 (25% shade) (Fig. 7). The effect was observed to be the same under the four plant population densities / spacings, with the maximum number of leaves (14.36) under T_3 (20 × 15cm) and the minimum (12.40) under T_1 (10 × 15cm) spacing. The shade × population density interaction effect did not exhibit any significant variation with regard to the number of leaves per plant at 4 MAP.

Combined analyses of data [Table 4(e)] indicated significant variation among the number of leaves per plant under the three levels of shade at 5 MAP. The effect was observed to be the same for plant population density at 5 MAP. Increase in the shade level was found to lead to a corresponding increase in the number of leaves. Maximum number of leaves (16.52) was observed under 75% shade (S_3), whereas the minimum (13.55) was seen under 25% shade (S_1). With increase in spacing, a corresponding increase in the number of leaves was observed. Maximum number of leaves (16.83) was observed under T_4 (30 × 15cm) spacing and the minimum (13.48) under T_1 (10 × 15cm) spacing (Fig. 8). The interaction effect of shade × population density was found to be non-significant at 5MAP.

Table 4(a). Effect of different levels of shade and spacing on number of leaves in *Eryngium foetidum* at 1 MAP

	T_1	T_2	T_3	T_4	MEAN (SHADE)	CD
S_1	4.98	5.62	5.76	6.32	5.67	NS
S_2	5.86	7.06	6.38	6.50	6.45	NS
S_3	6.68	6.80	7.76	7.54	7.19	NS
MEAN (SPACING)	5.84	6.49	6.63	6.78		
POOLED ANALYSIS						
SHADE	1.12					
SPACING	NS					
SHADE × SPACING	NS					

NS – Non-Significant

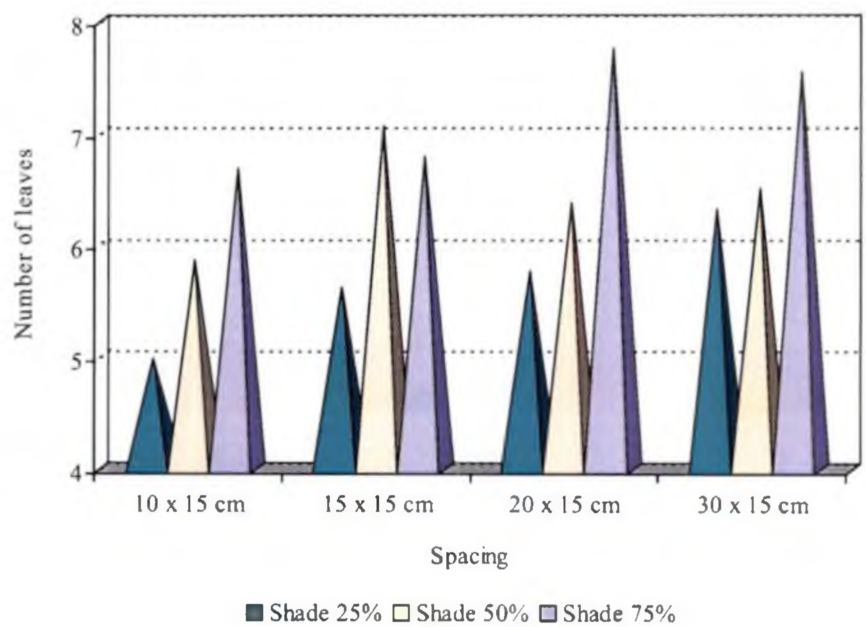

Fig. 4. Effect of different levels of shade and spacing on number of leaves in *Eryngium foetidum* at 1 MAP

Table 4(b). Effect of different levels of shade and spacing on number of leaves in *Eryngium foetidum* at 2 MAP

	T_1	T_2	T_3	T_4	MEAN (SHADE)	CD
S_1	7.34	7.96	8.44	8.94	8.17	NS
S_2	8.94	10.02	9.42	9.32	9.42	NS
S_3	9.58	9.58	11.14	10.10	10.10	NS
MEAN (SPACING)	8.60	9.18	9.60	9.45		

POOLED ANALYSIS

SHADE	1.40
SPACING	NS
SHADE × SPACING	NS

NS – Non-Significant

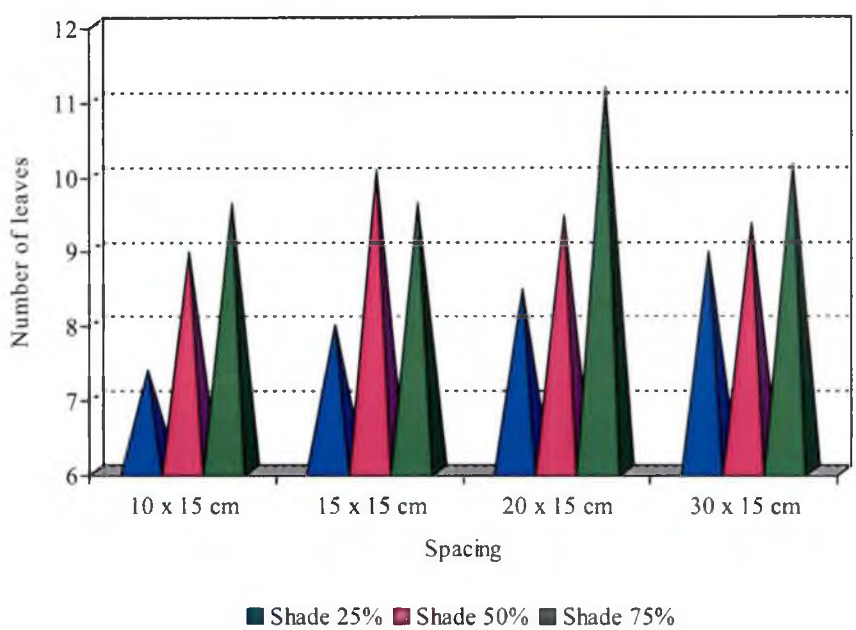

Fig. 5. Effect of different levels of shade and spacing on number of leaves in *Eryngium foetidum* at 2 MAP

Table 4(c). Effect of different levels of shade and spacing on number of leaves in *Eryngium foetidum* at 3 MAP

	T_1	T_2	T_3	T_4	MEAN (SHADE)	CD
S_1	9.20	10.04	10.82	11.00	10.26	NS
S_2	11.32	12.60	11.82	11.88	11.90	NS
S_3	12.60	12.34	14.52	13.84	13.32	NS
MEAN (SPACING)	11.04	11.66	12.38	12.24		
POOLED ANALYSIS						
SHADE	1.631					
SPACING	NS					
SHADE × SPACING	NS					

NS – Non-Significant

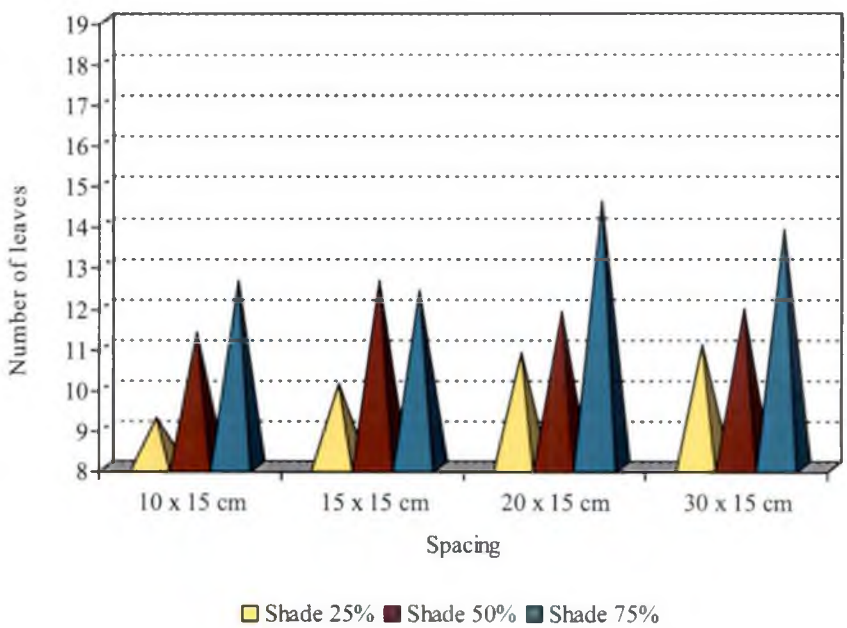

Fig. 6. Effect of different levels of shade and spacing on number of leaves in *Eryngium foetidum* at 3 MAP

Table 4(d). **Effect of different levels of shade and spacing on number of leaves in *Eryngium foetidum* at 4 MAP**

	T_1	T_2	T_3	T_4	MEAN (SHADE)	CD
S_1	11.08	11.90	12.60	12.90	12.13	1.321
S_2	12.60	14.38	14.06	14.44	13.87	NS
S_3	13.54	14.66	16.38	15.40	14.99	NS
MEAN (SPACING)	12.40	13.64	14.36	14.24		

POOLED ANALYSIS

SHADE	1.155
SPACING	1.333
SHADE × SPACING	NS

NS – Non-Significant

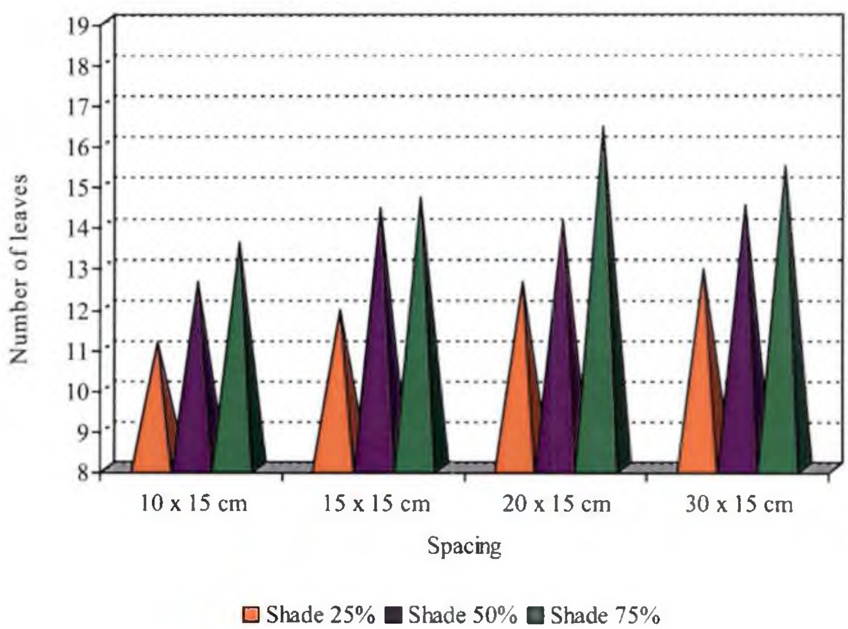

Fig. 7. Effect of different levels of shade and spacing on number of leaves in *Eryngium foetidum* at 4 MAP

Table 4(e). Effect of different levels of shade and spacing on number of leaves in *Eryngium foetidum* at 5 MAP

	T_1	T_2	T_3	T_4	MEAN (SHADE)	CD
S_1	11.90	12.72	14.06	15.52	13.55	1.49
S_2	13.90	15.40	15.22	16.86	15.34	1.72
S_3	14.64	15.20	18.14	18.12	16.52	2.09
MEAN (SPACING)	13.48	14.44	15.80	16.83		
POOLED ANALYSIS						
SHADE	0.97					
SPACING	1.12					
SHADE × SPACING	NS					

NS – Non-Significant

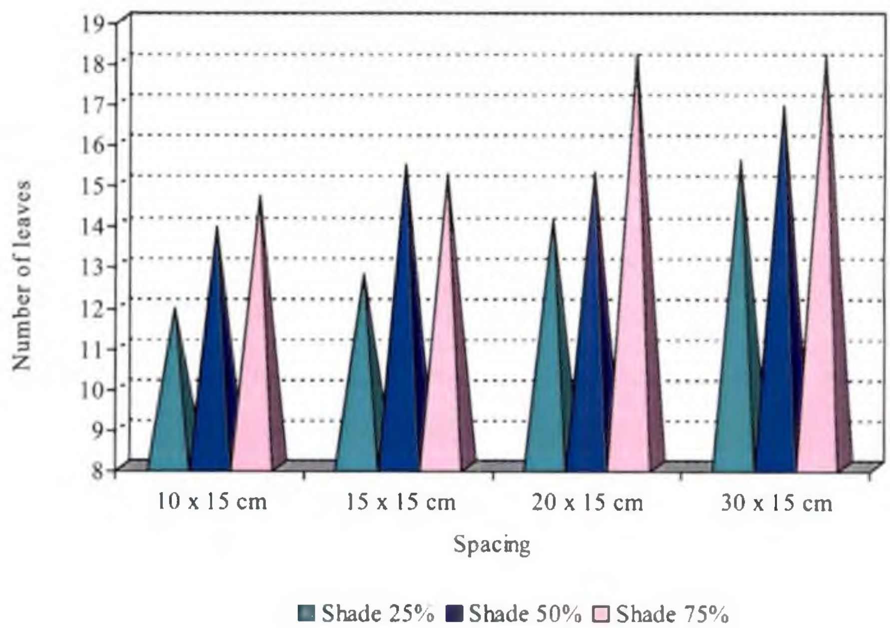

Fig. 8. Effect of different levels of shade and spacing on number of leaves in *Eryngium foetidum* at 5 MAP

4.1.1.5 Number of Plants with Flower Shoots

The mean number of plants with flower shoots presented in Table 5 (a) – 5 (e) show the effect of three levels of shade at four population densities on flowering percentage of plants.

Analysis of the three experiments showed that, in the first month after planting, there was significant variation among flowering percentage values between the four population densities under the three levels of shade. The treatments S_1T_1 (25% shade, 10 × 15cm), S_2T_2 (50% shade, 15 × 15cm) and S_3T_3 (75% shade, 20 × 15cm) recorded the maximum flowering percentages of 23.18%, 23.64% and 30.32%, respectively. Overall analysis of data [Table 5(a)] indicated that plant population density exhibited significant variation in the number of plants with flower shoots. Maximum number of plants with flower shoots (22.82%) was recorded under T_2 (15 × 15 cm) and the minimum (12.84%) under T_4 (30 × 15cm). Shade (S_1, S_2 and S_3) and the interaction effect of shade × population density were found to be non-significant with respect to flowering percentage.

The four plant population densities were found to be significantly different with respect to flowering percentage values only under S_1 (25%) level of shade at 2 MAP and 3 MAP upon individual analysis of data. T_2 (15 × 15cm) spacing recorded the highest flowering percentage, 45.16% and 63.64% at 2 MAP and 3 MAP, respectively. Combined analysis of data shown in Table 5(b) indicated statistically significant variation for flowering percentage values for the four plant population densities (T_1, T_2, T_3 and T_4). Highest percentage of flowering (47.4%) was observed under T_1 (10 × 15cm) spacing and the lowest (26.2%) under T_4 (30 × 15cm). Shade and the interaction effect of shade × population density were found to be non-significant with respect to the number of plants with flower shoots at 2 MAP. Overall analysis of data furnished in Table 5(c) shows no significant difference under varying intensities of shade, plant population density and shade × population density with respect to the number of plants with flower shoots at 3 MAP.

Table 5(a). Effect of different levels of shade and spacing on number of plants with flower shoots (%) in *Eryngium foetidum* at 1 MAP

	T_1	T_2	T_3	T_4	MEAN (SHADE)	CD
S_1	23.18	24.34	15.40	11.56	18.62	8.81
S_2	23.50	23.64	14.72	14.22	19.02	7.56
S_3	20.28	20.48	30.32	12.74	20.95	11.73
MEAN (SPACING)	22.32	22.82	20.14	12.84		

POOLED ANALYSIS	
SHADE	NS
SPACING	6.62
SHADE × SPACING	NS

NS – Non-Significant

Table 5(b). Effect of different levels of shade and spacing on number of plants with flower shoots (%) in *Eryngium foetidum* at 2 MAP

	T_1	T_2	T_3	T_4	MEAN (SHADE)	CD
S_1	41.88	45.16	29.90	21.48	34.60	12.63
S_2	52.72	46.14	34.90	32.88	41.66	NS
S_3	47.62	41.30	54.88	24.24	42.01	NS
MEAN (SPACING)	47.40	44.20	39.89	26.20		

POOLED ANALYSIS

SHADE	NS
SPACING	12.64
SHADE × SPACING	NS

NS – Non-Significant

Table 5(c). Effect of different levels of shade and spacing on number of plants with flower shoots (%) in *Eryngium foetidum* at 3 MAP

	T_1	T_2	T_3	T_4	MEAN (SHADE)	CD
S_1	56.46	63.64	49.90	42.90	53.26	12.98
S_2	71.00	66.88	55.72	55.88	62.37	NS
S_3	61.22	55.90	67.16	38.74	55.77	NS
MEAN (SPACING)	62.89	62.16	57.62	45.86		
POOLED ANALYSIS						
SHADE	NS					
SPACING	NS					
SHADE × SPACING	NS					

NS – Non-Significant

Table 5(d). Effect of different levels of shade and spacing on number of plants with flower shoots (%) in *Eryngium foetidum* at 4 MAP

	T_1	T_2	T_3	T_4	MEAN (SHADE)	CD
S_1	74.98	83.80	73.06	65.48	74.33	NS
S_2	90.00	84.98	75.82	77.24	82.01	NS
S_3	64.66	66.16	80.00	52.24	65.76	NS
MEAN (SPACING)	76.54	78.31	76.29	64.98		
POOLED ANALYSIS						
SHADE	NS					
SPACING	NS					
SHADE × SPACING	NS					

NS – Non-Significant

Table 5(e). Effect of different levels of shade and spacing on number of plants with flower shoots (%) in *Eryngium foetidum* at 5 MAP

	T_1	T_2	T_3	T_4	MEAN (SHADE)	CD
S_1	96.16	100.00	94.00	80.82	92.74	13.06
S_2	100.00	100.00	100.00	91.82	97.95	NS
S_3	69.56	70.48	82.00	59.24	70.32	NS
MEAN (SPACING)	88.57	90.16	92.00	77.29		

POOLED ANALYSIS

SHADE	10.77
SPACING	NS
SHADE × SPACING	NS

NS – Non-Significant

At 4 MAP, analysis of individual experiments showed no significant variation among the four plant population densities under the three shade levels. Analysis combining the shade levels given in Table 5(d) indicated shade, plant population density and the interaction effect of shade × population density to be non-significant with respect to the number of plants with flower shoots at 4 MAP.

Data for flowering percentage at 5 MAP upon individual analysis revealed that the different spacings recorded significant variation only under 25% shade level (S_1). Here, T_2 (15 × 15cm) spacing was observed to be the most responsive (100%). Combined analysis of data shown in Table 5 (e) revealed significant variation among the three levels of shade with respect to the number of plants with flower shoots at 5 MAP. Highest percentage of plants with flower shoots (97.95%) was observed under S_2 (50% shade) and the lowest (70.32%) under S_3 (75% shade). Plant population density and the interaction effect of shade × population density were non-significant.

4.1.1.6 Number of Roots

Table 6 depicts the effect of three levels of shade at four population densities on the number of roots per plant at the time of final harvest.

Combined analysis of data (Table 6) indicated that shade showed significant variation for the number of roots at the time of final harvest. With increasing levels of shade (S_1, S_2 and S_3), number of roots was observed to increase. Maximum number of roots (10.35) was seen under S_3 (75% shade) and the minimum (5.57) under S_1 (25% shade). Plant population density and the interaction effect of shade × population density were found to be non-significant. Plant population densities were without significant variation with regard to the number of roots at final harvest under three levels of shade upon analysis of data over different shade levels. Treatments S_1T_1 (25% shade, 10 × 15cm), S_2T_2 (50% shade, 15 × 15cm) and S_3T_4 (75% shade, 30 × 15cm) were seen to be with the maximum number of roots at the time of final harvest (5.68, 9.10 and 11.3).

Table 6. **Effect of different levels of shade and spacing on number of roots in *Eryngium foetidum* at the time of final harvest**

	T_1	T_2	T_3	T_4	MEAN (SHADE)	CD
S_1	5.68	5.62	5.48	5.52	5.57	NS
S_2	7.34	9.10	8.24	7.96	8.16	NS
S_3	9.06	9.80	11.24	11.30	10.35	NS
MEAN (SPACING)	7.36	8.17	8.32	8.36		

POOLED ANALYSIS

SHADE	1.35
SPACING	NS
SHADE × SPACING	NS

NS – Non-Significant

4.2 PHYSIOLOGICAL CHARACTERS

4.2.1 Photosynthetically Active Radiation (PAR)

Analyses of the individual experiments revealed that, at 6 MAP, among the four spacings (T_1, T_2, T_3 and T_4), no significant variation in the Photosynthetically Active Radiation (PAR) values was recorded under the three levels of shade (S_1, S_2 and S_3).

Overall analysis of data (Table 7) revealed significant difference between shade levels for PAR. S_1 (25%) shade level was found to record the maximum PAR value (972.39 μ mol m^{-2} s^{-1}) and S_3 (75%), the minimum (163 μ mol m^{-2} s^{-1}). Plant population density and the interaction effect of shade × population density were found to be not significant with regard to PAR.

Table 7. **Effect of different levels of shade and spacing on photosynthetically active radiation (μ mol m^{-2} s^{-1}) in *Eryngium foetidum* at 6 MAP**

	T_1	T_2	T_3	T_4	MEAN (SHADE)	CD
S_1	950.46	948.00	1034.50	956.60	972.39	NS
S_2	515.66	485.83	517.50	498.66	504.41	NS
S_3	124.33	174.50	128.83	224.83	163.12	NS
MEAN (SPACING)	530.16	536.11	560.28	560.03		

POOLED ANALYSIS

SHADE	67.16
SPACING	NS
SHADE × SPACING	NS

NS – Non-Significant

4.2.2 Stomatal Conductance

Table 8 (a) – 8 (c) shows the effect of three levels of shade at four plant population densities on the stomatal conductance of plants. The effect was found to be significant only at 6 MAP upon pooled analysis of data.

According to the individual analyses of data, the four plant population densities were found to have no statistically significant difference for stomatal conductance values under shade at three levels (S_1, S_2 and S_3) throughout the study period. However, S_1T_4 (25% shade, 30 × 15cm), S_2T_2 (50% shade, 15 × 15cm) and S_3T_4 (75% shade, 30 × 15cm) were observed to exhibit the maximum values for stomatal conductance, consistently over the entire period. Based on the combined analysis data furnished in Table 8(c), stomatal conductance values for the three levels of shade showed significant variation at 6 MAP, with S_1 (25%) shade level recording the maximum value (8.59 μ mol m^{-2} s^{-1}) and S_2 (50%), the minimum (5.78 μ mol m^{-2} s^{-1}). There was no significant variation among the values of stomatal conductance at 6 MAP when population density and the interaction effect of shade × population density were considered.

Table 8(a). Effect of different levels of shade and spacing on stomatal conductance (μ mol m^{-2} s^{-1}) in *Eryngium foetidum* at 2 MAP

	T_1	T_2	T_3	T_4	MEAN (SHADE)	CD
S_1	7.97	9.62	8.07	10.60	9.06	NS
S_2	11.34	13.18	11.26	10.45	11.56	NS
S_3	10.66	9.39	9.74	12.59	10.59	NS
MEAN (SPACING)	9.99	10.73	9.69	11.21		
POOLED ANALYSIS						
SHADE	NS					
SPACING	NS					
SHADE × SPACING	NS					

NS – Non-Significant

Table 8(b). Effect of different levels of shade and spacing on stomatal conductance (μ mol m^{-2} s^{-1}) in *Eryngium foetidum* at 4 MAP

	T_1	T_2	T_3	T_4	MEAN (SHADE)	CD
S_1	7.66	9.44	7.70	10.33	8.78	NS
S_2	8.48	9.26	8.37	7.46	8.39	NS
S_3	9.09	8.20	8.64	10.94	9.22	NS
MEAN (SPACING)	8.41	8.96	8.24	9.58		
POOLED ANALYSIS						
SHADE	NS					
SPACING	NS					
SHADE × SPACING	NS					

NS – Non-Significant

Table 8(c). Effect of different levels of shade and spacing on stomatal conductance (μ mol m^{-2} s^{-1}) in *Eryngium foetidum* at 6 MAP

	T_1	T_2	T_3	T_4	MEAN (SHADE)	CD
S_1	7.45	9.31	7.44	10.15	8.59	NS
S_2	5.98	6.30	5.80	5.04	5.78	NS
S_3	8.18	7.40	8.24	9.98	8.45	NS
MEAN (SPACING)	7.20	7.67	7.16	8.39		
POOLED ANALYSIS						
SHADE	2.20					
SPACING	NS					
SHADE × SPACING	NS					

NS – Non-Significant

4.2.3 Chlorophyll content

Table 9 (a) – 9 (i) shows the effect of three levels of shade at four population densities on chlorophyll 'a', chlorophyll 'b' and total chlorophyll content of plant leaves.

Analysis over different shade levels showed that chlorophyll 'a' content values for the different plant population densities showed no significant variation under shade at three levels (25%, 50% and 75%) 2 MAP. Pooled analysis of data furnished in the Table 9(a) indicated the different shade levels and population densities to have significantly different chlorophyll 'a' content values at 2 MAP. Highest value for chlorophyll 'a' content (10.28 mg g^{-1}) was recorded under S_3 (75% shade) and the lowest (4.18 mg g^{-1}) under S_1 (25% shade). Likewise, highest value (6.45 mg g^{-1}) was seen under T_4 (30 ×15 cm) spacing and the lowest (5.99 mg g^{-1}) under T_1 (10 × 15 cm) spacing. However, the shade × population density interaction effect on chlorophyll 'a' content of plants at 2 MAP was found to be non-significant.

Separate analyses of data for three shade levels indicated a similar trend for chlorophyll 'b' content at 2 MAP as that of chlorophyll 'a' content for the same time period. Combined analysis of data shown in Table 9 (b) indicated the three levels of shade recording significantly different values for chlorophyll 'b' content of plants at 2 MAP. Increasing levels of shade showed a corresponding increase in chlorophyll 'b' content in plants. Maximum (117.82 mg g^{-1}) was recorded under S_3 (75% shade) whereas the minimum (48.45 mg g^{-1}) was recorded under S_1 (25% shade). Plant population density and the shade × population density interaction were found to be non-significant at 2 MAP.

Table 9(a). Effect of different levels of shade and spacing on chlorophyll 'a' content (mg g^{-1}) in *Eryngium foetidum* at 2 MAP

	T_1	T_2	T_3	T_4	MEAN (SHADE)	CD
S_1	3.98	4.14	4.45	4.16	4.18	NS
S_2	4.33	4.15	4.15	4.34	4.23	NS
S_3	9.67	10.33	10.27	10.86	10.28	NS
MEAN (SPACING)	5.99	6.20	6.28	6.45		

POOLED ANALYSIS

SHADE	0.28
SPACING	0.32
SHADE × SPACING	NS

NS – Non-Significant

Table 9(b). Effect of different levels of shade and spacing on chlorophyll 'b' content (mg g^{-1}) in *Eryngium foetidum* at 2 MAP

	T_1	T_2	T_3	T_4	MEAN (SHADE)	CD
S_1	45.62	49.47	50.99	47.73	48.45	NS
S_2	49.59	47.54	47.53	49.69	48.58	NS
S_3	110.83	118.38	117.69	124.42	117.82	NS
MEAN (SPACING)	68.68	71.79	72.07	73.94		

POOLED ANALYSIS

SHADE	3.30
SPACING	NS
SHADE × SPACING	NS

NS – Non-Significant

Table 9(c). Effect of different levels of shade and spacing on total chlorophyll content (mg g^{-1}) in *Eryngium foetidum* at 2 MAP

	T_1	T_2	T_3	T_4	MEAN (SHADE)	CD
S_1	463.85	482.70	518.52	485.52	487.65	NS
S_2	504.35	483.49	483.34	505.38	494.14	NS
S_3	1126.19	1203.03	1195.91	1264.28	1197.35	NS
MEAN (SPACING)	698.12	723.07	732.59	751.72		

POOLED ANALYSIS	
SHADE	32.71
SPACING	37.77
SHADE × SPACING	NS

NS – Non-Significant

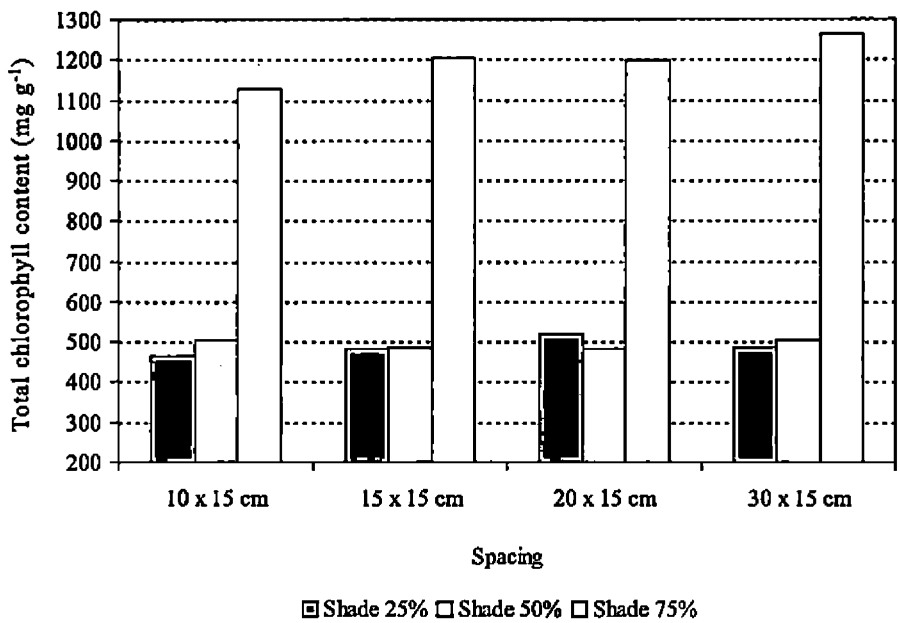

Fig. 9. Effect of different levels of shade and spacing on total chlorophyll content (mg g^{-1}) in *Eryngium foetidum* at 2 MAP

Four population densities showed no significant difference for total chlorophyll content under three levels of shade (S_1, S_2 and S_3) at 2 MAP according to individual analysis of data. According to the overall analysis data furnished in Table 9(c), three levels of shade and four plant population densities exhibited significantly different values for total chlorophyll content of plants at 2 MAP. With increase in shade level (S_1, S_2 and S_3), a corresponding increase in the total chlorophyll content was observed (Fig. 9). Maximum total chlorophyll content (1197.35 mg g^{-1}) was seen under S_3 (75% shade) and minimum (487.65 mg g^{-1}) under S_1 (25% shade). Similarly, maximum chlorophyll content (751.72 mg g^{-1}) was seen under T_4 (30 × 15 cm) spacing and minimum (698.12 mg g^{-1}) under T_1 (10 ×15 cm). The shade × population density interaction effect on total chlorophyll content at 2 MAP was found to be non-significant.

No significant difference between the values for chlorophyll 'a' content among the four plant population densities under three levels of shade was observed at 4 MAP according to the analysis of three individual experiments. A similar trend was observed with both chlorophyll 'b' and total chlorophyll contents at 4 MAP. Overall analysis of data furnished in Table 9(d) showed significant variation among chlorophyll 'a' contents of plants between the three shade levels at 4 MAP. Maximum chlorophyll 'a' content (10.59 mg g^{-1}) was seen under S_3 (75% shade) whereas the minimum (8.28 mg g^{-1}) was found under S_2 (50% shade). S_1 (25% shade) exhibited an intermediate value (9.54 mg g^{-1}). Plant population density and the interaction effect of shade × population density were found to be non-significant.

Combined analysis of data [Table 9(e)] showed significant differences between chlorophyll 'b' contents of plants among three shade levels at 4 MAP. Highest chlorophyll 'b' content (121.41 mg g^{-1}) was seen at S_3 (75% shade) and the lowest (94.96 mg g^{-1}) at S_2 (50% shade). Plant population density and the interaction effect of shade × plant population density were found to be non-significant with respect to chlorophyll 'b' content of plants at 4 MAP.

Table 9(d). Effect of different levels of shade and spacing on chlorophyll 'a' content (mg g^{-1}) in *Eryngium foetidum* at 4 MAP

	T_1	T_2	T_3	T_4	MEAN (SHADE)	CD
S_1	8.91	9.11	9.78	10.34	9.54	NS
S_2	8.76	7.53	7.91	8.96	8.28	NS
S_3	10.44	10.90	10.24	10.81	10.59	NS
MEAN (SPACING)	9.37	9.18	9.31	10.03		

POOLED ANALYSIS

SHADE	0.72
SPACING	NS
SHADE × SPACING	NS

NS – Non-Significant

Table 9(e). Effect of different levels of shade and spacing on chlorophyll 'b' content (mg g^{-1}) in *Eryngium foetidum* at 4 MAP

	T_1	T_2	T_3	T_4	MEAN (SHADE)	CD
S_1	102.15	104.36	112.06	118.53	109.27	NS
S_2	100.37	86.24	90.60	102.66	94.96	NS
S_3	119.64	124.89	117.30	123.81	121.41	NS
MEAN (SPACING)	107.38	105.16	106.65	114.99		

POOLED ANALYSIS

SHADE	8.26
SPACING	NS
SHADE × SPACING	NS

NS – Non-Significant

Table 9(f). Effect of different levels of shade and spacing on total chlorophyll content (mg g^{-1}) in *Eryngium foetidum* at 4 MAP

	T_1	T_2	T_3	T_4	MEAN (SHADE)	CD
S_1	1038.07	1060.51	1138.78	1204.48	1110.46	NS
S_2	1019.81	876.29	920.62	1043.12	964.96	NS
S_3	1215.60	1268.97	1191.80	1257.94	1233.58	NS
MEAN (SPACING)	1091.16	1068.59	1083.73	1168.51		

POOLED ANALYSIS

SHADE	84.04
SPACING	NS
SHADE × SPACING	NS

NS – Non-Significant

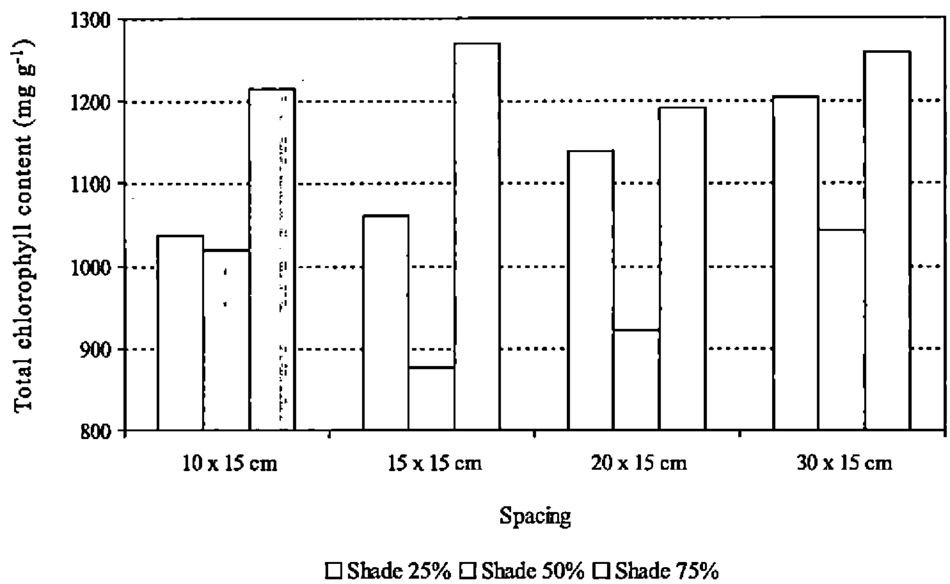

Fig. 10. Effect of different levels of shade and spacing on total chlorophyll content (mg g^{-1}) in *Eryngium foetidum* at 4 MAP

Table 9(g). **Effect of different levels of shade and spacing on chlorophyll 'a' content (mg g^{-1}) in *Eryngium foetidum* at 6 MAP**

	T_1	T_2	T_3	T_4	MEAN (SHADE)	CD
S_1	9.67	8.63	9.68	9.86	9.46	NS
S_2	8.90	8.10	8.31	9.91	8.80	NS
S_3	10.45	10.82	10.70	10.92	10.72	NS
MEAN (SPACING)	9.67	9.18	9.56	10.20		

POOLED ANALYSIS

SHADE	0.62
SPACING	0.72
SHADE × SPACING	NS

Table 9(h). Effect of different levels of shade and spacing on chlorophyll 'b' content (mg g^{-1})in *Eryngium foetidum* at 6 MAP

	T_1	T_2	T_3	T_4	MEAN (SHADE)	CD
S_1	110.82	98.95	110.95	113.05	108.44	NS
S_2	102.01	92.84	95.21	113.47	100.88	NS
S_3	119.74	123.98	122.52	125.09	122.83	NS
MEAN (SPACING)	110.85	105.25	109.56	117.20		

POOLED ANALYSIS

SHADE	7.15
SPACING	8.25
SHADE × SPACING	NS

NS – Non-Significant

Table 9(i). Effect of different levels of shade and spacing on total chlorophyll content (mg g^{-1}) in *Eryngium foetidum* at 6 MAP

	T_1	T_2	T_3	T_4	MEAN (SHADE)	CD
S_1	1126.09	1005.65	1127.49	1148.65	1101.97	NS
S_2	1036.48	943.26	967.35	1152.92	1025.00	NS
S_3	1216.56	1259.72	1244.83	1271.02	1248.03	NS
MEAN (SPACING)	1126.38	1069.54	1113.22	1190.86		

POOLED ANALYSIS

SHADE	72.63
SPACING	83.87
SHADE × SPACING	NS

NS – Non-Significant

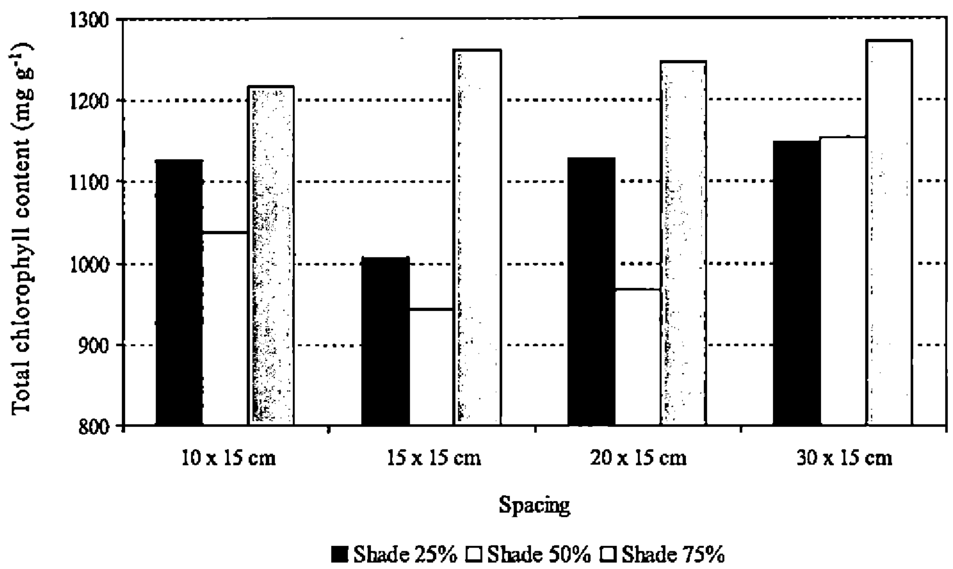

Fig. 11. Effect of different levels of shade and spacing on total chlorophyll content (mg g^{-1}) in *Eryngium foetidum* at 6 MAP

According to the combined analysis data [Table 9(f)], significant variations among total chlorophyll content values of plants under three separate levels of shade at 4 MAP were recorded. Maximum chlorophyll content (1233.58 mg g^{-1}) was observed under S_3 (75% shade) and minimum (964.96 mg g^{-1}) under S_2 (50% shade) (Fig. 10). Plant population density and the interaction of shade × population density were found to be non-significant at 4 MAP with regard to total chlorophyll content of leaves.

Individual analysis indicated that the four plant population densities were with significantly different chlorophyll 'a', chlorophyll 'b' and total chlorophyll content values under shade at all three levels at 6 MAP (Fig. 11). Combined analysis of data [Table 9(g)] indicated that shade (S_1, S_2 and S_3) and plant population density (T_1, T_2, T_3 and T_4) exhibited significant variation for chlorophyll 'a' content of plants at 6 MAP. Maximum chlorophyll 'a' (10.72 mg g^{-1}) was seen under S_3 (75% shade) and minimum (8.8 mg g^{-1}) under S_2 (50% shade). Similarly, maximum chlorophyll 'a' content (10.2 mg g^{-1}) was seen at T_4 (30 × 15 cm) spacing and the minimum (9.18 mg g^{-1}) at T_2 (15 × 15 cm) spacing. The interaction of shade × population density was found to be non-significant with respect to the chlorophyll 'a' content of the plant leaves at 6 MAP. A similar trend was recorded for chlorophyll 'b' and total chlorophyll contents at 6 MAP.

4.3 GROWTH ANALYSIS

4.3.1 Leaf Area Index

Table 10 (a) – 10 (c) shows the effect of three levels of shade at four population densities on Leaf Area Index (LAI) of plants (Fig. 12, 13 and 14).

At 2 MAP, analysis over different shade levels revealed that population densities varied significantly with regard to leaf area index only under S_2 (50%) and S_3 (75%) shade levels. The result was the same at 4 MAP and 6 MAP. Combined analysis of data furnished in Table 10 (a) indicated the three levels of shade and four population densities along with the interaction of shade × population density as being non-significant with respect to leaf area index of plants at 2 MAP. Pooled analysis of data given in Table 10(b) showed that for leaf area index values of plants at 4 MAP, population density and the interaction of shade × population density exhibited significant variation. Shade levels revealed no significant difference for LAI at 4 MAP. Highest value for LAI was recorded under T_4 (30 × 15 cm) spacing (1.229), whereas the lowest value for the same (0.645) was registered under T_1 (10 × 15 cm) spacing. Under T_1 (10 × 15cm) spacing, 25% shade recorded maximum LAI (0.771). Same was the case for T_2 (15 × 15cm) spacing. S_2 (50%) shade and S_3 (75%) shade registered the maximum LAI values, 1.299 and 1.435, under T_3 (20 × 15cm) and T_4 (30 × 15cm) spacing, respectively. Overall analysis of data [Table 10 (c)] indicated that shade, population density and the interaction of shade × population density showed significant variation for leaf area index of plants at 6 MAP. Highest LAI values of 0.878 and 1.063 were recorded under S_2 shade level (50%) and T_4 (30 × 15 cm) spacing, respectively. Lowest values for LAI (0.687 and 0.512) were registered under S_1 shade level (25%) and T_1 (10 × 15 cm) spacing, respectively. Under T_1 (10 × 15cm) spacing, S_1 (25%) shade gave the highest LAI value (0.536), whereas under T_2 (15 × 15cm) spacing, S_2 (50%) shade level gave the highest value of 0.735. Similar trend was observed for T_3 and T_4 spacing.

Table 10(a). Effect of different levels of shade and spacing on leaf area index in *Eryngium foetidum* at 2 MAP

	T_1	T_2	T_3	T_4	MEAN (SHADE)	CD
S_1	0.697	0.763	0.812	0.908	0.795	NS
S_2	0.592	0.744	1.293	1.256	0.971	0.490
S_3	0.493	0.595	0.767	1.477	0.833	0.376
MEAN (SPACING)	0.594	0.701	0.957	1.214		

POOLED ANALYSIS	
SHADE	NS
SPACING	NS
SHADE × SPACING	NS

NS – Non-Significant

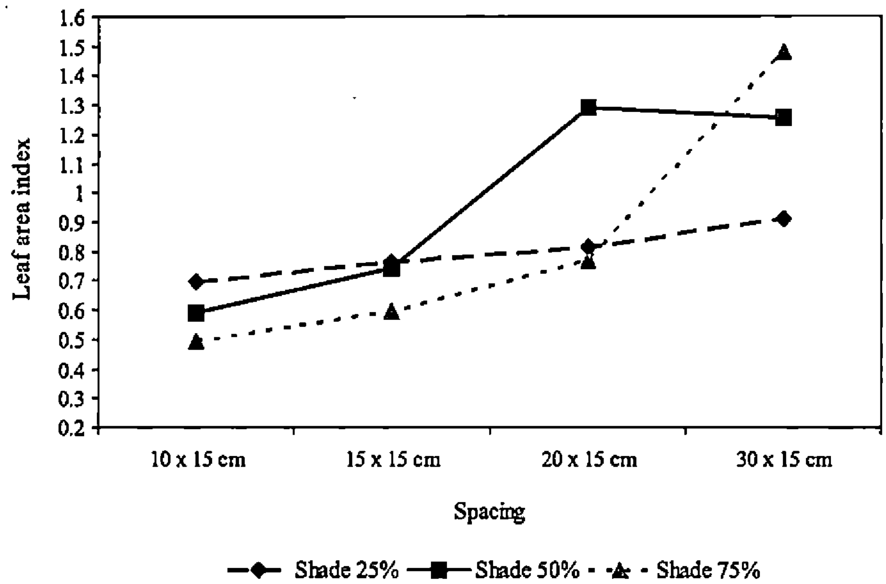

Fig. 12. Effect of different levels of shade and spacing on leaf area index in *Eryngium foetidum* at 2 MAP

Table 10(b). **Effect of different levels of shade and spacing on leaf area index in *Eryngium foetidum* at 4 MAP**

	T_1	T_2	T_3	T_4	MEAN (SHADE)	CD
S_1	0.771	0.872	0.889	0.962	0.873	NS
S_2	0.616	0.774	1.299	1.291	0.995	0.531
S_3	0.547	0.625	0.843	1.435	0.863	0.335
MEAN (SPACING)	0.645	0.757	1.010	1.229		

POOLED ANALYSIS

SHADE	NS
SPACING	0.224
SHADE × SPACING	0.389

NS – Non-Significant

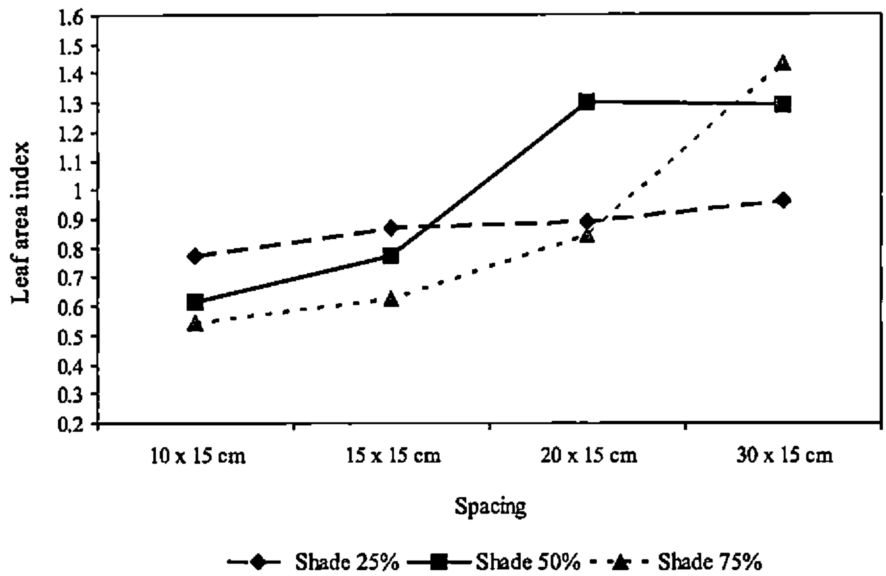

Fig. 13. Effect of different levels of shade and spacing on leaf area index in *Eryngium foetidum* at 4 MAP

Table 10(c). Effect of different levels of shade and spacing on leaf area index in *Eryngium foetidum* at 6 MAP

	T_1	T_2	T_3	T_4	MEAN (SHADE)	CD
S_1	0.536	0.710	0.715	0.785	0.687	NS
S_2	0.521	0.735	1.121	1.360	0.878	0.376
S_3	0.479	0.566	0.777	1.268	0.773	0.217
MEAN (SPACING)	0.512	0.671	0.871	1.063		

POOLED ANALYSIS

SHADE	0.144
SPACING	0.166
SHADE × SPACING	0.288

NS – Non-Significant

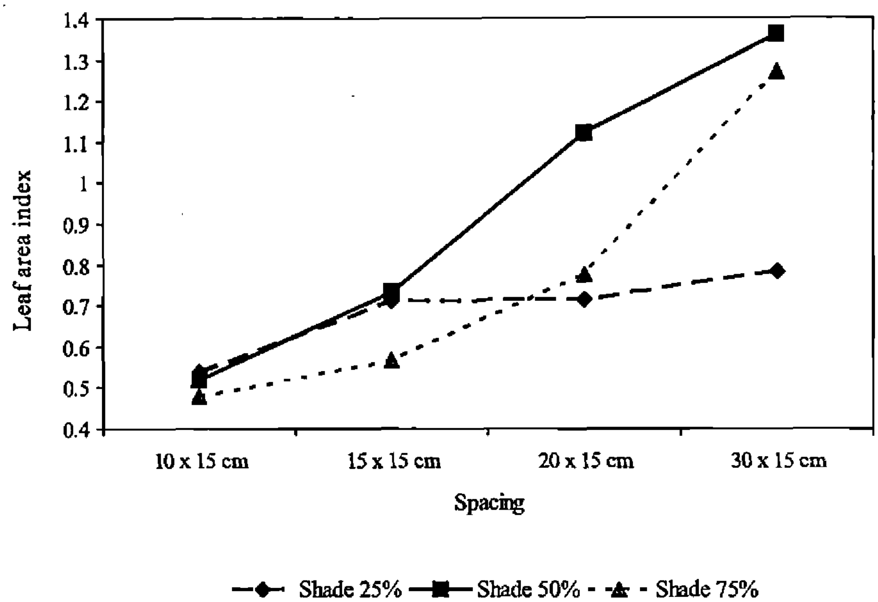

Fig. 14. Effect of different levels of shade and spacing on leaf area index in *Eryngium foetidum* at 6 MAP

4.3.2 Net Assimilation Rate

Table 11 (a) – 11 (b) shows the effect of three levels of shade at four population densities on the Net Assimilation Rate (NAR) of plants.

Between the 30 – 90 days period, according to individual analysis of data, population densities were observed to have significantly different NAR values only under the medium level of shade intensity (S_2). Here, T_1 (10 × 15cm) spacing was found to be the most responsive (0.96 g m^{-2} day^{-1}). Combined analyses of data given in the Table 11(a) showed significant difference among shade levels for NAR values of plants between 30 to 90 days of growth. Progressive increase in net assimilation rate was observed with increase in shade intensity. Maximum NAR (0.99g m^{-2} day^{-1}) was observed under S_3 (75% shade) and minimum of 0.4 g m^{-2} day^{-1} under S_1 (25% shade). Plant population density and the interaction of shade × population density revealed no such significant difference for NAR values.

During the 90 – 150 days period, significant variation among plant population densities with respect to NAR was observed only under S_1 (25%) and S_3 (75%) shade levels. T_1 (10 × 15cm) spacing was observed giving best results under both S_1 and S_3 shade levels. Overall analysis of data furnished in Table 11(b) showed plant population density to be significantly varied with regard to NAR of plants between 90 to 150 days of growth. Highest NAR value (1.19 g m^{-2} day^{-1}) was recorded under T_1 (10 × 15 cm) spacing and lowest (0.41 g m^{-2} day^{-1}) under T_4 (30 × 15 cm) spacing. Shade and the interaction of shade × population density were found to be non-significant with respect to net assimilation rate of plants during the 90 – 150 days period.

Table 11(a). **Effect of different levels of shade and spacing on net assimilation rate ($g\ m^{-2}\ day^{-1}$) in *Eryngium foetidum* between 30 – 90 days period**

	T_1	T_2	T_3	T_4	MEAN (SHADE)	CD
S_1	0.40	0.39	0.40	0.41	0.40	NS
S_2	0.96	0.74	0.45	0.49	0.66	0.21
S_3	1.18	1.13	1.07	0.57	0.99	NS
MEAN (SPACING)	0.85	0.75	0.64	0.49		

POOLED ANALYSIS

SHADE	0.23
SPACING	NS
SHADE × SPACING	NS

NS – Non-Significant

Table 11(b). Effect of different levels of shade and spacing on net assimilation rate ($g\ m^{-2}\ day^{-1}$) in *Eryngium foetidum* between 90 - 150 days period

	T_1	T_2	T_3	T_4	MEAN (SHADE)	CD
S_1	1.06	0.64	0.68	0.61	0.75	0.33
S_2	1.23	0.99	0.81	0.39	0.86	NS
S_3	1.29	1.00	0.62	0.23	0.76	0.53
MEAN (SPACING)	1.19	0.88	0.70	0.41		

POOLED ANALYSIS

SHADE	NS
SPACING	0.29
SHADE × SPACING	NS

NS – Non-Significant

4.3.3 Relative Growth Rate

Table 12 (a) – 12 (b) shows the effect of three levels of shade at four population densities on the Relative Growth Rate (RGR) of plants between a 30 – 150 days period of growth.

Analysis over different shade levels indicated that, during the initial 30 – 90 days period, population densities varied significantly for RGR values only under S_2 (50%) shade level. Here, T_1 (10 × 15cm) spacing gave the highest response (0.004 g m^{-2} day^{-1}). Combined analysis of data furnished in Table 12(a) indicated the three shade levels and four plant population densities to be significantly different with respect to RGR of plants between 30 to 90 days of growth. Peak value of RGR (0.005 g m^{-2} day^{-1}) was recorded under S_3 shade level (75%) and T_1 (10 × 15 cm) spacing. Lowest value (0.002 g m^{-2} day^{-1}) was recorded under S_1 shade level (25%) and T_4 (30 × 15cm) spacing. The interaction of shade × population density was found to be not significant with regard to RGR.

Between the 90 – 150 days growth period, individual analysis revealed significant variation among plant population densities for RGR under S_1 (25%) and S_3 (75%) shade levels. Here, T_1 (10 × 15cm) spacing was noticed giving the highest value for RGR (0.006 g m^{-2} day^{-1}). Overall analysis of data [Table 12(b)] recorded plant population densities showing significant difference for RGR during the 90 to 150 days period of growth. Maximum value of RGR (0.005 g m^{-2} day^{-1}) was recorded at T_1 (10 × 15 cm) spacing. Lowest value for RGR was registered at 0.002 g m^{-2} day^{-1}(T_4). Shade and the interaction of shade × population density were found to show no significant difference for RGR.

Table 12(a). Effect of different levels of shade and spacing on relative growth rate ($g\ m^{-2}\ day^{-1}$) in *Eryngium foetidum* between 30 – 90 days period

	T_1	T_2	T_3	T_4	MEAN (SHADE)	CD
S_1	0.003	0.003	0.002	0.002	0.002	NS
S_2	0.004	0.003	0.002	0.002	0.003	0.001
S_3	0.007	0.005	0.005	0.004	0.005	NS
MEAN (SPACING)	0.005	0.004	0.003	0.002		

POOLED ANALYSIS

SHADE	0.0007
SPACING	0.0008
SHADE × SPACING	NS

NS – Non-Significant

Table 12(b). Effect of different levels of shade and spacing on relative growth rate ($g\ m^{-2}\ day^{-1}$) in *Eryngium foetidum* between 90 – 150 days period

	T_1	T_2	T_3	T_4	MEAN (SHADE)	CD
S_1	0.006	0.003	0.003	0.003	0.004	0.001
S_2	0.004	0.003	0.003	0.001	0.003	NS
S_3	0.006	0.004	0.002	0.001	0.003	0.002
MEAN (SPACING)	0.005	0.003	0.003	0.002		

POOLED ANALYSIS

SHADE	NS
SPACING	0.004
SHADE × SPACING	NS

NS – Non-Significant

4.3.4 Absolute Growth Rate

The effect of three levels of shade at four population densities on the Absolute Growth Rate (AGR) of plants is shown in Table 13 (a) – 13 (b). Pooled analysis revealed a significant variation in AGR among the three levels of shade only during the initial 30 – 90 days period.

Pooled analysis of data [Table 13(a)] showed significantly different AGR values among the three shade levels in the initial 30 – 90 days period. With increase in shade (S_1, S_2 and S_3), a corresponding increase in AGR was noted. Highest AGR (0.71 g m day^{-1}) was recorded under S_3 (75% shade) and the lowest (0.31 g m day^{-1}) was recorded under S_1 (25% shade). Plant population density / spacing (T_1, T_2, T_3 and T_4) and the shade × population density interaction were found to be not significant.

Table 13(a). Effect of different levels of shade and spacing on absolute growth rate (g m day^{-1}) in *Eryngium foetidum* between 30 – 90 days period

	T_1	T_2	T_3	T_4	MEAN (SHADE)	CD
S_1	0.27	0.30	0.33	0.35	0.31	NS
S_2	0.55	0.55	0.48	0.60	0.54	NS
S_3	0.59	0.60	0.84	0.79	0.71	NS
MEAN (SPACING)	0.47	0.48	0.55	0.58		
POOLED ANALYSIS						
SHADE	0.13					
SPACING	NS					
SHADE × SPACING	NS					

NS – Non-Significant

Table 13(b). Effect of different levels of shade and spacing on absolute growth rate ($g\ m\ day^{-1}$) in *Eryngium foetidum* between 90 – 150 days period

	T_1	T_2	T_3	T_4	MEAN (SHADE)	CD
S_1	0.69	0.48	0.54	0.53	0.56	NS
S_2	0.73	0.70	0.76	0.45	0.66	NS
S_3	0.65	0.54	0.52	0.29	0.50	NS
MEAN (SPACING)	0.69	0.57	0.61	0.43		
POOLED ANALYSIS						
SHADE	NS					
SPACING	NS					
SHADE × SPACING	NS					

NS – Non-Significant

4.4 YIELD

4.4.1 Number of Marketable Harvests

Table 14 shows the effect of three levels of shade at four population densities on the possible number of marketable harvests.

Analysis of the three individual experiments revealed that there existed a significant difference among plant population densities with regard to the possible number of marketable harvests under S_2 (50%) shade level. Here, both T_1 (10 × 15cm) and T_3 (20 × 15cm) spacing gave the best result (4.8). Combined analysis of data furnished in Table 14 showed significant variation with respect to the number of marketable harvests for interaction of shade × population density. Under T_1 (10 × 15cm) spacing, S_2 (50%) shade level gave maximum number of harvests (4.8). The same result was replicated at T_3 (20 × 15cm) spacing. Under T_2 (15 × 15cm) spacing, S_3 (75%) shade level gave the best result (4.6), whereas under T_4 (30 × 15cm) spacing, both S_1 (25%) and S_3 (75%) shade levels gave maximum results (4.6). Shade and population density were observed to be with no significant variation with regard to the possible number of marketable harvests.

Table 14. Effect of different levels of shade and spacing on number of marketable harvests in *Eryngium foetidum*

	T_1	T_2	T_3	T_4	MEAN (SHADE)	CD
S_1	3.8	4.4	4.2	4.6	4.2	NS
S_2	4.8	4.0	4.8	4.2	4.4	0.5
S_3	4.4	4.6	4.2	4.6	4.4	NS
MEAN (SPACING)	4.3	4.3	4.4	4.4		

POOLED ANALYSIS

SHADE	NS
SPACING	NS
SHADE × SPACING	0.70

NS – Non-Significant

4.4.2 Total Herbage Yield / Fresh Weight

The data given in Table 15 shows the effect of three levels of shade at four population densities on the total herbage yield / fresh weight per plot of size 120cm × 150cm.

Plant population densities varied significantly for fresh weight only under S_2 (50%) shade level, according to the individual analysis of data. Here, T_1 (10 × 15cm) spacing gave the best result (1131.41g). Table 15 (Fig. 15) furnishes the data regarding overall analysis conducted on total herbage yield. It indicates significant variation in fresh weight values among the three levels of shade (S_1, S_2 and S_3), at the time of harvest. Maximum fresh weight (1411.04g) was recorded under S_3 (75% shade) (Plate 5) whereas the minimum (713.93g) was registered under S_1 (25% shade) (Fig. 15). Plant population density / spacing (T_1, T_2, T_3 and T_4) and the interaction of shade × population density were found to be non-significant with regard to fresh weight.

Table 15. Effect of different levels of shade and spacing on total herbage yield / fresh weight (g / plot) in *Eryngium foetidum*

	T_1	T_2	T_3	T_4	MEAN (SHADE)	CD
S_1	699.11	712.30	792.10	652.20	713.93	NS
S_2	1131.41	979.57	992.26	564.26	916.87	311.17
S_3	1809.46	1539.64	1326.06	969.00	1411.04	NS
MEAN (SPACING)	1213.32	1077.17	1036.81	728.48		

POOLED ANALYSIS

SHADE	247.46
SPACING	NS
SHADE × SPACING	NS

NS – Non-Significant
Plot size: 120cm × 150cm

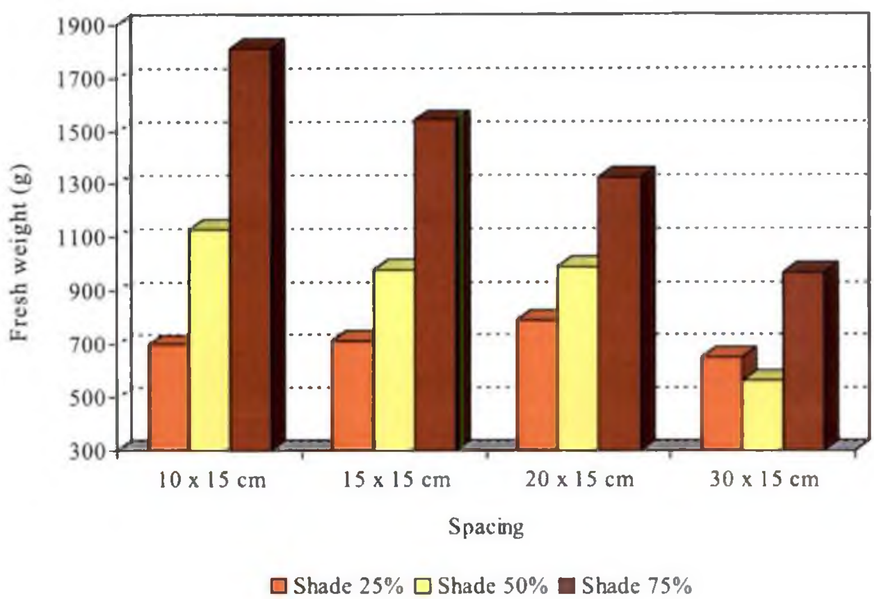

Fig. 15. Effect of different levels of shade and spacing on total herbage yield / fresh weight (g) in *Eryngium foetidum*

PLATE 5: PLANTS UNDER 75% SHADE AND 10x15cm SPACING

4.4.3 Dry weight of total biomass

The data provided in Table 16 shows the effect of three levels of shade at four population densities on dry weight of total biomass per plot of size 120cm × 150cm.

Analysis over different shade levels revealed plant population densities as showing significant variation for dry weight only under S_2 (50%) shade level. The spacing of 10 × 15cm (T_1) was recorded giving maximum dry weight (227.56g). Combined analysis of data given in Table 15 (Fig. 16) showed the interaction of shade × population density to be significant with regard to dry weight of total biomass at the time of harvest. At T_1, T_2, T_3 and T_4 spacing, S_3 consistently gave the highest dry weight values (347.28g, 282.30g, 239.36g and 199.30g) (Fig. 16). Shade and population density were found to be with no statistically significant variation for dry weight values.

Table 16. Effect of different levels of shade and spacing on dry weight of total biomass (g / plot) in *Eryngium foetidum*

	T_1	T_2	T_3	T_4	MEAN (SHADE)	CD
S_1	138.90	144.96	160.58	141.76	146.55	NS
S_2	227.56	183.48	190.00	122.40	180.86	57.70
S_3	347.28	282.30	239.36	199.30	267.08	NS
MEAN (SPACING)	237.91	203.58	196.64	154.51		

POOLED ANALYSIS

SHADE	NS
SPACING	NS
SHADE × SPACING	52.2

NS – Non-Significant
Plot size: 120cm × 150cm

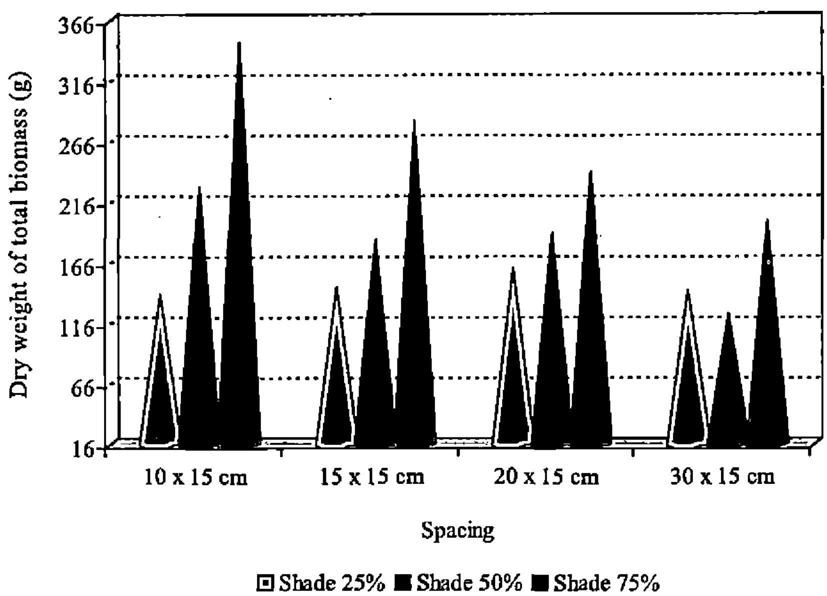

Fig. 16. Effect of different levels of shade and spacing on dry weight of total biomass (g) in *Eryngium foetidum*

4.5 CHEMICAL ANALYSIS

4.5.1 Volatile Oil

All the samples were analysed using Clevenger apparatus. But, no measurable quantity of oil could be obtained in any of the treatments.

4.5.2 Non -Volatile Ether Extract

Table 17 shows the effect of three levels of shade at four population densities on Non- Volatile Ether Extract (NVEE).

According to the analysis of individual experiments, population densities exhibited significant difference for NVEE content among them under all levels of shade. T_4 (30 × 15cm) spacing recorded maximum NVEE values under all shade levels (Fig. 17). Analyses combining the shade levels (Table 16) showed significant variation among the three shade levels for NVEE. A corresponding increase in NVEE of plants was observed with increase in shade (25%, 50% and 75%). Highest NVEE of 0.86% was observed under S_3 (75% shade) (Fig. 17), whereas the lowest (0.44%) was under S_1 (25% shade). Plant population density / spacing (T_1, T_2, T_3 and T_4) and shade × population density interaction were found to be non-significant.

Table 17. Effect of different levels of shade and spacing on NVEE (%) in *Eryngium foetidum*

	T_1	T_2	T_3	T_4	MEAN (SHADE)	CD
S_1	0.35	0.41	0.47	0.54	0.44	0.02
S_2	0.69	0.74	0.79	0.87	0.77	0.03
S_3	0.66	0.83	0.91	1.05	0.86	0.10
MEAN (SPACING)	0.57	0.66	0.72	0.82		

POOLED ANALYSIS	
SHADE	0.03
SPACING	NS
SHADE × SPACING	NS

NS – Non-Significant

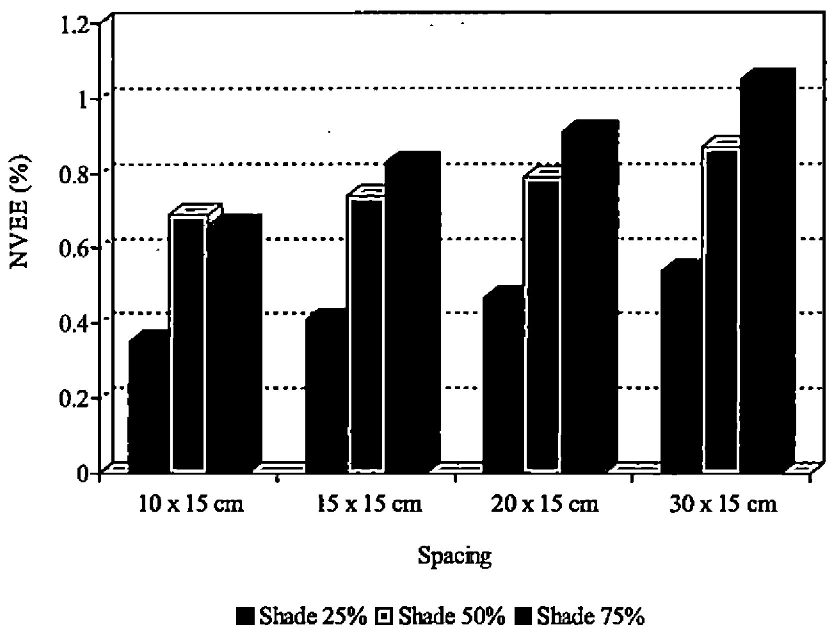

Fig. 17. Effect of different levels of shade and spacing on NVEE (%) in *Eryngium foetidum*

4.6 STORAGE STUDIES

4.6.1 Drying and Storing

Leaves were dried under room temperature, then oven dried and stored for studying shelf life. It was observed that the leaves dried under room temperature could be retained only for 5 to 6 days without deterioration whereas the oven-dried samples could be retained without any mould formation for 3 to 4 months. But no characteristic aroma could be detected. Those dried under room temperature developed a foul odour when compared to those dried in the oven.

4.6.2 Cold Storage / Shelf Life

Table 18 depicts the data for the effect of shade at four population densities on the shelf life of plants.

Pooled analysis of data (Table 18) indicated significant variation in shelf life values of the three shade levels. With increase in shade intensity (25%, 50%, 75%), an increase in shelf life was noted. Longest shelf life of 109.6 days was recorded under S_3 (75% shade) and the shortest (99.6 days) under S_1 (25% shade). Spacing / population density (T_1, T_2, T_3 and T_4) and the interaction of shade × population density were found to be non-significant with respect to shelf life.

Table 18. Effect of different levels of shade and spacing on shelf life in cold storage (days) of *Eryngium foetidum*

	T_1	T_2	T_3	T_4	MEAN (SHADE)	CD
S_1	99.8	100.8	96.4	101.6	99.6	NS
S_2	96.4	99.0	106.8	103.4	101.4	NS
S_3	110.6	109.6	118.8	106.6	109.6	NS
MEAN (SPACING)	102.2	103.1	105.0	103.8		
POOLED ANALYSIS						
SHADE	5.17					
SPACING	NS					
SHADE × SPACING	NS					

NS – Non-Significant

4.6.2 Storage under ambient temperature

Table 19 shows the effect of three levels of shade at four population densities on the storage under ambient temperature.

Individual analysis of data revealed that significant difference among the population densities for storage under ambient temperature existed only under S_2 (50%) level. Here, T_3 (20 × 15cm) spacing gave the best result (5.2 days). Overall analysis of data furnished in Table 19 revealed that interaction of shade × population density was with significant difference for storage under ambient temperature. Under T_1 (10 × 15cm) spacing, S_2 (50%) shade gave the best result (5.0 days). This result was observed to be replicated for T_3 (20 × 15cm) spacing also. Under T_2 (15 × 15cm) spacing, S_3 (75%) shade recorded the maximum (4.9 days), whereas under T_4 (30 × 15cm) spacing, S_1 (25%) registered the highest (5.0 days).

Table 19. Effect of different levels of shade and spacing on storage under ambient temperature (days) in *Eryngium foetidum*

	T_1	T_2	T_3	T_4	MEAN (SHADE)	CD
S_1	4.0	4.5	4.1	5.0	4.4	NS
S_2	5.0	4.2	5.2	4.5	4.7	0.6
S_3	4.8	4.9	4.0	4.7	4.6	NS
MEAN (SPACING)	4.6	4.5	4.4	4.7		

POOLED ANALYSIS	
SHADE	NS
SPACING	NS
SHADE × SPACING	0.7

NS – Non-Significant

PLATE 6: GALL FORMATION ON THE ROOTS OF *Eryngium foetidum*

4.7 INCIDENCE OF PESTS AND DISEASES

The plants grown under the various treatments were observed to be pest and disease free throughout the study period. But, at the time of final harvest, extensive gall formation was noticed on the roots of the plants. (Plate 6).

4.8 ECONOMICS OF CULTIVATION

Estimated expenditure and benefit: cost ratio of *Eryngium foetidum* L. under three levels of shade and at four population densities are given in Table 20. Total expenditure for the best yielding treatment of *Eryngium foetidum* L. (S_3T_1 - 75% shade, 10 × 15cm) came to Rs. 1,42,162 ha^{-1} (Table 20). Gross income for the same was estimated as Rs. 1,80,945 ha^{-1}. So, when grown at a spacing of 10 × 15cm under 75% shade, the benefit: cost ratio is as follows:

Net income = Gross income – Total expenditure

= Rs. **38,783**

$$\text{Benefit: cost ratio} = \frac{\text{Gross income}}{\text{Total Expenditure}}$$

= **1.27**

However, the highest benefit: cost ratio of 1.28 was observed in the treatment S_3T_2 (15 × 15cm spacing in 75% shade).

Table 20. Estimated expenditure and return per hectare of *Eryngium foetidum* under S_3T_1 (75 % shade and 10 × 15cm spacing).

A) Estimated expenditure

i) Cost of labour			
Sl. No	Details of Work	Labour	Amount (Rs.) @ Rs. 195 / day
1.	Main field preparation	60	11, 700
2.	Preparation of beds	15	2925
3.	Erection of shade nets	10	1950
4.	Planting in main field	20	3900
5.	Irrigation (6 months)	60	11, 700
6.	Manuring	5	975
7.	Harvesting	15	2925
	TOTAL		**36,075**

ii) Cost of inputs			
	Items	Qty	Price (Rs.)
1.	Planting material (seedlings) (nos.) @ 10 Ps. / seedling	6.6 lakhs	66, 000
2.	FYM @ Rs. 450 / t	10 tonnes	4500
3.	Fertilisers		
	Urea @ Rs. 5 / kg	141 kg	705
	Mussoriephos @ Rs. 5 / kg	211.8 kg	1059
	MOP @ Rs. 7 / kg	70 kg	490
4.	Shade net: 75% shade net @ Rs. 20 / m^2 (Cost distributed over three years and six crops)	10, 000 m^2	33,333
	TOTAL		**1,06,087**

B) Gross income (@ Rs. 18 / kg) = Rs. 1, 80, 945

Table 21. Benefit: cost ratios of all treatments under three levels of shade and at four population densities.

TREATMENT	B:C RATIO	TREATMENT	B:C RATIO
S_1T_1	0.63	S_2T_3	0.95
S_1T_2	0.64	S_2T_4	0.60
S_1T_3	0.79	S_3T_1	**1.27**
S_1T_4	0.73	S_3T_2	**1.28**
S_2T_1	0.82	S_3T_3	**1.21**
S_2T_2	0.85	S_3T_4	0.98

Discussion

5. DISCUSSION

Spiny coriander (*Eryngium foetidum* L.) is used mainly as a seasoning in the preparation of a range of foods, including vegetable and meat dishes, chutneys, preserves, sauces and snacks. Although used in small quantities, its pungent, unique aroma gives the characteristic flavour to the dishes into which it is incorporated and this is responsible for its increasing demand among ethnic populations. It is also widely used in herbal medicines and reportedly beneficial in the treatment of a number of ailments (Wong, 1976). Though this shade loving plant is much utilized, it is a little understood herb. Hence, a study entitled, "Performance of spiny coriander (*Eryngium foetidum* L.) under different shade regimes" was taken up to evaluate the adaptability, performance and feasibility of the crop for Kerala homesteads. The results of the investigation are discussed below.

5.1. BIOMETRIC OBSERVATIONS

5.1.1 Growth Characters

Significant difference in growth characters existed among plants raised under three separate levels of shade and at four plant population densities. At 1 MAP, S_3T_2 (75% shade, 15 × 15cm) attained maximum height of 13.13cm. Overall analysis indicated that S_3 shade level (75% shade) recorded the highest value for plant height (12.65cm). Effect of shade, thus is observed to be having significant influence upon plant height at one month after planting. This is in accordance with the work done by Sreelathakumary (2000) in capsicum and Hedge *et al.* (2000) in ginger. At 2 MAP, analysis of the three individual experiments showed S_3T_3 (75% shade, 20 × 15cm) as recording highest value for plant height (16.8cm). Combined analysis of data indicated that the maximum plant height (16.26cm) was recorded under S_3 (75%) shade level. This result corroborates that of Yinghua and Jianzhen (1998) in capsicum, Jayachandran *et al.* (1991) in ginger. Effect of plant population density and the interaction effect of shade ×

population density were found to be insignificant. At 3 MAP, analysis of data over different shade levels indicated that the plant height values varied significantly across plant population densities and under different shade levels, and the treatment S_3T_2 (75% shade, 15 × 15cm) showed maximum response for plant height (19.04cm). At 3 MAP, closer spacing recorded the tallest plants. This maybe due to the greater competition of plants for available nutrients which in turn encouraged apical dominance. Shade showed significant influence over plant height upon combined analysis of data whereas population density and the interaction of shade × population density did not. Under S_3 (75%) shade level, plants recorded the highest value for plant height (18.64cm). At 4 MAP, upon individual analysis of data, S_1T_4 (25% shade, 30 × 15cm) registered the highest value for plant height (20.1cm). Pooled analysis of data indicated that only shade had a significant effect on plant height at 4 MAP. Similar trend was observed at 5 MAP, with S_1T_4 (25% shade, 30 × 15cm) recording maximum plant height of 21.34cm and S_3 (75% shade level) plants showing a maximum height of 20.27cm. The increase in plant height under shade can be attributed to the cell elongation effect to catch up with the neighbouring plants. Spacing has a marked influence on the capacity of the plants to utilize environmental factors in building up of plant tissues through regulation of absorption capacity of plants. Hence, widely spaced plants exhibited maximum height. Plant height is not a stable character. It quite depends on the climate and the genotype of plants.

A significant effect was exhibited by shade on stem girth throughout the study period. Overall analysis showed that plants grown under S_1 (25%) level of shade recorded the maximum stem girth for the first four months after planting. S_3 (75%) shade level recorded the maximum stem girth of 5.05cm in the last month of study (5 MAP). This result is in conformity with that of Nagaota *et al.* (1979) who observed that, in general, plants grown under lower light intensities were found to be taller, with thinner stems than those grown under open conditions. Interaction effect of shade × population density on stem girth was found to be significant for the first three months after planting. S_1T_2 (25% shade, 15 × 15cm) was found to be the most responsive with respect to stem girth for the first three months. S_1T_4 (25% shade, 30 ×15cm) and S_3T_4 (75% shade, 30 × 15cm) were found to give maximum values of 4.23cm and 5.31cm at 4 MAP and 5 MAP, respectively. Plant population density was observed to have a significant influence on stem girth at 2 MAP and 3 MAP. T_3 (20 × 15cm) recorded maximum stem girth both these times. The significant improvement in growth parameters under wider spacing might be due to relatively less competition for growth factors.

Pooled analysis of data indicated that shade had a significant influence on spread of the plant whereas population density and the interaction of shade × population density did not. Plants grown under S_3 (75%) shade level recorded the maximum plant spread in general. This result is in corroborance with that of Panikar *et al.* (1969) in tobacco. Analysis of data over different shade levels revealed that there was no significant variation among the four plant population densities under the three levels of shade with respect to plant spread throughout the period of study. Here, the treatment S_3T_2 (75% shade, 15 × 15cm) recorded the maximum plant spread for the entire study period.

The effect of shade on the number of leaves per plant was observed to be significant throughout the length of study upon overall analysis. Plants grown under S_3 (75%) shade level consistently registered the maximum number of leaves for the whole of the study period. Individual analysis, showed the treatment S_3T_3 (75% shade, 20 × 15cm) to be the best performer with respect to the number of leaves put forth at 4 MAP (16.38) and 5 MAP (18.14). The veracity of this result is confirmed by similar findings of Devadas and Chandini (2000) in pepper and Maheswarappa (2000) in arrowroot. More number of leaves was also observed in plants grown in shade than in full light in mentha (Prasanta K. Patra, 2003). Under shade, the production as well as retention of leaves was higher. Under shaded condition, reduced radiation may prevent scorching or wilting of leaves caused by marked increase in temperature within the leaf tissue from strong sunlight (Aasha, 1986) and thereby increases the leaf life under shade resulting in maximum retention of leaves. Influence of plant population density and the interaction effect of shade × population density on the number of leaves per plant were found to be non-significant under pooled analysis.

According to the pooled analysis of data, plant population density influenced the number of plants with flower shoots significantly at the beginning of the study (1 MAP and 2 MAP). This effect was shown to be not significant towards the end of the study (3 MAP, 4 MAP and 5 MAP). T_2 (15 × 15cm) spacing recorded the maximum flowering percentage (22.82%) at 1 MAP and T_1 (10 × 15cm) spacing recorded the highest (47.4%) at 2 MAP. The earlier works of Sharma and Rastogi (1992) in cauliflower and Muthuramalingam *et al.* (2000) in aggregatum onion vindicate this result. The effect of shade was seen to have a significant positive effect on the number of plants with flower shoots 5 MAP. Here, S_2 (50%) shade level recorded the maximum flowering percentage of 97.95%. This result finds resonance in the study of Devadas (1997) in black pepper. Interaction effect of shade × population density was found to be uniformly insignificant in its influence over flowering percentage throughout the period of study. Analysis of the three individual experiments showed that the four levels of spacing (10 × 15cm, 15 × 15cm, 20 × 15cm and 30 × 15cm) were significantly varied with respect to the number of plants with flower shoots at all three levels of shade (25%, 50% and 75%) at 1 MAP. Treatment S_3T_3 (75% shade, 20 × 15cm) recorded the maximum percentage of flowering (30.32%). At 2 MAP, 3 MAP and 5 MAP, the same effect was observed only under S_1 (25%) shade conditions with T_2 (15 × 15cm) spacing being the most responsive in all three.

Analysis combining the three shade levels showed the number of roots of the plant at the time of final harvest to be a character responsive to shade. At the time of final harvest, S_3 (75%) shade level registered the maximum number of roots (10.35). Such a result may be due to the better vigour of the plants under S_3 (75%) shade level. This result is in accordance with that of Sreekala (1999) in ginger. The effect of plant population density and the interaction effect of shade × population density on the number of roots were found to be non-significant.

The plants under the various treatments were observed for production of any suckers or seedlings at their base. But no such phenomena were noticed.

5.1.2 Physiological Characters

Photosynthetically Active Radiation (PAR) was observed to be a character responsive to shade. Combined analysis of data revealed that, at 6 MAP, shade had a significant effect on PAR values, with S_1 (25% shade) registering the maximum value (972.39 μ mol m^{-2} s^{-1}).

Stomatal conductance as a physiological parameter has been found to be unresponsive to the effects of shade, population density and interaction of shade × population density upon overall analysis of data. However, S_2T_2 (50% shade, 15 × 15cm) at 13.18 μ mol m^{-2} s^{-1}, S_3T_4 (75% shade, 30 × 15cm) at 10.94 μ mol m^{-2} s^{-1} and S_1T_4 (25% shade, 30 × 15cm) at 10.15 μ mol m^{-2} s^{-1} recorded the maximum values for stomatal conductance at 2, 4 and 6 MAP respectively. Similar findings were also reported by Andersen *et al.*, 1991 in *Acuba japonica* cv. Variegata.

Under pooled analysis of data, chlorophyll 'a', chlorophyll 'b' and total chlorophyll contents of plants were found to be significantly influenced by shade at all three levels (25%, 50% and 75%) for the entire duration of the study. At 2 MAP, under S_3 (75%) shade level, plants recorded the maximum values for chlorophyll 'a', chlorophyll 'b' and total chlorophyll content at 10.28 mg g^{-1}, 117.82 mg g^{-1} and 1197.35 mg g^{-1}, respectively. This pattern was repeated at 4 MAP and 6 MAP. This result finds resonance in the studies of Bai, 1981 in colocasia and Sreelathakumary (2000) in chilli. Similar trend was noticed by Ramanujan and Jose (1984) in cassava and Sreekala (1990) in ginger. The increased chlorophyll 'a' and 'b' pigments of shade leaves is attributed to the increase in the number and size of chloroplasts, the amount of chlorophyll per chloroplast and better grana development (Prasanta K. Patra, 2003). Similarly, a significant positive effect was noticed on chlorophyll 'a', chlorophyll 'b' and total chlorophyll contents by plant population density at 6 MAP. Here, T_4 (30 × 15cm) spacing grown plants consistently recorded the highest chlorophyll 'a', chlorophyll 'b' and total chlorophyll content values of 10.2 mgg^{-1}, 117.2 mgg^{-1} and 1190.86 mgg^{-1} respectively. This increase may be due to the fact that wider spacing provides sufficient space for plant growth and lesser plant to plant competition for available nutrients which leads to vigorous growth of plants in terms of more leaf area and the number of leaves. This result is supported by the works of Dimri and Lal (1997) in tomato and by Naruka and Dhaka (2001) in garlic. At 2 MAP, population density significantly affected chlorophyll 'a' and total chlorophyll content, but there was no significant influence over chlorophyll 'b' content.

5.1.3 Growth Analysis

The effect of shade on Leaf Area Index (LAI) of plants was found to be significant in the latter part of the study. At 6 MAP, the effect of shade on leaf area index was found to be significant and the medium shade level of S_2 (50%) was found to be the most responsive with a maximum LAI value of 0.878. This is in accordance with the studies of Mullakoya (1982) in guinea grass. Shading resulted in the production of larger leaves, that is, a greater mean area per mature leaf. This was probably an adaptation that increased light interception. Shade had no significant positive influence on LAI values at 2 MAP and 4 MAP. Pooled analysis also indicated the effect of population density and the interaction effect of shade × population density on LAI to be of significance at 4 MAP and 6 MAP. Highest value for LAI at 1.229 was recorded by T_4 (30 × 15cm) spacing at 4 MAP. Similar trend was observed at 6 MAP with a peak value of 1.063. This could be ascribed to the overall improvement in plant growth, vigour and production of sufficient photosynthates through increased leaf area by the plants at this spacing. According to the combined analysis of data, at 4 MAP, S_3T_4 (75% shade, 30 × 15cm) was found to be the best performing treatment with respect to leaf area index (1.435). At the same time, at 6 MAP, S_2T_4 (50% shade, 30 × 15cm) registered maximum LAI value (1.360), which was on a par with S_2T_3 (50% shade, 20 × 15cm) that recorded an LAI value of 1.121 and were thus considered the best performing treatments. This result finds cognizance with earlier works of Korikanthimath *et al.* (1998) in cardamom and Maheswarappa *et al.* (2001) in galangal. Analysis over different shade levels indicated that, over the entire study period, the four plant population densities varied significantly for LAI values only under S_2 (50%) and S_3 (75%) shade levels.

According to analysis combining different shade levels, the effect of shade on Net Assimilation Rate (NAR) of plants was found to be significant in the early phase of study and non-significant towards the end. NAR between 30 to 90 days period was found to be positively influenced by shade, with S_3 (75%) shade level being the most responsive at 0.99 g m^{-2} day^{-1}. This result is in accordance with the findings of Ravisankar and Muthuswamy (1987) in ginger. High NAR at higher shade levels could be attributed to the increased rate of photosynthesis under shade. Shade was found to have no significant influence on NAR during the 90 to 150 days period. Overall analysis also indicated that population density had a significant influence on NAR of plants between 90 to 150 days, but not so in the initial 30 to 90 days period. T_1 (10 × 15cm) spacing exhibited the highest NAR value of 1.06 g m^{-2} day^{-1} during the later 90 to 150 days period. Thus plants in closer spacing were found to register higher NAR values towards the latter part of the study. Closer spacing provided better nutrient environment for plant growth, expressed in terms of assimilate production (Austin *et al.*, 1976). Interaction effect of shade × population density was found to be insignificant with respect to NAR of plants.

Combined analysis of data indicated that the effect of plant population density on the Relative Growth Rate (RGR) of plants was significant consistently through the entire 30 to 150 day period of study. In the initial 30 to 90 day period, T_1 (10 × 15cm) spacing was found to register the maximum RGR value of 0.005 g m^{-2} day^{-1}. Similar trend was observed in the latter 90 to 150 day phase also. Denser stands had more rapid growth because they displayed more photosynthetic surface per unit area of ground and thus synthesized more material. This result finds support in the works of Blackman (1968) and Aliyu (2000) in pepper who observed an increase in RGR values with closer spacing. The effect of shade on RGR was found to be significant only during the initial period of study (30 to 90 days). During this period, S_3 (75%) shade level recorded the maximum RGR value of 0.005 g m^{-2} day^{-1}. This result finds reflection in the work of Evans and Murray (1953) in cocoa.

Absolute Growth Rate (AGR), as a physiological parameter, was found to be positively influenced by shade in the initial part of the study (30 to 90 days). Here, S_3 (75%) shade level registered the maximum value of AGR at 0.71 g m day^{-1}. Thus, an increase in AGR values was noticed with an increase in shade levels during the early part of the study. In the latter part of the study (90 to 150 days), the effect of shade on AGR was observed to be not significant. Similarly, the influence of population density and the interaction effect of shade × population density were found to be not significant with respect to AGR of plants. This result is corroborated by the findings of Shrivastava (1996) in onion.

5.1.4 Yield

Pooled analysis of data revealed that the interaction effect of shade × population density on the possible number of marketable harvests was found to be significant. S_2T_1 (50% shade, 10 × 15cm) and S_2T_3 (50% shade, 20 × 15cm) were found to be the best performing treatments (4.8). S_1T_1 (25% shade, 10 × 15cm) recorded the minimum number of marketable harvests (3.8), with all other treatments being more or less on par with each other. Both the effect of shade and the effect of spacing were found to be non-significant with regard to maximum possible number of marketable harvests.

The effect of shade on fresh weight was found to be significant under combined analysis. S_3 (75%) shade level recorded maximum fresh weight of 1411.04g. The higher herbage yield at low light intensity can be attributed to many growth parameters like increased plant height, number of leaves, plant spread and leaf area. Upon individual analysis, only the medium shade level of S_2 (50%) showed significant variation among the plant population densities with regard to fresh weight. Under S_2 (50%) shade level, T_1 (10 × 15cm) spacing registered maximum fresh weight of 1131.41g. This result finds resonance in the work of Ravisankar and Muthuswamy (1981) in ginger. The effect of plant population density and the interaction effect of shade × population density on fresh weight were found not significant.

According to the pooled analysis of data, shade and population density had significant influence over the dry weight of biomass. S_3 (75%) shade level recorded the maximum dry weight of 267.08g. This result finds support in the works of Sulikeri (1986) in cardamom and Shen and Seely (1983). T_1 (10 × 15cm) spacing recorded the maximum dry weight of 237.91g. Dry weight was found to reduce drastically, to almost half, with wider spacing. Higher yield at closer spacing maybe due to the higher plant density and dry matter production. This result derives support from the works of Singh & Neopaney (1993), Hore *et al.* (2004) in ginger; Maheswarappa *et al.* (2001) in kacholam and Kandiannan & Chandaragir (2006) in turmeric.

5.1.5 Chemical Analysis

No measurable quantity of oil could be obtained from any treatment. However, the unique aroma contributed to by the volatile oil, could may be accurately estimated by other improved technology and sophisticated equipment for the purpose.

The effect of shade on Non-Volatile Ether Extract (NVEE) of plants was found to be significant, under combined analysis. Overall analysis showed that S_3 (75%) shade level registered maximum value for NVEE (0.869%). NVEE of plants was found to increase consistently with increase in shade intensity. Upon individual analysis, it was revealed that plant population densities varied significantly in NVEE levels at all three levels of shade. T_4 (30 × 15cm) spacing showed maximum value for NVEE under all three levels of shade (25%, 50% and 75%).

5.1.6 Storage studies

Leaves when dried under room temperature and also in an oven lost the unique aroma of *Eryngium foetidum* probably because of the loss of the negligible quantity of volatile oil present in the leaves.

Shade was observed to have a significant positive effect on the shelf life of plants. The shelf life of plants increased consistently with each successive increase in shade levels. S_3 (75%) shade level recorded the longest shelf life of 109.6 days. Plant population density and the interaction effect of shade × population density were observed to have no significant influence over shelf life of plants.

Analyses combining the data of three shade levels revealed that the interaction effect of shade × population density on storage under ambient temperature was significant. The treatment S_2T_3 (50% shade, 20 × 15cm) recorded maximum storage life (5.2 days). S_1T_1 (25% shade, 10 × 15cm) and S_3T_3 (75% shade, 20 × 15cm) registered the lowest storage life (4.0 days), with all other treatments being on a par with each other. Both the effect of shade and the effect of spacing were found to be non-significant with regard to storage under ambient temperature.

5.2 INCIDENCE OF PESTS AND DISEASES

No serious pests and diseases were observed, but at the time of final harvest, gall formation was noticed on the roots of certain plants infested by the root-knot nematode, *Meloidogyne* sp. Other scientists have also reported root-knot nematode infestation in *Eryngium foetidum* L. (Ramcharan. C, 1999).

5.3 ECONOMICS OF CULTIVATION

Economic analysis is important to ascertain whether a system is sustainable or not. Benefit: cost relationship under three levels of shade (25%, 50% and 75%) and at four spacing (10 × 15cm, 15 × 15cm, 20 × 15cm and 30 × 15cm) was analysed in order to identify the prospects of cultivation of *Eryngium foetidum* as a shade grown crop and thereby enable the farmers to undertake this enterprise on a commercial basis.

Benefit: cost analysis showed that the treatments S_3T_2 (75% shade, 15 × 15cm), S_3T_1 (75% shade, 10 × 15cm), and S_3T_3 (75% shade, 20 × 15cm) showed superior performance in terms of leaf fresh weight yield and registered the highest benefit: cost ratios of 1.28, 1.27 and 1.21 respectively. Evaluation of shade response of *E. foetidum* indicated that there was an increase in yield with shade intensity. Maximum yield was obtained from plants grown under 75% shade (S_3). The general trend of shade limiting biological productivity in plants was not on exhibition in this study and hence it can be deduced that *E. foetidum* is a shade loving plant and that for optimum growth it prefers shade. Though spacing was found to have no significant effect on the fresh weight of biomass, better yields were obtained with closer spacing, purely because of the larger number of plants growing under closer rather than wider spacing. Thus, the benefit: cost analysis indicates that the crop can be cultivated as a profitable enterprise under low light intensities that maximise its utility under intercropping and multi-storeyed cropping patterns of Kerala homesteads.

Future line of work

Eryngium foetidum L. was found to perform better in 75% shade. Hence, a higher level of shade can be tried for standardising the optimum level to get economic returns. Further studies on intercropping and multiple cropping of *Eryngium foetidum* L. under the existing homestead farming situations and other shaded situations like coconut, rubber, oil palm and other perennial tree crops of Kerala are necessary. Studies on manurial and other cultural practices are essential to evaluate the feasibility of *Eryngium foetidum* under Kerala conditions and to develop a package of practices recommendation for this crop. Popularisation of the crop and development of appropriate marketing strategy are necessary for making the crop more remunerative.

Summary

6. SUMMARY

Investigations for studying the performance of spiny coriander (*Eryngium foetidum* L.) under different shade regimes were carried out at the Department of Plantation crops and Spices, College of Agriculture, Vellayani, during 2004 – 2006. Eryngium is a biennial herb also known as Mexican coriander. The experiment was undertaken to evaluate the adaptability and performance of *Eryngium foetidum* under varying levels of shade and plant population densities. Three levels of shade (25%, 50% and 75%) and four spacings (10 ×15cm, 15 × 15cm, 20 × 15cm and 30 × 15cm) were tried.

The salient findings of the above studies are summarized in this chapter.

1. With an increase in shade (25%, 50% and 75%), a corresponding increase in height was observed. A height of 12.65cm, 11.46cm and 10.26cm were observed at 75%, 50% and 25% respectively at 1 MAP, 2 MAP and 3 MAP.
2. Stem girth also showed the same trend in the later stages of growth. With increased shade (75%), stem girth also increased (5.05cm) at 5 MAP; the interaction effect of shade × population density showed that S_3T_4 (75% shade, 30 × 15cm) had maximum stem girth of 4.42cm at 5 MAP.
3. Highest value for spread of plant (302.61 cm^2) was observed at 75% shade and the lowest value of 218.16cm^2 at 25% shade level. The interaction of shade × population density revealed that the treatment S_3T_2 (75% shade, 15 × 15cm) recorded the maximum spread at all stages of plant growth.
4. The effect of shade on the number of leaves per plant was significant throughout the growth period. Plants grown under 75% shade produced the maximum number of leaves. The treatment S_3T_3 (75% shade; 20cm × 15cm) produced 16.38 and 18.14 leaves at 4 MAP and 5 MAP, respectively.
5. On the contrary, the number of plants with flower shoots which was expressed in percentage flowering was found to be the highest under the low shade level of 25% at a spacing of 15 × 15cm, recording 45.16% and 63.64% at 2 MAP and 3 MAP respectively.

6. The effect of shade on the number of roots at the time of final harvest was found to be significant. Maximum number of roots (10.35) was seen under 75% shade. But the effect of plant population density and the interaction effect were insignificant.
7. Photosynthetically active radiation (PAR) was found to be maximum for the plants grown under 25% shade level (972.39 μ mol m^2 s^{-1}). But the other effects were insignificant at 6 MAP.
8. Significant variation in stomatal conductance was observed at 6 MAP with a highest value of 8.59 μ mol m^{-2} s^{-1} at the lowest shade intensity and a spacing of 30 × 15cm.
9. The effects of shade and population density on the chlorophyll content of treatment plants were found to be significant at 6 MAP. Chlorophyll 'a', 'b' and total chlorophyll were highest at 75% shade level at a spacing of 30 × 15cm.
10. The leaf area index of plants at 6 MAP was found to be significant at different shade levels, population density and their interaction effects, when analysed. Under 25% shade level, 30 × 15cm spacing gave the highest value of LAI (0.785).
11. At 90 – 150 days duration, the Net Assimilation Rate (NAR) was found to be significant at 25% and 75% shade and a spacing of 10 × 15cm.
12. Maximum RGR value (0.002 g $m^{-2}day^{-1}$) was recorded at a spacing of 10 × 15cm which was significantly superior to other treatments under both 25% and 75% shade. But the effect of shade × population density was insignificant.
13. With an increase in shade level, a corresponding increase in Absolute Growth Rate (AGR) was noted between 30 – 90 days of growth. At 75% shade, the AGR was highest (0.71 g m day^{-1}) which was significantly superior to other shade levels. But the effects of spacing, population density and their interaction were found to be insignificant.
14. The interaction effect of shade and population density was significantly superior at 10 × 15cm and 20 × 15cm spacing under 50% shade level, on the number of marketable harvests of *Eryngium foetidum*.
15. Maximum fresh weight was obtained from the plants grown at 75% shade (1411.04g) and also those planted at a spacing of 10 × 15cm (1131.41g), whereas

the interaction effect of shade and spacing on total herbage yield (fresh weight) was not significant.

16. Dry weight of total biomass of *Eryngium foetidum* was also highest at a spacing of 10 × 15cm under 75% shade (267.08g).
17. No measurable quantity of volatile oil could be estimated in any of the treatments.
18. In the quality analysis for Non-Volatile Ether Extract (NVEE), it was found to increase with increasing levels of shade. Under 75% shade, NVEE content was 0.869%. When spacing is considered, 30 × 15cm recorded the maximum NVEE value under all three shade levels.
19. Leaves of *Eryngium foetidum* dried under room temperature could be retained for 5 to 6 days without deterioration, whereas those dried in oven could be retained for about 3 to 4 months.
20. The longest shelf life of 109.65 days was observed for the leaves obtained from the plants grown in 75% shade, kept under refrigerated condition.
21. Fresh leaves obtained from the treatment under 75% shade and 20 × 15cm spacing could be stored for about 5.2 days under ambient temperature.
22. Except some gall formation in the roots, no serious pests and diseases were noted.
23. Benefit: cost ratio of the best performing treatment of *Eryngium foetidum* (75% shade and a spacing of 10 × 15cm) was 1.27, whereas the highest benefit: cost ratio (1.28) was obtained in the treatment under 75% shade and 15 × 15cm spacing.

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PERFORMANCE OF SPINY CORIANDER (*Eryngium foetidum* L.) UNDER DIFFERENT SHADE REGIMES

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Abstract of the thesis submitted in partial fulfillment of the requirement for the degree of

Master of Science in Horticulture

Faculty of Agriculture
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2008

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ABSTRACT

The studies on the "Performance of spiny coriander (*Eryngium foetidum* L.) under different shade regimes" were carried out at the Department of Plantation Crops and Spices, College of Agriculture, Vellayani, during 2004-2006. The objectives were to evaluate the adaptability and performance of *Eryngium foetidum* L. under varying levels of shade and plant population densities and also to study the feasibility of cultivating *Eryngium foetidum* L. under the homestead conditions of Kerala. Its use, both as a flavouring agent and herbal medicine, and also as a home remedy for various ailments point towards its inclusion as an important item in Kerala homesteads.

The performance of *Eryngium foetidum* was studied at three levels of shade (25, 50 and 75%) and four spacings (10cm × 15cm, 15cm × 15cm, 20cm × 15cm and 30 cm × 15 cm). High Density Poly Ethylene shade nets of appropriate mesh size were used for providing the required shade levels. Observations on growth parameters, physiological characters, growth analysis, yield characters, bio-chemical analysis, storage studies etc., were taken and the benefit: cost ratio was worked out.

From the experiment, it was found that the crop performed best under 75 per cent shade level in most of the characters studied. Maximum yield (1411.04 g/plot of size 120 × 150 cm) was recorded under 75% shade level and also at a closer spacing of 10x 15cm (1131.41 g/plot). But the interaction effect of shade and population density on total herbage yield was not significant. On analysis, no measurable quantity of volatile oil could be estimated. The highest NVEE of 0.86 per cent was obtained from the plants grown under 75 per cent shade and a spacing of 30 × 15cm. From the storage studies it was concluded that under ambient temperature the leaves could be stored for a maximum of 5.2 days and 4.8 days when grown under 50 per cent and 75 per cent shade respectively, whereas under cold storage, the leaves from 75% shade could be stored for a maximum of 109.65 days without any deterioration. Maximum benefit: cost ratios of 1.28, 1.27 and 1.21 were obtained in the treatments 75% shade and 15cm × 15 cm

spacing, 75% shade and 10cm × 15 cm and 75% shade and 20cm × 15 cm spacing, respectively.

In general, as the intensity of shade increased, performance of the crop was better. Since the highest level of shade (75%) was found to be the best for the growth and yield of *Eryngium foetidum*, a higher level of shade, can be studied. Further studies on intercropping *Eryngium foetidum* under the existing homestead farming situations and other shaded situations like coconut, rubber, oil palm and other perennial tree crops are necessary. Popularization of the crop and development of appropriate marketing strategy are necessary for making the crop more remunerative.

Appendix

APPENDIX – I

Year and Month	Maximum Temperature (°C)	Minimum Temperature (°C)	Total Rainfall (mm)	Relative Humidity (%)
2006				
June	29.7	23.5	320.8	85.7
July	29.2	23.1	226.8	85.1
August	29.4	23.2	138.1	82.5
September	30.0	23.3	174.6	83.0
October	30.4	23.6	515.9	84.0
November	30.5	23.2	169.0	82.5
December	31.2	21.6	-	77.1
2007				
January	31.5	21.7	6.8	76.9
February	32.2	22.1	0.4	75.3