GROWTH AND PHYSIOLOGICAL RESPONSE OF *Dendrobium* cv. EARSAKUL IN DIFFERENT GROWING CONDITIONS

by

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THESIS

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requirement for the degree of

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2014

DECLARATION

I hereby declare that this thesis entitled "**Growth and physiological response of *Dendrobium* cv. Earsakul in different growing conditions**" is a bonafide record of research done by me during the course of research and that the thesis has not previously formed the basis for the award of any degree, diploma, fellowship or other similar title, of any other University or Society.

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DEDICATED TO *DENDROBIUM* ORCHID GROWERS

Introduction

1. INTRODUCTION

Floriculture has become one of the important high value agricultural industries in many countries of the world. Due to globalization and its effect on income enhancement in different regions of the world, a growing per capita consumption of floricultural products is witnessed in most of the countries. All over the world, the floriculture sector can now-a-days be characterized as a sector experiencing rapid changes. Besides the traditional centres of production (USA, Japan, Italy, the Netherlands, and Columbia), new production centres are developing fast. In Asia, countries like India, China, Vietnam etc. seems to be moving in the direction of more intensive floriculture. The floriculture industry in India comprises the florist trade, nursery plants, potted plants, bulb and seed production, micro-propagated material and extraction of essentials oils from flowers. The area of floriculture in India is 2,53,000.65 ha, total production of loose flowers was 16,51,000.61 MT and cut flowers 75,065.98 million flowers. The total quantity of 27,776.20 MT of flowers was exported to different countries with worth of Rs. 28, 645.40 lakhs during 2010-2011 (NHB, 2012).

Orchids, the most spectacular cut flower among the flowers, are unique with their versatility in colour, form, size, shape and longer life span of the plant and flower. They are famous for their long lasting character and beauty which fetch a very high price in the international market. Taxonomically, it belongs to the most highly evolved monocotyledons family, Orchidaceae with 600-800 genera and 25,000-35,000 species. Orchids have a wide range of growing habit, from terrestrial to epiphytic. In the past couple of decades, they have occupied a coveted position in the international flower market, evolving into a multi billion dollar business. With the recent increase in the world floriculture trade, orchids have become the second most popular plants as cut flowers as well as pot plants with an annual growth rate of 10-20 per cent (Hossain, 2010). Orchids are present in all the countries, except in Antartica and majority of the cultivated orchids are native to tropical countries, occurring in their greatest diversity in humid tropical

forests of South and Central America, Mexico, India, Ceylon, Burma, China, Thailand, Malaysia, Philippines, New Guinea and Australia. Orchids are grown worldwide with almost 8 per cent share in the world's floriculture trade (Asghar *et al*., 2011). In many countries, orchid industry plays an important role as a source of foreign exchange.

India being one of the mega biodiversity regions in the world, is endowed with a rich heritage of orchids with about 1300 species in 167 genera distributed in various parts of the country especially in the Eastern Himalayas and the Western Ghats which are the two major biodiversity hot spots. Sikkim, West Bengal (Darjeeling and Kalimpong), Kerala, Karnataka and Maharashtra are leading states in India for orchid cut flower production. The climatic condition of Kerala is highly congenial for growing orchids. Among the cultivated epiphytes, *Dendrobium* was the most popular one. In Kerala, *Dendrobium* occupy more than 75 per cent of cultivated orchids. The popular hybrids here are Earsakul, Sonia 17, Sonia 28, Renappa, Sabine Red, Emma White, Kasem White, Pink, Fairy White and Pravit White. These hybrids are highly floriferous and occur in all possible shape, size and colour. Being sympodial in growth, they are easy to house and maintain. These hybrids differ not only with respect to morphological features of plants and blooms but also in their response to various external factors.

The type of nutrients, their quality and frequency of application play an important role on the growth and quality of flower. In orchids, growth and floral initiation is determined by the genotype and its interaction with the environmental conditions. Temperature, humidity, light and photoperiod are some of the important environmental conditions that influence reproductive biology of orchids. Regulation of light intensity is essential for successful orchid culture. During plant development, the transition from vegetative to reproductive growth is triggered by a number of environmental and endogenous signals. Under controlled conditions of greenhouse, the flowers exhibit the best quality attributes required for the market. For better growth, yield and quality of the flowers, the system of growing is very important. Micro climate inside the growing system

may drastically influence the growth, flowering and quality of flowers. In their natural habitat, epiphytes usually meet with a greater degree of environmental stress.

To optimize orchid growth and flowering, a commercial grower must have an understanding of some basic physiological processes that are relevant to orchid cultivation including photosynthesis, respiration, mineral nutrition, control of flowering and partitioning of assimilates. The ability to control flowering in tropical orchids using physiological tools is indeed crucial. Optimization of the production process and ensuring a quality product for the market is equally important. To achieve this goal, a good understanding of orchid physiology is essential to solve the key physiological issues. This is crucial in the optimization of the growth and yield of orchids in commercial farms.

Keeping in view all these problems, the present experiment entitled 'Growth and physiological response of *Dendrobium* cv. Earsakul in different growing conditions' was taken up with the objective to study the response of *Dendrobium* cv. Earsakul to nutrients, plant growth promoting root endophyte (PGPRE) (*Piriformospora indica*) and plant growth regulators under three microclimatic conditions.

Review of literature

2. REVIEW OF LITERATURE

In this chapter, relevant literature based on the objectives of the study are reviewed and presented in the order of response of nutrients, growth regulators and plant growth promoting root endophyte on the growth, flowering and physiology of orchids. The effect of crop to environmental factors and microbial associations are also reviewed.

2.1 Response of crop to varying levels of nutrients

The type of nutrients, their quality and frequency of application play an important role on the quality of flower. The growth, flowering, yield and physiology of the crop are influenced by nutrients at various stages of growth and development. Studies on the response of the crop to different nutrients are reviewed and presented here under.

2.1.1 Growth characters

2.1.1.1 Organic manures

Vermiwash contains N 0.020 %, P 0.007 %, K 0.100 % and Zn 170 ppm and some nitrogen fixing bacteria, *Nitrosomonas* and *Nitrobacter*. Nitrogen present in vermiwash helps to promote vegetative growth (Ramachandran and Thimmaraju, 1983). Sanfilippo *et al.* (1990) suggested that microbes associated with earth worm body probably produce auxin and gibberellin like substances, which promotes seedling growth in plants.

Vermiwash is a transparent, pale yellow, liquid biofertilizer. It is a mixture of excretory products and mucous secretion of earthworms (*Lampito mauritii* and *Eisenia foetida*) and organic micronutrients of soil, which may be promoted as a potent fertilizer for better growth and yield of plants (Shweta *et al*., 2005).

The vermiwash contains a considerable amounts of mucus and excretory substances (urea, ammonia and phenols), which directly promote plant growth

and beneficial microbes producing plant growth promoters (Suthar, 2010). The vermiwash may contain cytokinins, auxin, amino acid, vitamins and enzymes possibly derived from microbes associated with earth worms (Suthar, 2010). In *Cyamopsis tertagonoloba* seedlings, the maximum root length and shoot length was in 100 per cent vermiwash treatment i.e. 8.65 ± 0.44 cm and 12.42 ± 0.91 cm, respectively and number of leaves also higher in 100 per cent vermiwash treated plants (Suthar, 2010).

Karuppaiah and Sendhilnathan (2011) applied foliar organic nutrients *viz.*, vermiwash (1 per cent and 2 per cent), panchagavya (1per cent and 2 per cent), humic acid (0.2 per cent and 0.3 per cent) and tender coconut water (1:1 and 1 : 2 dilution) at four days and eight days interval in *Dendrobium* cv. Sakura pink and reported that vermiwash 1 per cent at 4 days interval was found to be optimum for vegetative growth.

The highest uptake of nitrogen was recorded in the treatment involving 1:10 groundnut oilcake during shoot emergence stage, in both the varieties *i.e. Dendrobium* var. Sonia 17 and Sonia 28. During spike emergence, the highest uptake was recorded by 500 mg l^{-1} BA in Sonia 17 and 1:10 groundnut oilcake in Sonia 28. In Sonia 17, the highest value of P during both the stages was recorded in plants treated with 0.1 per cent NPK 13:27:27. In Sonia 28, the highest uptake of P at both the stages was with the treatment 1:10 groundnut oil cake. In Sonia 17, the highest K uptake was with 1:20 groundnut oilcake during the emergence of shoot and during the emergence of spike, the highest uptake was with 0.1 per cent NPK. In Sonia 28, during the emergence of shoot, the highest uptake of K was with a combination of 0.1 per cent greencare + 1:10 groundnut oilcake whereas during the emergence of spike, the highest value was recorded in plants receiving 1:10 groundnut oilcake alone (Nair, 2001).

Growth of *Phalaenopsis* in sugarcane bagasse was reported to improve significantly by increasing the nitrogen dose from 70 ppm to 200 ppm and also by inclusion of 10-40 per cent organic fertilizer (Wue *et al*., 1994).

Specific organic manures for orchids stimulate rooting and vegetative growth. Generally, they consist of bone or shell meal, castor meal and contain additional substances such as IBA that stimulate rooting in some cases (Novais and Rodrigues, 2004). Rapeseed oil cake and bone meal in equal proportions were found to improve the uptake of nutrients by *Cattleya* plants grown in sphagnum moss (Tanaka *et al*., 1989).

Organic manures like cow dung, neem cake, groundnut cake and poultry manures etc. were used for orchids. These were soaked in water 4-5 days for fermentation, diluted 10-15 times with water, filtered and sprayed over the plants. Fresh cow's urine (1:20-25 with water) is also useful as foliar spray (Singh, 2006). Holttum (1964) stated that judicious manuring would be beneficial to orchids grown on charcoal and brick.

Wong and Chua (1974) made a comparison between chicken manure (64 g, 129 g and 257 g per plant per month) and an inorganic fertilizer. *Arachnis* 'Maggie Oei', *Aranda* 'Deborah', *Aranda* 'Nancy' and *Aranthera* 'James Storie', when given chicken manure, gave significantly higher inflorescence yields and faster growth than those grown using inorganic fertilizer. Comparing the chicken manure treatments, *Arachnis* 'Maggie Oei' responds significantly to manuring and the other hybrids showed no significant yield differences.

Several organic substances were found to stimulate growth and development in orchids. Fresh as well as dry cowdung, sheep, chicken, pig, fish manure, dried leaves, oil cakes and bone meal are some of the common manures used for feeding orchid plants (Chua, 1976). Chua (1976) suggested that recommended level of chicken manure for *Dendrobium* and *Oncidium* was 100 g and 50 g per plant once in three months, respectively. Diluted pig manure was found to enhance the vegetative growth in *Oncidium* 'Caldwell' (Koay and Chua, 1979).

Fresh as well as dry cow dung, sheep, chicken, pig or fish manure, dried leaves, oil cakes and bone meal are some of the common manures used for feeding orchids. Application of dilute urine, one part in ten parts of water is beneficial, as it contains all necessary nutrient elements and also certain growth promoting substances. Abraham and Vatsala (1981) found that beer at the strength of one quart per 10 gallons of water is beneficial for the growth of the orchids. Spraying with supernatent liquid of cow dung slurry (1 kg fresh cow dung in 5 l water) was recommended in orchids (KAU, 2011).

The growth of young plants of *Dendrobium* hybrids was found to improve when they were provided with 20 per cent coconut milk. This treatment increased leaf number and height of pseudobulb, although when treated without coconut milk application, more pseudobulbs were produced (Sagarik and Siripong, 1963).

Plant height and number of leaves per plant was maximum (30.00 cm and 7.32 cm respectively) in the treatment combination of NPK 30:10:10 (0.2 per cent) weekly once + 3% panchagavya, whereas the maximum number of shoot per plant (4.57) and the maximum length and breadth of leaves were recorded highest in the treatment combination of NPK 30:10:10 (0.2%) weekly once + 3% panchagavya + 3% manchurian tea in *Dendrobium nobile* under Kalimpong conditions (Anon, 2004-2005).

In *Cymbidium* "Red Star'', it was observed that application of NPK 30:10:10 (0.2per cent) weekly once + 3% panchagavya + 3% manchurian tea + 3% vermiwash produced tallest plant (113.61 cm) (Anon , 2004-2005).

2.1.1.2 Inorganic nutrients

In comparison study of different levels of N in growing medium of *Phalaenopsis* and *Cattleya* seedlings, Sheehan (1962) reported increase in leaf growth with increase in nitrogen application. Penningsfield and Fast (1962) reported the effect of deficient and excess use of nitrogen in *Cattleya*. Increased use led to rotting of roots and leaves and deficiency resulted in yellowing and wilting of leaves.

An increase in N was found to have a favourable effect on plant height as reported by Sagarik and Siripong (1963) in young *Dendrobium* hybrids. Northen (1970) observed that excess nitrogen increased vegetative growth and delayed flowering in orchids. A combination of NPK was found best for growth and flowering of a large number of species and hybrids suitable for growing under warm humid conditions (Bose and Bhattacharjee, 1972).

For *Aranda* Wendy Scott, both vegetative and reproductive growth is affected by increasing nitrogen levels (36, 72 mg per plant per application). The magnitude of increase in growth was also depending on potassium and phosphorus levels (Wong and Chua, 1974).

Dendrobium nobile plants grown in sphagnum moss (*Sphagnum magellanicum* Brid.) or hemlock (*Conium maculatum* L.) bark were given 10 different combinations of 0, 250 mg l^{-1} , 500 mg l^{-1} , and 1000 mg l^{-1} N, P, and K over a period of two years (Miwa and Ozaki, 1975). Pseudobulb number, pseudobulb length, width, and leaf number were highest at 1000 mg l^{-1} N. With the exception of one nutrient combination containing 500 mg l^{-1} N, 1000 mg l^{-1} N produced the least flowering nodes and resulted in the greatest number of keikis (aerial shoots).

Bhattacharjee (1977) reported that spraying N, P_2O_5 and K_2O 100 ppm each at fortnightly intervals was beneficial in *Bulbophyllum*. In *Cymbidium* and *Phalaenopsis* seedlings, 100 ppm N together with 50 ppm P and 25 ppm K was found to be optimal (Poole and Seeley, 1978). Based on their studies on nutrient culture of *Cattleya, Cymbidium* and *Phalaenopsis,* they concluded that N concentration was the most important factor determining growth of all the three orchid genera.

Poole and Seeley (1978) found that for three orchid genera (*Phalaenopsis*, *Cymbidium* and *Cattleya*), 50 mg l^{-1} K was sufficient for growth and higher levels had no further effect except in *Cattleya* at 200 mg l^{-1} K, which resulted in fewer leaves.

Of the rates used (50 mg l^{-1},100 mg l^{-1} and 200 mg l^{-1} N), 100 mg l^{-1} N was recommended for *Phalaenopsis* and *Cymbidium* because it resulted in greater leaf and root dry weights and larger, more leaves and increased plant height (Poole and Seeley, 1978).

Poole and Seeley (1978) reported that *Cymbidium* plants had fewer number of leaves when supplied with 200 mg l^{-1} K than plants receiving 50 mg l^{-1} or 100 mg l^{-1}. In *Cymbidium* seedlings, 100 ppm N, 50 ppm P and 25 ppm K was found optimum (Poole and Seeley, 1978).

In *Phalaenopsis* seedlings, 100 ppm N together with 50 ppm P and 25 ppm K was found optimum for their better growth (Poole and Seely, 1978). Gomi *et al*. (1980) recommended nutrient solution containing 77.0 ppm, 15.5 ppm, 39.1 ppm, 80.1 ppm and 12.2 ppm N, P, K, Ca and Mg respectively, for maximum vegetative growth, which was thrice that of standard level of application in four-year-old *Phalaenopsis* hybrids. The growth of orchids is markedly improved by regular schedule of fertilizing the plants in liquid form (Bose and Bhattacharjee, 1980).

In a study conducted in *Aranda* 'Noorah Alsagoff' the nutrient requirement found optimum for enhancing growth parameters was 20.90 mg nitrogen, 5.00 mg phosphorus and 21.80 mg potassium applied at weekly intervals (Khaw and Chew, 1980).

The elements N, P and K in the ratio of 20:20:20 used every week followed by 10:30:20 NPK mixture was found to be successful recommendation for various orchids grown under south Indian conditions (Abraham and Vatsala, 1981). Bhattacharjee (1981a) reported that in *Dendrobium moschatum* cv. 'Wall', both 500 mg l^{-1} and 1000 mg l^{-1} K levels resulted in plants that had more leaves than plants receiving 0 mg l^{-1} K.

According to Arditti and Ernst (1981), ammonium nitrate is the best source of N during the early *ex vitro* stage of orchids. Bhattacharjee (1981a) studied the effect of N, P and K of 0, 500 and 1000 ppm on *Dendrobium moschatum* and concluded that they markedly improve vegetative growth.

Addition of P_2O_5, influenced all vegetative characters. Concentration of 500 ppm of all the three nutrients was the best.

A fertilizer mixture of NPK (30:10:10) rich in nitrogen was found to be good for vegetative growth of orchids as reported by Boodley (1981); Linda (1987); Stewart (1988); Marguerite (1989) and Peter (1990).

Abraham and Vatsala (1981) and Singh (1992) reported that N has significant influence on the vegetative growth of orchids. The N:P:K:Mg ratio of 1.25: 0.4: 0.75: 0.1 has been suggested for the growth of *Cattleya* (Poole and Sheehan, 1982). The optimum NPK ratio for *Dendrobium pompadour* has been identified as 1.5:1.5: 1 (Poole and Sheehan, 1982; Hew and Yong, 1997).

The application of liquid fertilizers, 500 ppm potassium nitrate, 500 ppm ammonium nitrate and 100 ppm ammonium sulphate on seedlings of *Cymbidium* 'Pharoah pathfinder' resulted in overall increase in vegetative growth when applied as spray at weekly intervals for a period of six months (Bik and Berg, 1983).

Nutrient solution containing 100 ppm N, 20 ppm P and 75 ppm K was recommended for improving vegetative growth in *Cymbidium* and *cattleya* (Johnson, 1984). Higher dose of nitrogen was found to be beneficial under outdoor cultivation of orchids and longer pseudobulbs were produced when nitrogen was applied at 48 mg l^{-1} (Sakai *et al*., 1985). Schum and Fisher (1985) obtained higher number of leaves and fresh weight with N and K applied in the ratio 1:1. Yadav and Bose (1986) reported that spraying of N, P and K at 1000 ppm each, enhanced length and number of leaves in *Aerides multiflorum*, but plants deficient in nitrogen showed stunted growth and early maturity.

Yadav and Bose (1986) found that, in *Aerides multiflorum*, plants with nitrogen deficiency showed stunted growth and early maturity. Spraying of 1000 ppm each of N, P and K enhanced the length and number of leaves. In *Dendrobium* 'Lim Hepa', increasing nitrogen dose from 50 ppm to 300 ppm and potassium from 25 ppm to 150 ppm showed clear effects on vegetative growth. Nitrogen at 300 ppm enhanced stem length (Uesato *et al*., 1987). Stewart (1988)

recommended a combination of 3:1:1 NPK for better vegetative growth and 1:1:1 for sustained growth respectively. Several formulae for fertilizer solutions have been recommended by various workers (Yadav and Bose, 1986).

Mukherjee (1990) recommended a formulation containing calcium nitrate, magnesium sulphate, potassium nitrate and ammonium sulphate as major components in addition to trace elements for ideal growth of pot grown orchids. Seeni and Latha (1990) suggested that combination of diammonium phosphate and potassium nitrate (20:10:10 NPK) was most effective in terms of rapid leaf and root growth in *Phalaenopsis*. Since the length of the juvenile period of *Phalaenopsis* orchid is directly associated with the speed of leaf production and leaf area expansion (Lee, 1991), it may be beneficial to use a high concentration of fertilizer (200 mg N l^{-1}) on young plants for rapid growth.

Wen and Hew (1993) concluded that the growth of roots and leaves of *Cymbidium sinense* was considered to be fastest when the plants were grown with ammonium nitrate as the nitrogen source.

Nitrogen (both NH_4-N and NO_3-N) at concentration between 1 and 10 µ mol increases leaf number, leaf growth and flower number of *Cymbidium sinense*. At high concentration (50 µ mol) of NH_4-N and NO_3-N, both leaf growth and flower number decreases. Generally NO_3-N is a better nitrogen source for *Cymbidium sinense*. However, excellent leaf and root growth were observed when NH_4-N and NO_3-N were supplied together as nitrogen sources at appropriate concentrations (Wen and Hew, 1993; Pan and Chen, 1994).

NPK 17:17:17 complex sprayed at weekly intervals at 10 g l^{-1} could increase the number of clumps and leaves in *Cymbidium traceanum* (Sobhana and Rajeevan, 1995).

Wadasinghe and Hew (1995) suggested that the leaves of backshoots of *Dendrobium* cv. Jashika Pink were an important source of photosynthates for the growth and flower production. Hence adequate nutrition in the current season becomes beneficial for the succeeding vegetative growth as well as flowering.

Thekkayam (1996) reported that 75 per cent light with 400-500 ppm of N, P and K can be recommended for good growth in *Dendrobium* Sonia 17.

Wang (1996 a) found no statistical differences between six water soluble NPK mixtures 10:30:20, 15:20:30, 15:20:25, 20:5:19, 20:10:20 and 20:20:20 which was tested at concentrations of 100 mg l^{-1} or 200 mg l^{-1}, applied to *Phalaenopsis* by fertigation and concluded that the highest concentration 200 mg l^{-1}, corresponding to 1.0 g l^{-1} of 20:20:20 should be used in the initial growth stage. For adult plants, however, a lower concentration should be used to avoid exaggerated leaf growth, which would require more space on the benches, thus raising production costs.

Wang (1996a) observed that higher nitrogen rate produced wider leaf spread and more number of leaves, regardless of the type of the fertilizer used in young seedling of *Phalaenopsis* cv.Tam Butterfly. In *Phalaenopsis* 'Pink Chiffon' an increment of nitrogen from 50 ppm to 1000 ppm showed positive results on vegetative characters, especially on the number of leaves (Sheehan, 1996).

Phalaenopsis grown in a medium of 70 per cent fine grade fir bark and 30 per cent peat produced taller plants, greater pseudobulb number and larger leaves that were wider when N was applied at the higher rate of 100-400 mg l^{-1} (Wang, 1996 b).

Thekkayam (1996) reported that plants grown under 75 to 100 per cent light and a nutrient dosage of 300 ppm N, 400 ppm P and 300 ppm K from the time of planting to nine months after planting and thereafter a dosage of 400 to 500 ppm N, 400 ppm P and 500 ppm K showed positive results in growth characters in *Arachnis* 'Maggie Oei Red Ribbon' grown in trenches.

In *Arachnis* Maggie Oei 'Red Ribbon' the trench grown plants under 50 per cent and 75 per cent light had a greater number of leaves and leaf area. The plants receiving 500 ppm of P and K under 100 per cent light had a shorter stature. The direct effect and interactions of nutrients on growth were observed at certain months during the experimental period which was indicative of differences

in the requirement at different stages of growth. The dry matter content of the stem and apical shoot was greater in the plants receiving 500 ppm P (Thekkayam, 1996).

Taejung *et al*. (1998) reported that *Cymbidium* showed slightly different growth responses, especially in terms of root growth, depending on the ratio of NPK. Shoot and root growth were favoured when NPK ratio of liquid fertilizer was 5:10:5. Healthy, compact plants were produced in the presence of fertilizers containing a high content K.

Studies conducted by Umamaheswari (1999) in *Dendrobium* Sonia-17, showed that nitrogen at 6.0 mg per plant increased the plant height, number of leaves and number of back bulbs. Upto 90 DAP, 2.0 mg of N was found to increase the stem girth and after that 6.0 mg was found to be favourable. Phosphorous had less influence on growth. P at 6 mg increases the stem girth and number of backbulbs at early stages. Potassium at 2.0 mg had influence on the plant height, number of leaves and number of back bulbs.

Sobhana (2000) reported in *Dendrobium* that out of the different nutrient solutions tried, 30:10:10 NPK mixture (0.1-0.2 per cent) sprayed on alternate days gave best results in terms of number of shoots and number of leaves. Wang (2000) found that for *Phalaenopsis,* grown in a mixture consisting of douglas fir bark and sphagnum peat, 50 mg l^{-1} P was adequate for good vegetative growth and reproductive development.

In *Dendrobium* var. Sonia 17, plant height was significantly superior with the combination of NPK 30:10:10 at 0.2 per cent applied weekly twice. Among the other vegetative characters, number of shoots, number of leaves, total leaf area and biomass progress were superior with the combination of 30:10:10 NPK at 0.2% + GA 200 ppm, applied weekly twice (Swapna, 2000).

Devi and Chezhian (2001) observed highest leaf length (12.85 cm) and width (6.04 cm) in *Dendrobium* hybrid Sonia-17 in the treatment 30:10:10 NPK sprayed at 0.2 per cent weekly twice.

Many growers suggested eliminating urea from fertilization programmes, while several researchers and growers of *Phalaenopsis* concluded that a fertilizer solution rich in urea gives more vigorous plants with larger leaves than when using a solution where nitrogen is present only in the form of nitrate or ammonium (Bergman, 2002; Wang and Konow, 2002). Hew *et al*. (2002) reported in *Vanda* 'Miss Joaquim' that longer canes were produced in the treatment receiving higher levels of N.

Binisha (2003) found that the treatment combination of NPK 10:5:10 at 0.2 per cent concentration along with *Azospirillum* proved to be very effective in improving vegetative characters like plant height, number of leaves, number of shoots and girth of shoot in *Dendrobium*.

Shanker *et al.* (2003) studied the effect of potting media *viz*. charcoal and gravel chips and nutritional spray of two concentrations @ 1 g l^{-1} and 1.5 g l^{-1} from 19:19:19 NPK based water soluble fertilizer at an interval of once in 4 and 8 days on the growth and yield of *Dendrobium* hybrid white hairy. The vegetative parameters like plant height and number of leaves were found to be favourably influenced by both potting media and spraying of nutrients.

Dendrobium 'Sonia 17' produced the highest plant height (20.6 cm) with the application of NPK at 20:10:10 (0.2 per cent). However, the interaction effect of NPK and BA showed the highest plant height of 28.33 cm with the application of NPK at 10:10:10 at 0.2 per cent in combination with BA at 100 ppm. The number of shoots per plant was highest (5) with the application of distilled water spray in combination with GA_3 50 ppm (Anon, 2003-04).

During pre-blooming stage, plant height and number of leaves per plant was maximum with treatment combination of NPK 30:10:10 (0.2 per cent) weekly once + 3% panchagavya, whereas the maximum number of shoots per plant and the maximum length and breadth of leaves were recorded highest in the

treatment combination of NPK 30:10:10 (0.2 per cent) weekly once + 3% panchagavya + 3% manchurian tea in *Dendrobium nobile* under Kalimpong conditions (Anon, 2003-2004).

In *Dendrobium* 'Sonia-17' grown under Coimbatore conditions, it was observed that the maximum plant height and number of shoots per plant were 50.1 cm and 12.0, respectively in the treatment NPK (10:5:10) 0.2 per cent spray at weekly twice + root dipping of *Azospirillum* + *Phosphobacteria* before planting (Anon, 2003-2004).

Ramachandrudu (2008) reported that plant height (49.35 cm), internodal length (5.99 cm) and total number of canes per clump (6.80) in *Dendrobium* K.B. Pink, number of leaves per cane (14.87) and cane girth (7.25 cm) in *Dendrobium* Burena Zeb, leaf length (15.46 cm) in *Dendrobium* Singapore White and leaf width (6.62 cm) in *Dendrobium* Thongchai Gold were maximum among *Dendrobium* varieties when the plants were applied with 19:19:19 NPK @ 0.2 per cent concentration twice a week.

Bichsel and Starman (2008) reported that plants were taller and had more nodes when they were supplied with N, P 100 mg l^{-1} and K 200 mg l^{-1} compared with lower and higher rates in Nobile *Dendrobium*. Barman *et al*. (2008) found that application of 200 ppm each of N, P and K recorded highest pseudobulb diameter in *Cymbidium* "Soulhunt-6".

Cymbidium plants grown in leaf mould + FYM + charcoal + coconut husk + rotten log (2:1:1:1:1) media and applied with N 200 ppm, P 100 ppm, K 100 ppm + BA 100 ppm and GA_3 100 ppm for breaking juvenility and N 200 ppm, P 200 ppm, K 200 ppm + BA 500 ppm + GA_3 500 ppm for enhancing flowering frequency significantly improved vegetative parameters as well as flowering (Barman *et al.*, 2008).

Dhinesh (2009) reported that in *Dendrobium* cv. Earsakul, among the growth characters, upto 12 months after planting, different treatments did not show appreciable difference in plant height. But during later stages of growth, significantly higher plant height was recorded in treatment combinations of POP

recommendations of KAU for orchids (3:1:1 $N:P_2O_5:K_2O$ during vegetative growth and 1:2:2 $N:P_2O_5:K_2O$ during flowering @ 0.2 per cent applied weekly twice) + *Piriformospora indica* and in POP+ organic mixture+ vermiwash+ *P. indica* + bone meal. In general, no significant variation in number of leaves and number of shoots was observed among different treatments. Maximum girth of the shoots was resulted by providing POP+ organic mixture+ vermiwash+ *P. indica* + bone meal from 9 months after planting. Among the different treatments, maximum internodal length was recorded by providing POP + *P. indica* towards the later stages of growth.

For one-year-old plants of *Cymbidium*, NPK ratio of 30:10:10 @ 0.1 per cent was found to be the best in terms of growth attributes like leaf length, leaf width, pseudobulb length, pseudobulb girth and number of pseudobulbs per clump. For intermediate growth stage (two year old), the NPK ratio of 20:20:20 @ 0.1 per cent was found suitable for growth characters (Naik *et al*., 2010).

Nair and Sujatha (2010) reported that among the growth characters, the number of leaves per plant was maximum (18.31) in the plants which received 1:2:1 NPK, number of productive canes per plant was maximum (5.99) in the plants with the combination of 1:6:1 NPK and the length of the canes was significantly superior (49.23 cm) in the plants which received 3:4:1 levels of NPK at 0.2%, sprayed at biweekly intervals in *Dendrobium* cv. Sonia 17.

Naik *et al.* (2010) found in *Cymbidium* 'Pine Clash Moon Venus' that the various growth parameters *viz.,* leaf length, leaf width, pseudobulb length, girth and number of pseudobulbs per clump were highest in the treatment 30:10:10 NPK for young *Cymbidium* (during first year) while for intermediate growth of *Cymbidium* (during second year), the fertilizer dose of 20:20:20 NPK was best among the different doses of NPK. The fertilizer dose 30:10:10 NPK recorded 10 per cent and 14.6 per cent increase in leaf length and width, 12 per cent and 6.4 per cent increase in pseudobulb length and girth, 42.9 per cent increase in number of pseudobulb per clump, respectively over control during first year. However, NPK 20:20:20 showed 14.5 per cent and 12.92 per cent increase in leaf length and width, 27.3 per cent and 6.6 per cent increase in pseudobulb length and girth,

55.6 per cent increase in number of pseudobulb per clump, respectively over control during second year.

Nair and Sujatha (2010) reported in *Dendrobium* var. Sonia 17 that the maximum number of productive canes per plant (6.73) was recorded with the combination of 1:6:1 NPK at 0.2 per cent, applied at biweekly intervals during March 2007. The maximum number of leaves per plant (24.3) was recorded with the combination of 3:1:1 NPK during March 2007.

Tiwari and Kumar (2011) reported that plant height, number of leaves, number of shoots, girth of the pseudobulb and length of the pseudobulb were higher with the combination of NPK 19:19:19 @ 0.1 per cent applied weekly once in *Cymbidium iriodiodes* plants compared to other varieties.

Foliar sprays of supernatent liquid of cowdung slurry, inorganic nutrients of $N:P_2O_5:K_2O$ 3:1:1 during vegetative stage, 1:2:2 during flowering period @ 0.2 per cent weekly twice are recommended for orchids (KAU, 2011).

Kabir *et al*. (2012) reported that in *Dendrobium* sp. the trend of increase in leaf length, leaf width, leaf area index, leaf number, leaf area and total leaf area was the highest with the combination of N:P:K 10:25:30 sprayed weekly once, while the plant height and stem diameter were maximum with the combination of N:P:K 15:20:20 sprayed weekly once.

Sugapriya *et al*. (2012) reported that among different *Dendrobium* sp. grown under fan and pad polycarbonate green house, height of the pseudobulb (54.97 cm) in Burana fancy, girth of the pseudobulb (6.23 cm) in Medameuraiwan, number of pseudobulbs per plant (17.00) in Manel, number of leaves per pseudobulb (18.33) in Medameuraiwan and length of internode (15.5 cm) in Manel were maximum compared to others which were sprayed with 3:1:1 NPK during vegetative phase and 1:2:2 NPK during blooming phase @ 0.2 per cent at weekly twice.

2.1. 2 Flowering

2.1. 2.1 Organic manures

In a two–year pot trial with *Oncidium* Golden Shower and *Dendrobium* Louisae Dark, dried chicken manure at 50 g, 100 g or 200 g per plant every three months was compared with a complete nutrient solution foliar spray at 25 g in 4.5 liters of water every 10 days. Chicken manure increased flower yield in *Dendrobium* and increased inflorescence length and number of flowers per spray in both orchids, but the highest rate was sometimes detrimental. The intermediate rate was best for *Dendrobium* and lowest rate was best for *Oncidium* (Chua, 1974).

In *Oncidium* 'Goldiana', the use of chicken manure only increases the spike length when compared with those treated with chemical fertilizers. Flower yield decreases when high dosages of chicken manures are applied (200 g per plant once in three months). The recommended level of chicken manure is 100 g and 50 g per plant once in 3 months (Chua, 1976). Nutrient content is generally low in animal manure (Khaw, 1982). The organic manure retains moisture and nutrients and it releases nutrient slowly.

2.1.2.2 Inorganic nutrients

Sheehan (1962) recorded increased yield of spikes and flowers in *Phalaenopsis* by applying high dose of nitrogen. Vachorotayan and Keethapirom (1975) found improvement in flowering of *Dendrobium* Madame Pompadour with NPK ratio of 3:3:2 to 5:5:2.

With an increase in the NPK dose of 3:2:2 to 5:5:2, improvement in flowering of *Dendrobium* Madame Pompadour was observed (Vachorotayan and Keethapirom, 1975). Miwa and Ozaki (1975) reported in *Dendrobium* cv. Red Emperor 'Prince' that flowering was delayed when phosphorus was not applied.

Pradhan (1976) recommended the use of 1:1:1 of NPK mixture for flowering season. Bose (1978) suggested that growth and flowering in orchids are improved by a regular schedule of fertilizers in liquid form. Increased nitrogen supply in *Phalaenopsis* upto 1000 ppm produced longer flower spike and spike with increased girth.

Maximum flower production in *Dendrobium moschatum* was obtained by the application of 1000 ppm nitrogen and 500 ppm each of phosphorous and potassium (Bhattacharjee, 1981 a).

In *Cattleya*, an increase of NPK dose from 77:15.5:39.1 ppm to 308:62:156.40 ppm resulted in early flowering and increased fresh weight of flowers (Tanaka *et al*., 1981, 1988a, 1988b, 1989).

Influence of different levels of N, P and K fertilization was investigated by Bhattacharjee (1982) on *Aerides multiforum*. It showed marked improvement in the production of number of flower stalks per plant with maximum number of large sized flowers on longer stalks with 100 ppm each of N and P_2O_5 spray.

Boon (1982) and Merriman (1987) recommended N, P and K in the ratio 11:13:60 at weekly intervals for increased flower production during summer and autumn in *Oncidium* and *Cymbidium,* respectively.

N, P and K in the ratio of 11:13:6 at weekly intervals is recommended for flower production during summer and autumn in *Oncidium* (Boon, 1982; Merriman, 1987). Stewart (1988) suggested that use of a high K content combination of NPK 1:1:3 was beneficial for flowering. Longman (1989) recommended foliar feeding of mature flowering plants using NPK at 18:18:18.

Increasing the N concentration from 50 mg l^{-1} to 200 mg l^{-1} promoted flowering in a white- flowered hybrid *Phalaenopsis* (Wang and Gregg, 1994). Heavy fertilization was reported to result in greater flower count in *Phalaenopsis* (Wang and Gregg, 1994; Wilcock, 1973).

Wang and Gregg (1994) reported that increasing the nitrogen application from 0.25 to 1.00 g l^{-1} increased the flower number, stalk diameter and stalk length in *Phalaenopsis*.

Thekkayam (1996) reported that nitrogen at 500 ppm increased the length of inflorescence, number of florets per inflorescence and span area of the flowers. The number of inflorescences produced was also greater in the plants receiving 400 ppm or 500 ppm nitrogen, 400 ppm or 500 ppm K and in those receiving 500 ppm P in *Dendrobium* 'Sonia 16'.

Wang (1996 b) reported that fertilizer application using 20.00, 8.60 and 16.60 NPK @ 1 g l^{-1} in *Dendrobium* 'Renappa' resulted in more number of inflorescence and flowers.

Yoneda *et al.* (1999) studied the effect of macro element concentration on growth, flowering and nutrient absorption in *Odontoglossum* hybrid. They observed that low N rates resulted in shorter and thinner stalks, fewer flowers and advanced flowering date.

Swapna (2000) reported that application of NPK as ammonium nitrate, orthophosphoric acid and potassium nitrate 10:20:20 at 0.2 per cent applied weekly twice was significantly superior to all other nutrient treatments for highest spike production in *Dendrobium* var.Sonia-17.

Wang (2000), found that there was a decrease in flower number when *Phalaenopsis* was grown in a mixture of 80 per cent douglas fir bark and 20 per cent sphagnum peat were switched to low N (30 mg l^{-1}) and high P (390 mg l^{-1}) and K (506 mg l^{-1}) levels at the beginning of being induced to spike, and concluded that adequate N levels were more essential to flowering than high P levels.

In *Dendrobium* 'Sonia 17' earliest flowering (300 DAP) was recorded in plants which received the treatment combination of NPK 30:10:10 at 0.2 per cent, applied weekly twice + BA 200 ppm followed by NPK 20:10:10 (Swapna, 2000).

Studies were conducted on regulation of flower yield and quality in *Dendrobium* 'Sonia 17' through the use of different combinations of nutrients and growth regulators. A combination of NPK 10:20:10 at 0.2 per cent applied twice a week and monthly application of BA 50 mg l^{-1} and GA_3 10 mg l^{-1} produced the highest number of spikes. The number of florets, number of spikes, spike length, rachis length and internodal length were maximum with NPK 10:20:10 at 0.2 per cent. High concentration of phosphatic fertilizer, such as 10:20:10 has been known to promote blooming in *Dendrobium*. The balance between N and K is, however important and for best results it should be 1:1, unless media requiring high nitrogen are used for growing the plants (Swapna, 2000; Rajeevan and Swapna, 2003).

Swapna (2000) found that nutrients, their frequency of application and growth regulators markedly influenced flower quality and yield. A combination of NPK 10:20:10 at 0.2 per cent, applied weekly twice + BA 100 ppm recorded the maximum number of spikes per year and number of florets per spike. Spike length was significantly superior for NPK 10:20:20 at 0.2 per cent, applied weekly twice + GA_3 20 ppm in *Dendrobium* var. Sonia 17.

Wang (2000) studied the long term effect of reduced fertilizer application and use of low N, high P and K fertilizer on reproductive performance and flower longevity of hybrid *Phalaenopsis* orchid.

Zhao *et al*. (2001) recorded maximum number of flower spikes of *Cymbidium* on groundnut husk + sand media and applied with $N:P_2O_5:K_2O$ (10:30:20). Increased levels of phosphorous and potassium at blooming stage has been found to have a positive effect on flowering in orchids (Rajeevan *et al*., 2002).

NPK 20:10:10 at 0.2 per cent concentration and inoculation with *Azospirillum* at the time of planting was found to improve the floral characters like days to first flower opening, days to last flower opening, number of flowers per spike, larger flowers and spike length in *Dendrobium* (Binisha, 2003).

The number of florets in *Dendrobium* 'Sonia 17' was highest (10.7) with the application of NPK 10:5:10 (0.2 per cent) spray at weekly twice + root dipping of *Azospirillum* + *Phosphobacteria* before planting under Coimbatore conditions (Anon, 2003-2004).

Growth and flowering of *Phalaenopsis* was not affected by varying rates of phosphorus. They found that 25-50 mg l^{-1} P was adequate to produce a good crop (Wang *et al.,* 2005).

Over fertilization delay spiking. Nitrate did not delay (Chansean *et al*., 2006) and 50 per cent or higher NO_3-N accelerated spiking, compared to 100 per cent and 75 per cent NH_4-N in *Phalaenopsis* (Wang, 2008).

In plants of *Cymbidium* 'Show Girl Cook's Bridge' grown in media containing perlite + coco chips + brick pieces + leaf mould (1:1:1:1), the spike length and rachis length increased with increasing concentrations of N and recorded maximum of 45.00 cm and 30.25 cm respectively, with the application of NPK 20:5:5 @ 0.3 per cent. The number of flowers per spike increased with increasing concentration of nitrogen and was maximum (5.5) with the application of NPK 15:5:5 @ 0.3 per cent. However, number of flowers per spike decreased with further increase in N concentrations above 15:5:5 NPK. Maintaining a relatively high concentration of N fertilizer is crucial for the better development of spike length, rachis length, number of flowers per spike and number of spikes per clump (Naik and Barman, 2006).

Among *Dendrobium* varieties, maximum spike length (62.94 cm) and higher floret diameter (8.63 cm) in *Dendrobium* Mona Red, more number of spikes per plant (3.55) in *Dendrobium* Singapore White and more number of florets per spike (23.82) in *Dendrobium* Burena Zeb were recorded with the treatment of 10:30:30 NPK @ 0.2 per cent sprayed twice a week (Ramachandrudu, 2008). Bichsel and Starman (2008) reported in orchids that, application of P increased total flower count, indicating that P is needed for initiating more flower primordia.

Dhinesh (2009) reported that among flower characters, earliest flowering, days to first flower opening, days to last flower opening, spike length, flower size and number of flowers per spike were recorded in the treatment receiving 3:1:1 $N:P_2O_5:K_2O$ during vegetative stage and 1:2:2 $N:P_2O_5:K_2O$ during flowering stage @ 0.2 per cent applied, weekly twice + *Piriformospora indica* inoculated at the time of planting in *Dendrobium* cv. Earsakul.

Nair and Sujatha (2010) reported in *Dendrobium* cv. Sonia 17 that the maximum number of spikes per plant per month (0.91), highest number of spikes per plant per year (10.93), more number of florets per spike (12.01), highest length of the spike (66.11 cm) were recorded from 1:6:1 NPK treated plants, while highest flower diameter (9.12 cm) from 2:6:1 NPK treatment was recorded with the combination of 2:1:1 levels of NPK at 0.2 per cent applied at biweekly intervals.

Among different green house grown *Dendrobium* orchids, *Dendrobium* Sonia-17 took less number of days (187.1) for flower bud initiation, exhibited a minimum time interval (31.4 days) from flower bud initiation to flower bud development, least time interval for first floret opening to harvest (24.5 days) in *Dendrobium* Sripatum red and more number of spikes (8.67) in *Dendrobium* Sonia-17 were recorded in plants sprayed with the combination of 3:1:1 NPK during vegetative phase and 1:2:2 NPK during blooming phase @ 0.2 per cent applied weekly twice grown under fan and pad polycarbonate covered green house (Sugapriya *et al*., 2012).

2.1.3 Physiological attributes

2.1.3.1 Leaf area

Poole and Seeley (1978) reported that *Cattleya* had larger leaves and greater dry weight of leaves when supplied with 50 mg l^{-1} N. Wang (1996 a) reported that *Phalaenopsis* plants applied with higher rates of N (100 and 200 mg l^{-1}) produced larger leaves.

Leaf area is a more direct indication of photosynthetic efficiency of a plant. In *Dendrobium*, it is more so, because, being an epiphytic plant, nutrition is little through the growing media. Instead, foliar spray is the common practice for supplying nutrients where increased leaf area favours increased absorption. Total leaf area showed an increase with the increase in nutrient concentration (Swapna, 2000).

Ex vitro established, six months old tissue culture plantlets of *Dendrobium* cv. Sonia-17 when treated with N, P & K in 30:10:10 at 0.2 per cent concentration along with BA 200ppm proved very effective in improving the leaf parameters such as length and width of leaf (Nandini, 2000).

Fernandez (2001) in *Dendrobium* reported that the shade treatments had a direct influence on leaf area during the summer season. Highest leaf area was noticed in 50 per cent double level shading which was much reflected during 6^{th}, 7^{th}, 8^{th} and 9^{th} months after planting.

In *Dendrobium* cv. Earsakul, among the physiological parameters, higher leaf area was resulted by POP of KAU + organic mixture + *Piriformospora indica* + vermiwash + bone meal (Dhinesh, 2009).

Sugapriya *et al*. (2012) recorded highest leaf area (61.06 cm^2) in *Dendrobium* 'Medameuraiwan' grown under fan and pad polycarbonate covered green house. Plants were sprayed with 3:1:1 NPK during vegetative phase and 1:2:2 NPK during flowering @ 0.2 per cent applied weekly twice.

Kabir *et al*. (2012) reported that total leaf area was relatively higher (119.17 cm^2, 127.50 cm^2, 140.87 cm^2 and 167.27 cm^2) in plants which received composition of spray formulation of 10:15:20 NPK sprayed at 45 DAP, 15:20:25 NPK 90 DAP, 10:25:25 NPK 135 DAP and 10:25:30 NPK sprayed at 180 DAP, respectively in *Dendrobium*.

2.1.3.2 Chlorophyll content

Chlorophyll content of leaves was highest in *Cymbidium sinence* applied with ammonium as a source of nitrogen (Wen and Hew, 1993).

He *et al*. (1998) found evidence of shade adaptation in two *Dendrobium* cultivars. In the twelve orchid taxa investigated, chlorophyll *a/b* ratios were usually lowest in the non-velamentous, green root tips and highest in the leaves, which may reflect the exposure levels of the three organ types when growing as epiphytes in their natural habitats.

Chae *et al.* (1998) expressed that the ratio of chlorophyll a, b was in the ratio of 2:1 in several *Dendrobium nobile* cultivars. Based on a study in *Dendrobium*, Khoo and Hew (1999) reported that the chlorophyll a:b ratio was same in the case of flowers and leaves whereas the total chlorophyll content in flowers declined as they matured.

An increase in the content of total chlorophyll, chlorophyll a and chlorophyll b occurred in *Dendrobium* var. Sonia 17 plantlets treated with 40 g l^{-1} of sucrose (Samasya, 2000).

Nair (2001) reported in *Dendrobium* Sonia 28 that maximum chlorophyll content during the emergence of shoot was reported in plants receiving 0.1 per cent 13:27:27 NPK applied weekly twice.

Application of 3:1:1 $N:P_2O_5:K_2O$ during vegetative phase, 1:2:2 $N:P_2O_5:K_2O$ during flowering @ 0.2 per cent, weekly twice along with application of bone meal, resulted in maximum chlorophyll content in *Dendrobium* cv. Earsakul (Dhinesh, 2009).

The highest level of chlorophyll in fresh leaves of *Cyamopsis tetragonoloba* and *Trigonella foenum-graecum* was recorded in 100 per cent vermiwash treatment (Suthar, 2010).

2.1.3.3 RGR, NAR and CGR

As Ulger *et al.* (1997) asserted, taking into account the direct relationship and positive correlation of leaf area and crop growth rate, high leaf area index seems to indicate photosynthesis potential and dry matter accumulation.

Samasya (2000) reported in *Dendrobium* Sonia -17 that plantlets subjected to the treatment with 50 per cent light and below 70 per cent relative humidity recorded higher CGR value. A similar trend was also observed in the case of NAR.

Net assimilation rate (NAR) and relative growth rate (RGR) were found to be high at 40 g l^{-1} of sucrose concentration in *Dendrobium* Sonia 17 (Samasya, 2000).

Physiological parameters like dry matter production, crop growth rate and relative growth rate were promoted by foliar feeding with fertilizer mixture of $N:P_2O_5:K_2O$ 3:1:1 during vegetative period and 1:2:2 during flowering period @ 0.2 per cent spraying at weekly twice (POP, KAU) along with *Piriformospora indica* application. POP + vermiwash + *P. indica* + bone meal produced maximum net assimilation rate in *Dendrobium* cv. Earsakul (Dhinesh, 2009).

Mojaddam *et al*. (2012) in a study in sunflower reported that effect of different nitrogen levels on relative growth rate and net assimilation rate was not significant. However, crop growth rate increased with increasing nitrogen consumption amount and highest growth rate in heading stage was seen for 140 and 200 kg of net nitrogen levels.

2.1.3.4 Dry matter production

Flower yield is depending on number of leaves and dry matter accumulation (Bhattacharjee, 1981b). The dry matter production of the stem and apical shoot was enhanced by 500 ppm phosphorus in *Arachnis* Maggie Oei 'Red Ribbon' (Thekkayam, 1996).

In *Dendrobium* var. Sonia-17, biomass production (dry weight) was the highest (6.94 g plant^{-1}) with the combination of 30:10:10 NPK @ 0.2 per cent applied weekly twice + BA 200 ppm (Swapna, 2000).

Fernandez (2001) reported that significant superiority in dry matter accumulation was observed for treatments provided with 50 per cent single level shade as well as 25 per cent double level shading. Twenty five per cent double level shading recorded the highest biomass production of 5.86 g in *Dendrobium*.

Binisha (2003) reported in *Dendrobium* that treatments receiving 20:10:10 NPK @ 0.2 per cent applied weekly twice along with *Azospirillum* and *Phosphobacteria* recorded the highest dry matter production of 9.39 g, whereas the treatment receiving the same inorganic nutrients inoculated with *Azospirillum* alone recorded 9.22 g of dry matter.

In commercial orchid production, application of NPK fertilizers in combination with micronutrients and organic manures resulted in the higher dry matter production than the application of any one of these alone (Rodrigues *et al*., 2010).

2.1.3.5 Stomatal characters

Withner *et al*. (1974) observed that in orchids stomata are generally with a greater extent found on the lower surface than in the upper surface of the leaf depending on species. In the five economically important species of the genus *Paphiopedilum*, the stomata occurred only on the lower epidermis and all the species had a stomatal frequency ranging from 13.7 to 46.8 stomata per mm^2.

In different species of *Dendrobium*, the stomatal frequency on abaxial leaf surfaces varied from 57.3 to 111.0 per mm^2 (Yukawa *et al*., 1992). Paeke and Jun (1995) studied the size and frequency of stomata in 33 orchid leaves and revealed that the number of stomata increased with age and ranged from 516 per cm^2 in *Blettilla sp.* to 2711 per cm^2 in *Paphiopedilum* and 26,988 per cm^2 in *Cymbidium* sp. The size tend to decrease with age.

Stomatal frequency had a significant negative correlation with stomatal size (Handique and Handique, 1996). Organic supplements proved better for the stomatal frequency.

Comparison of leaf anatomy, stomatal size and stomatal count was made between the leaf tissue of *in vitro* cultured and greenhouse grown plants of *Dendrobium* hybrid 'Sonia-17'. Reduction in size of the guard cells of tissue cultured plants was observed compared to plants grown in green house (Anitha *et al*., 2000).

2.1.3.6 Photosynthesis

The orchids with thin leaves (thickness < 1 mm) (such as *Oncidium* and *Cymbidium*) typically perform C_3 fixation. Other orchids with thick leaves (such as *Phalaenopsis* and *Dendrobium*) usually undergo CAM photosynthesis (Mc Williams, 1970; Neales and Hew, 1975).

The diurnal acidity fluctuation is barely detectable in young protocorms of the CAM orchid *Dendrobium taurinum*. Young leaves of *Dendrobium* seedlings exhibited diurnal acidity fluctuation but the magnitude was considerably lower than that of the leaves of adult plants. CAM capacity increases as the seedling grows (Hew and Khoo, 1980).

Kumar and Tieszen (1980) reported that the net photosynthetic rates of shade-tolerant plants provided with shading are nearly twice as high as those of unshaded ones.

In *Cattleya,* Lacey (1981) reported that peak photosynthetic efficiency at 20 ^{o}C was at 10,000 lux and that shading was necessary to maintain the illumination at 10,000 lux.

Hocking and Anderson (1986) suggested that the two *Cymbidium* orchids viz. *Cymbidium canaliculatum* and *Cymbidium madidum* fix CO_2 through C_4 photosynthesis. Generally, thick-leaved orchids perform CAM whereas those with thin leaves exhibit C_3 photosynthesis (Goh and Kluge, 1989).

The photosynthesis type in orchids can be classified into C_3 and crassulacean acid metabolism (CAM) by leaf thickness (Arditti, 1992; Hew and Yong, 1997).

The photosynthetic rate of *Cymbidium sinense* is low and ranges between 2.0 and 2.6 μ mol CO_2 m^{-2} s^{-1} which is about $^1/_5$ of that of most C_3 plants. Photosynthesis of *Cymbidium sinense* leaf saturates around 200 μ molCO_2 m^{-2} s^{-1} with light compensation of about 5 μmol m^{-2} s^{-1} indicating that it is a shade loving orchid (Ye *et al*., 1992b). There is no difference in the photosynthetic rates of one-and two-year-old leaves, and the rate declines significantly in three-year–old leaves (Ye *et al*., 1992a). The optimum temperature for photosynthesis is 25 ^oC. At high CO_2 (5 per cent), high light intensity (200 μmol m^{-2} s^{-1}) and optimum temperature (25 ^oC), the photosynthetic rate increases to 7.3 μmol CO_2 m^{-2} s^{-1}.

Highest photosynthetic rates (0.87, 1.28, 1.45 and 2.25 μmol CO_2 m^{-2} s^{-1}) was observed in *Cymbidium sinence* leaves supplied with ammonium nitrate as a nitrogen source at 30, 60, 90 and 100 days after treatment respectively (Wen and Hew 1993).

New sink organs affect leaf photosynthesis in a C_3 orchid *Oncidium* Goldiana. The formation of inflorescence and axillary bud increases the photosynthetic rates of the subtending leaf (leaf L_3) and main leaf (leaf L_2) (Hew and Yong, 1994).

Wang (1996 a) reported that *Phalaenopsis* cv. Joseph Hampton, required a PPF of 160 μmol m^{-2} s^{-1} for 12 h daily and at 20/15 ^oC day/night temperature spiking was observed in an average of 28 days.

Based on the studies on CAM *Dendrobium* cv. Sonia by He *et al*. (1998) for the response of leaves and flowers to high light and high temperature conditions, it was observed that severe damage occurred in flowers at 38 ^oC than at 28 ^oC under a higher photon flux density (PFD) of 1500 μmol m^{-2} s^{-1}.

Of the three primary photosynthetic carbon fixation pathways (C_3, C_4 and CAM), CAM species are unique in that their stomata are closed during the day, an adaptive advantage minimizing water loss in hot, dry environments. CAM plants fix carbon during the night when their stomata are open rather than during the day like in C_3 and C_4 species. Carbon dioxide is fixed through the action of phosphoenol pyruvate carboxylase, forming oxaloacetate from phosphoenolpyruvate. During the day when the stomata are closed, malate formed from oxaloacetate is decarboxylated and the CO_2 refixed through the reductive pentose phosphate cycle (Borland *et al*., 2000; Markovska, 1999; Maze, 2000).

Many studies have reported that shade-tolerant species have high P_N values when grown under shade (Fischer *et al*., 2000; Regnier *et al*., 1988; Stoller and Myers, 1989). Furthermore, Zhang *et al.* (2004) suggested that under full sunlight, photosynthesis is largely restricted by low stomatal conductance in shade tolerant species, which acts as a protective response to excess transpiration.

The photosynthetic rates (P_N) of plants in summer suffered midday depression because of the high irradiance at noon (Mohotti and Lawlor, 2002). In orchids, optimization of the production processes and ensuring a quality product for the market is very important. To achieve this goal, a good basic understanding of orchid physiology is essential. Physiological processes that determine crop yield are photosynthesis, respiration, water relations, mineral nutrition, partitioning of assimilates and storage capacity (Hew and Yong, 2004).

Tropical orchids have CAM, C_3 or C_4 mode of photosynthesis and these are usually associated with thick leaves and thin leaves. Thick leaved orchids fix CO_2 through the CAM pathway while thin leaved orchids fix CO_2 through the Calvin's cycle. Photosynthesis of orchid leaves is affected by both physiological and environmental factors including leaf age, light, temperature, water stress, sink demand and elevated carbon dioxide (Hew and Yong, 2004). *Dendrobium candidum* plants grown under high light condition closed stomata to decrease water loss and adapted to high light irradiance (Dai *et al*., 2009). Chang *et al*.

(2010) measured the photosynthetic parameters on the second leaf of the current shoot in *Oncidium*.

Chang *et al*. (2010) reported in *Oncidium* Gower Ramsey 'Sunkist' that the photosynthesis was highest (with a maximum of 5.8 µmol $CO_2m^{-2}s^{-1}$) in the growth chamber, where the temperature was well controlled at a constant (25 ^oC) and the Photosynthetic Photon Flux Density (*PPFD*) at 250 µmol m^{-2} s^{-1}. In a phytotron, where the temperature was 25 ^oC and the *PPFD* does not exceed 400 µmol m^{-2} s^{-1}, the photosynthesis of *Oncidium* was moderately high, with a maximum of 4.0 µmol m^{-2} s^{-1} CO_2. The lowest photosynthetic rate was observed on plants in the rain shelter, where the maximum rate was 1.0 µmol m^{-2} s^{-1} CO_2 and the photosynthesis was below 0 µmol m^{-2} s^{-1} CO_2 between 10.00 h and 11.00 h.

In *Dendrobium candidum*, the photosynthetic values (P_N) were highest under 88 per cent shade treatment. Plants grown under 93 per cent, 88 per cent and 85 per cent shade treatments showed a midday depression at 11:00 h, while plants under 75 per cent shade treatment showed the depression at 13:30 h. In winter, P_N values in four shade treatments (75, 85, 88 and 93 per cent) fluctuated and were negative most of the time (Zheng *et al*., 2012 a).

2.1.4 Root growth

At high light intensity, there is a tendency to produce increased root growth resulting in increased plant size (Tester *et al*., 1986; Wiebe, 1984 and Veierskov, 1985). Swapna (2000) reported that number of roots was markedly higher with the combination of 30:10:10 NPK @ 0.2 per cent applied weekly twice along with BA 200 ppm, which produced 42.00 roots in *Dendrobium* var. Sonia-17.

Medium containing BAP at 4 mg l^{-1} to 8 mg l^{-1} and IBA at 2 mg l^{-1} to 6 mg l^{-1} produced more number of roots and highest root length in *Dendrobium* (Sobhana, 2000).

In *Dendrobium*, highest number of roots (59.67) and maximum root length (59.00 cm) was recorded with the combination of 20:10:10 NPK @ 0.2 per cent applied weekly twice along with *Azospirillum, Phosphobacteria* and *AMF*. However, plants inoculated with *Azospirillum, Phosphobacteria* and *AMF* along with 10:5:10 NPK @ 0.2 per cent applied weekly twice recorded highest root volume (Binisha, 2003).

Dhinesh (2009) reported that among the root parameters studied, at 6 MAP, highest number of roots was recorded in treatment combinations of $N:P_2O_5:K_2O$ 3:1:1 during vegetative phase and 1:2:2 $N:P_2O_5:K_2O$ during flowering @ 0.2 per cent spraying at weekly twice (POP) + organic mixture+ *Piriformospora indica* + bone meal. At the time of flower bud formation, treatment receiving organic mixture+ vermiwash+ *P. indica* + bone meal recorded the maximum root length. Highest root volume was resulted by providing POP + *P. indica* at flower bud formation stage in *Dendrobium* cv. Earsakul.

Tiwari and Kumar (2011) reported that total number of roots per clump and the length of the roots were higher with the combination of NPK 19:19:19 @ 0.1 per cent applied weekly once in *Cymbidium iriodiodes* plants compared to other varieties.

2.1.5 Uptake of nutrients

Poole and Sheehan (1970) observed nutrient uptake by orchid leaves. However, the study by Benzing and Pridgeon (1983) revealed that the rate of absorption by leaves was less than one eighth of that observed roots. Sinclair (1990) was also of the opinion that under natural conditions, the absorption of nutrients by orchid leaves was rarely significant.

The rates of nitrate and ammonium uptake in tropical orchids were lower than those of other non-orchidaceous plants. The rate of nitrogen uptake in tropical orchids was only one-third to one-seventh of the rate in barley (Rao and Rains, 1976; Hew *et al*., 1993).

Phosphorous application in *Phalaenopsis* as a foliar spray resulted in greater uptake by the plants. In *Cattleya*, there was absorption of 35 per cent of the P supplied through foliar spray within 24 h. Therefore, the higher levels of P, which was supplied through foliar sprays, might have contributed to the production of more number of canes and subsequently more spike (Rahayu, 1980).

Both mineral uptake and growth were enhanced when the culture media were supplemented with sucrose. When *Dendrobium* plantlets were grown under high light intensity, the percentage of nitrate uptake increased while the pattern of uptake remained the same. The uptake pattern of various minerals (N, P, K, Ca and Mg) by roots of *Aranda* Tay Swee Eng, *Dendrobium* Multico White and *Oncidium* Gower Ramsey plantlets grown on Vacin and Went media were similar (Hew and Lim, 1989). Uptake efficiency of N and P in agar medium by *Dendrobium* roots was found to be 13 per cent and 4 per cent respectively (Hew, 1990).

Tsai *et al.* (1996) reported that nutrient uptake rate in *Cymbidium sinense* was highest with 20:10:15 NPK rate and with 0.5 per cent organic fertilizer. The nutrient composition of the leaves in both the cultivars of *Arachnis* Maggie Oei 'Red Ribbon' and *Dendrobium* 'Sonia-16' was enhanced by the 400 ppm and 500 ppm doses of N and P and 500 ppm of K (Thekkayam, 1996).

Taejung *et al.* (1998) reported that healthy, compact plants were produced in *Cymbidium* with NPK combination having high content of K. Leaf analysis showed high content of N when 30:10:10 NPK was applied. The nutrient composition of the plants was enhanced by 10.0 mg of N, 6.0 mg of P and 10.0 mg of K in *Dendrobium* Sonia-17 (Umamaheswari, 1999).

Dematte and Graziano (2000) reported that *Dendrobium nobile* orchid plant growth was increased with higher concentrations of S (up to 1.6 g kg^{-1} of dry

weight), Cu (up to 46 mg kg^{-1} of dry weight) and Zn (up to 147 mg kg^{-1} of dry weight), and decreased with higher concentrations of Ca (up to 13.2 mg kg^{-1} of dry weight), Mg (up to 6.6 g kg^{-1} of dry weight) and B (up to 19 mg kg^{-1} of dry weight). High Mo (up to 5.3 mg kg^{-1} of dry weight) caused a more intense loss of leaves after planting.

Nutrient content within the plant indicated an influential effect of shade. Total nitrogen and phosphorus contents were maximum in fifty per cent double level shading. Thirty five per cent single level shade had maximum potassium content in *Dendrobium* (Fernandez, 2001).

Nutrient content in *Dendrobium* plant was found to be high when inoculated with both the biofertilizers *viz., Azospirillum* and *Phosphobacteria* sprayed with 20:10:10 NPK combination at 0.2 per cent concentration (Binisha, 2003).

Application of NPK 20:10:10 at 0.2 per cent along with *Azospirillum* and *Phosphobacteria* resulted in maximum nitrogen (1.37 per cent), Phosphorus (0.39 per cent) and potassium ((2.63 per cent) contents in *Dendrobium* plants (Binisha, 2003).

The total N and K content of *Cymbidium* 'Show Girl Cook's Bridge' was significantly influenced by foliar application of different combination of nitrogen (Naik and Barman, 2006). Highest N content of 10.1 g kg^{-1} was recorded in the treatment combination of 20:5:5 NPK @ 0.3 per cent applied weekly twice.

Naik and Barman (2006) reported that nitrogen content was highest in the treatment 20:5:5 NPK @ 0.3 per cent, sprayed weekly twice. As the nitrogen levels increased, the corresponding potassium content of leaves decreased except for the treatment 10:5:5 NPK and showed antagonism between nitrogen and potassium in *Cymbidium* hybrid.

Naik *et al*. (2006) observed that during flowering stage, the total N content of orchid species varied from 1.1 g kg^{-1} dry weight in *Vanda cristata* to 2.8 g kg^{-1} dry weight in *Dendrobium fimbriatum*, the total P content varied from 1.1 g kg^{-1} dry weight in *Vanda cristata* to 1.6 g kg^{-1} dry weight in *Dendrobium fimbriatum*,

the total K content varied from 5.7 g kg^{-1} dry weight in *Vanda cristata* to 14.2 g kg^{-1} dry weight in *Dendrobium aphyllum,* the total Ca content varied from 21.0 g kg^{-1} dry weight in *Dendrobium chrysotoxum* to 36.6 g kg^{-1} dry weight in *Luisia filiformis*, the total Mg content varied from 11.0 g kg^{-1} dry weight in *Dendrobium chrysotoxum* to 30.0 g kg^{-1} dry weight in *Vanda cristata* and the total S content varied from 10.0 g kg^{-1} dry weight in *Vanda cristata* to 23.0 g kg^{-1} dry weight in *Dendrobium densiflorum.*

Naik and Barman (2007) studied the tissue analysis of *Bulbophyllum, Coelogyne*, *Dendrobium, Eria and Paphiopedilum* species and reported that during vegetative stage, N ranged from 2.0 to 8.7 g kg^{-1} dry matter among various orchid species, having highest in *Dendrobium chrysanthum* and lowest in *Eria dayspogons*. Phosphorus content ranged from 0.3 to 2.3 g kg^{-1} dry matter in leaves of various orchid species having highest content in *Paphiopedilum insigne*. Potassium ranged from 3.2 to 14.3 g kg^{-1} dry matter among the various orchid species, having highest in *Bulbophyllum caudatum*.

2.2 Response of crop to varying levels of plant growth regulators

Plant growth regulators such as gibberellins, auxins, cytokinins and abscicic acid have been successfully used in the orchid cut flower industry for many purposes including flower initiation and development. Cytokinins are considered as a critical physiological signal in triggering the process of flowering. Response of crop to varying levels of plant growth regulators are reviewed as detailed below.

2.2.1 Growth

A single application of 1 mg of BAP was adequate to stimulate the development of axillary buds from the stem base of *Paphiopedilum* plants (Stewart and Button, 1977). Gibberellic acid (GA_3) was not effective when applied alone but when added in combination with BAP seems to accelerate

slightly BAP effect (Goh and Yang, 1978). Plant hormones such as GA_3 (10^{-4} *M*) and BAP (10^{-4} *M*) have reported to stimulate root production in orchids (Goh, 1983).

For *Dendrobium*, BAP did not induce any floral bud initiation on the newly grown pseudobulbs where vegetative growth has not yet terminated (Goh and Arditti, 1985). *Aranda* orchids produce inflorescences following BAP application only during or just before the flowering season and, at other times, plants produce vegetative growth (Hew, 1993).

Zheng *et al*. (1998) reported that in *Cymbidium* ABA @ 5, 10 or 20 mg each and GA_3 10 mg at shoot initiation stage stimulated root growth which in turn promoted shoot development, particularly when applied during summer.

Xia *et al*. (1999) reported in *Dendrobium nobile* that plants treated with BA (benzyladenine), NAA and PP_{333} (paclobutrazol) especially with 10 mg l^{-1} benzyladenine, increased the effective tillering rate of *D. nobile*. Although GA_3 (gibberellic acid) inhibited tillering, it promoted bud development.

Sobhana (2000) reported that in *Dendrobium,* BA at 50 mg l^{-1} at fortnightly intervals gave maximum number of shoots and leaves. Maximum height of the seedlings was obtained with GA_3 10 mg l^{-1} sprayed at fortnightly intervals.

Among different levels of hormone combination, BA and NAA tried showed that BA 2.0 mg l^{-1} + NAA 2.0 mg l^{-1} responded with the earliest plantlet development, but number of shoots produced was more in BA 8.0 mg l^{-1} + NAA 8.0 mg l^{-1} . Number of shoots was maximum in BA and IAA, each at 8.0 mg l^{-1} , in *Dendrobium* (Sivamani, 2004).

Matsumoto (2006) reported that BA (25 or 50 mM) treatment promoted new vegetative shoots in *Miltoniopsis* orchid. Khatun *et al*. (2010) reported that the hormonal combination of BAP + IBA @ 1.0 mg l^{-1} each was found suitable for shoot regeneration and for root development in *Dendrobium* hybrid orchid.

Cardoso *et al*. (2012) reported that spraying with 125 mg l^{-1} GA_3 twice at an interval of 14 days, recorded highest leaf length (18.1 cm) and leaf width (5.8 cm) in *Phalaenopsis*.

2.2.2 Flowering

BA has been reported to stimulate flowering of *Aranda* (Goh, 1977) and *Dendrobium* (Goh, 1979; Sakai *et al*., 2000).

Foliar application of benzyladenine (BA) alone or with gibberellic acid (GA) in *Phalaenopsis* accelerated inflorescence emergence and decreased time to flower by 13 to 25 days, when plants were exposed to inductive temperatures (Yoneda and Momose, 1990).

Application of cytokinins can promote flowering of *Phalaenopsis* (Yoneda and Momose, 1990; Ichihashi, 1997; Blanchard and Runkle, 2008 a).

Cytokinins are suggested to act as one of the multifactorial components that function as the floral stimulus (Bernier *et al*., 1993). The stimulation of flowering after the application of BA suggests that endogenous cytokinins at least partially regulate flower induction in *Doritaenopsis* and *Phalaenopsis*. Cytokinins are suggested to act as one of the multifactorial components that function as the floral stimulus (Bernier *et al*., 1993).

Chen *et al*. (1997) after studying the effect of BA and GA_3 on flowering plants of *Phalaenopsis* 'Leda', found that at concentrations of 1,3 and 5µgshoot $^{-1}$, flowers were deformed. The deformity was reduced by BA combination but internodes were reduced.

Gibberellins influence the stimulus to flowering in different ways, activating promoter genes in the meristem such as *LEAFY* (Blasquez *et al*., 1998), replacing the period of low temperatures required for the flowering of many species and increasing the C/N ratio in leaves through the activation of hydrolytic enzymes (Kerbauy, 2008).

In certain species of *Cymbidium*, GA_3 application induces flowering. The length of the flower spike and size of individual flowers were increased by GA_3 (Yadav and Basak, 1999). Cytokinins induces flowering in *Dendrobium*. Treatment of mature pseudobulbs with BA stimulated flowering. BA at 4000 ppm prevents decrease in flower number. Anti auxins and growth retardants were found effective in stimulating flowering in *Aranda* (Yadav and Basak, 1999).

Gibberellins applied exogenously promote the flowering induction and flower development in plants that normally require long days under the conditions of short days, however, the reverse does not occur, although there are exceptions (Cid, 2000).

Chou *et al*. (2000) investigated the changes in the concentration of endogenous cytokinins in the leaves of *Phalaenopsis* hybrid 'Taisuco Snow' grown at high temperature (30/ 25 ^{0}C day/ night) and low temperature (25/ 20 ^{0}C) for 20 days. The application of BA during low temperature treatment may supplement the natural increase in endogenous active cytokinins and enhance flower induction.

The application of cytokinin enhanced the number of flower buds on inflorescence in *Dendrobium* (Sakai *et al*., 2000). Plant growth regulators such as gibberellins, auxins, cytokinins and abscicic acid have been successfully used in the orchid cut flower industry for many purposes including flower initiation and development. Cytokinins are considered as a critical physiological signal in triggering the process of flowering (Bonhomme *et al*., 2000).

Sakai *et al*. (2000) reported that the injection of 100 mM 6-benzyladenine (BA) into first-year leaved stems of *Dendrobium* Jaquelyn Thomas 'Uniwai Princes' significantly increased the number of inflorescences (8.9) compared with untreated plants (0.5). The addition of 100 mM gibberellic acid to the BA solution increased inflorescence length and reduced the percentage of abnormally formed flowers.

Campos and Kerbauy (2004) reported that cytokinin levels significantly increased in pseudobulb lateral buds of *Dendrobium* subjected to cool temperatures 25 ºC/10 ºC (day/night) compared to control plants grown at 25 ºC /25 ºC (day/night). Orchid flower initiation is usually associated with light intensity (Kataoka *et al*., 2004), temperature and photoperiod (Vaz *et al*., 2004) or hormonal changes (Campos and Kerbauy, 2004).

Flower induction in plants is controlled by primary and secondary environmental factors such as photoperiod, temperature, irradiance, and water avialabilty (Bernier and Perilleux, 2005). These environmental factors can promote the synthesis of floral stimulus that is transported through vascular tissues to the shoot apical meristem and subsequently induces flower initiation.

Inhibition of flowering in *Phalaenopsis amabilis* grown under high temperature (30 °C/ 25 ºC, day/ night) could be reversed by gibberellin (GA_3) treatment (Chen *et al*., 2006). Under normal conditions, *Dendrobium* hybrids have a long juvenile period requiring at least two to five years to reach maturity and flowering stage (Hee *et al*., 2007). Therefore, there is a need to develop a method to speed up the flowering process of *Dendrobium* in order to be competitive in the ever growing orchid industry.

The effect of supplying exogenous cytokinin in inducing *in vitro* flowering was also observed in *Dendrobium* Sonia-17 (Tee *et al*., 2008), *Dendrobium* Madame Thong–In (Sim *et al*., 2007), *Dendrobium* Chao Praya Smile (Hee *et al*., 2007), *Cymbidium niveomarginatum* Mak (Kostenyuk *et al*., 1999) and *Phalaenopsis* Pink Loepard 'Petra' (Duan and Yazawa, 1994). BAP was used to induce *in vitro* flowering of *Dendrobium* Chao Praya Smile in just six months from regeneration (Hee *et al*., 2007). A mixture of BAP and coconut water was used to induce *in vitro* flowering of *Dendrobium* 'Madame Thong–In' in just five months (Sim *et al*., 2007).

Foliar application of BA at 200 or 400 mg l^{-1} increased mean inflorescence number by 1.0 and 3.0 in *Phalaenopsis* Brother Apollo '072' and Golden Treasure '470', respectively (Blanchard and Runkle, 2008a).

Blanchard and Runkle (2008a) suggested that in *Phalaenopsis*, plants treated with BA alone at 200 or 400 mg l^{-1} had a visible inflorescence, 3-9 days earlier and had a mean of 0.7 to 3.5 more inflorescences and 3-8 more flowers per plant than untreated plants. The application of BA + GA had no effect on inflorescence number and total flower number at the rates tested.

For *Dendrobium* Sea Mary 'Snow King', 3 weeks at 13 ^{o}C was reported to saturate the cooling requirement (Yen *et al*., 2008). The success of BAP in regulating inflorescence initiation in orchids has been previously reported by Blanchard and Runkle (2008 a) who indicated that BAP could at least partially regulate the inflorescence initiation in *Doritaenopsis* and *Phalaenopsis* orchids.

Runkle (2010) reported that once an inflorescence has developed, time to open flower is a function of temperature and variety. Exogenous application of gibberellic acid (GA) can be used to increase inflorescence length, but more commonly, chemicals that inhibit the biosynthesis of active GA are used to suppress inflorescence elongation. In addition, cytokinins such as benzyladenine will increase inflorescence number of *Phalaenopsis* when applied near the onset of exposure to inductive temperatures.

Sakai and Ichihara (2010) reported that application of 900 mg l^{-1} BA produced more number of inflorescences (2.7) per plant and greater number of flowers (8.9) per plant in *Dendrobium* Red Emperor 'Prince'.

Nambiar *et al*. (2012) reported that percentage of inflorescence production was highest (85 per cent) in the plants sprayed with 200 mg l^{-1} of BAP, first inflorescence emergence (days) was formed on day 53 in the plants sprayed with 200 mg l^{-1} to 300 mg l^{-1} of BAP while plants treated with 300 mg l^{-1} BAP were the earliest to have its flowers to bloom (59.2 days). Highest length of the inflorescence (43.3 cm), more number of flowers (14) and maximum width of the

flower (6.2 cm) was recorded in the plants sprayed with 200 mg l^{-1} of BAP on a weekly basis for the first month, followed by once in two weeks in subsequent months in *Dendrobium* orchid.

Cardoso *et al*. (2012) reported that spraying with 125 mg l^{-1} GA_3 twice at an interval of 14 days, recorded highest percentage of flowering (50 per cent), highest inflorescence length (45.5 cm), more flower count (6.6) and maximum diameter of the flower (9.4 cm) in *Phalaenopsis* orchid hybrid.

2.3 Response of crop to environmental factors

In orchids, floral initiation is determined by the genotype and its interaction with the environmental conditions. Temperature, humidity, light and photoperiod are some of the environmental conditions. Plants often respond to changes in photoperiod and temperature so that they naturally flower when environmental conditions are favourable for reproduction. Under controlled conditions of greenhouse, the flowers exhibit best quality attributes required for the market. Information pertaining to response of crop to environmental factors are reviewed hereunder. Abiotic agents such as climate, soil nutrients and water have long been understood to be primary environmental factors influencing indoor and outdoor plant cultivation (Zheng *et al*., 2012b).

2.3.1 Light

In *Cattleya*, Lacey (1981) reported that peak photosynthetic efficiency at 20 ^{o}C was at 10,000 lux and that shading was necessary to maintain the illumination at 10,000 lux.

In modern light intensity, plants generally bear longer internodes, and are less tough and more succulent with larger leaves than those grown in intense light (Barber and Anderson, 1992). In *Dendrobium nobile,* to reach their full flowering potential, they must have reached maturity under high-light conditions before the cooling period (Nash, 1996).

Thekkayam (1996) reported that in *Dendrobium,* the length of the internode had influential effects of shade especially during the initial period of vegetative growth i.e. upto five months. Internodal length was high for treatments subjected to more shade intensities *viz.,* 50 per cent single level shading, 35 per cent and 50 per cent double level shading with more length during most of initial months. Since flowering had started, no significant variation in the length of the internode was observed among treatments.

In commercial systems, many orchids are planted under shade since high light affects both vegetative and reproductive tissues. However, plants grown continuously under low light may also suffer from a reduction in the rate of photosynthesis and reduction in growth rate (Khoo *et al*., 1997).

For *Dendrobium* Nodoka and *Dendrobium* Snowflake 'Red Star' (both are nobile type), high light is not necessary during flower bud initiation. However, exposure to low light during that time can result in leaf chlorosis and defoliation (Ichihashi, 1997).

Shade loving orchids such as *Dendrobium*, *Oncidium* and *Phalaenopsis* do not tolerate direct exposure to tropical full sun and they would be scorched within hours if exposed to the strong mid-day sun directly (Bose *et al*., 1999).

Most *Dendrobium* species and hybrids can tolerate higher light intensities than other orchid genera of *Cattleya*, *Cymbidium*, *Miltoniopsis, Phalaenopsis* and *Zygopetalum* **(**Dole and Wilkins, 1999).

Fernandez (2001) reported that in *Dendrobium*, remarkable increase in plant height was noticed in treatments with 35 per cent and 50 per cent shading (both at double level) and 50 per cent single level shading. The plant height was considerably less in intense light conditions.

Light intensity influences plant growth through photosynthesis. Chlorophyll 'a' influences photosynthetic efficiency which in turn helps in efficient carbon assimilation, which reflects on better growth and better spike

formation. Reported evidences showed that the concentration of chlorophyll per unit weight of leaf increases with shading. Similarly, varying light intensities also influence flower colour which in turn determines the flower quality in *Dendrobium* (Fernandez, 2001).

In *Dendrobium*, double level shading at 50 per cent produced spikes of maximum length, high vase life, high longevity of spike on plant, maximum number of flowers per spike, the maximum anthocyanin content of the flowers and the highest content of chlorophyll 'a' in the leaf. Total chlorophyll 'a' and chlorophyll 'b' were the maximum under 35 per cent double level shading (Fernandez, 2001).

Dry matter accumulation, plant height, leaf number and leaf area development of the *Phaius tankervilliae* and *Vanda coerulea* were best at the light intensity of 74 µmol m^{-2} s^{-1} (Puangpaka *et al*., 2001).

In *Dendrobium*, higher leaf production was noticed in double level shading, mainly 35 per cent and 50 per cent shade levels (Fernandez, 2001). Light intensity interfered with growth and development of *Dendrobium thrixspermum* (Stancato *et al*., 2002).

The photosynthetic capacity of *Dendrobium* Jaquelyn Thomas can be increased by increasing irradiance (decreasing percentage shade in the greenhouse) on their leaves, thus increasing flower number (Hew and Yong, 2004).

Talukdar *et al*. (2008) reported that *Phaius tankervilliae* plants grown under shade conditions (average light intensity of 5400 lux) performed better in terms of morphological characters. Plants grown in open condition with light intensity of 7200 lux, exhibited the earliest flower bud visibility (109.84 days) and requires less time for full bloom (208.17 days) while, number of flowers open at a time (7.28), number of flowers/ spike (19.33), flower diameter (11.34 cm), number of spikes/ plant (2.91) and spike length (104.29 cm) were maximum in

plants which were grown under partial shade condition with light intensity of 5400 lux.

2.3.2 Temperature

In *Dendrobium nobile*, despite photoperiod, 13 °C was found to trigger flower bud initiation. Plants grown at 18 °C for upto four months had delayed flowering until the preferred blooming date (Rotor, 1952). Spike emergence often did not occur when temperatures were over 28 ºC during the growth period (Sakanishi *et al*., 1980).

In commercial production of *Phalaenopsis*, day/night temperatures of 25 ºC/20 °C are used to promote flowering. Spiking of *Phalaenopsis* hybrids is triggered by air temperatures of 26 °C or lower (Sakanishi *et al*., 1980).

Many studies (Lee and Lin, 1984, 1987; Sakanishi *et al*., 1980; Yoneda *et al*., 1992) have proved the requirement of relatively low temperatures for inducing the elongation of the reproductive bud (spiking).

Inflorescence length of a *Phalaenopsis* hybrid grown at a day/ night temperature of 30 °C / 25 ºC was 68 per cent longer than that of plants at 20 °C / 15 ºC (Lee and Lin, 1984). Goh and Arditti (1985) postulated that photoperiod and low temperature modify concentrations of endogenous growth regulators. Low temperature and short days could change the concentrations of endogenous growth regulators leading to induction of flowering in sympodial orchids.

Dendrobium nobile Lindley plants exposed to 13 ºC produced flowers regardless of the photoperiod, whereas plants held at 18 ºC remained vegetative (Goh and Arditti, 1985). It has been reported that day temperature above 25 ºC promotes aerial shoot formation in *Dendrobium* Snow flake 'Red Star' (Sinoda *et al*., 1988).

Sawa (1991) found that when the temperature dropped from high (35 ºC day-30 ºC night) to low (20 ºC day – 15 ºC night), the wilting of *Dendrobium* Sonia flower buds increased. Low or fluctuating temperatures are known to

facilitate spike emergence and bud differentiation in *Phalaenopsis* (Chen *et al*., 1994). Flower bud initiation occurs after the reproductive stem (spike) has reached a certain length under the required environmental conditions (Lin, 1994).

The effect of temperature on *Dendrobium nobile* is critical during both vegetative growth and flower initiation. During the spring and summer in both Hawaii and Japan, *Dendrobium nobile* is grown in lower elevations where the pseudobulbs can mature completely in a warmer climate before being taken to higher elevations where flower initiation can begin under cooler conditions (Nash, 1996). In *Dendrobium* Malones 'Fantasy', flower bud initiation was optimal at night temperatures between 7.5 °C and 10 °C. The number of flower buds decreased and flowering was delayed with night temperatures of 15 °C or higher (Suto *et al*., 1984). The cooler temperatures (10 °C to 15 °C) together with the termination of fertilizer after pseudobulb maturity produces the best flower display of *Dendrobium nobile* (Nash, 1996). For all cultivars, flower bud initiation is inhibited by day temperatures above 25 °C (Ichihashi, 1997).

Lower day temperature can cause leaf yellowing, defoliation and reduced growth rate; higher temperature can delay flower bud development in *Dendrobium* (Ichihashi, 1997). Ichihashi (1997) reported that under 25 °C day and 15 °C night conditions, *Dendrobium* Hinode 'Toutenkou' had fewer flowers on the upper nodes and *Dendrobium* Snowflake 'Red Star' produced aerial shoots. Both clones required temperatures above 25 °C day and 15 °C night in order for pseudobulbs to mature timely for flower induction.

In most *Dendrobium* orchids, rapid vegetative growth occurs at temperatures between 24 ^{o}C and 30 ^{o}C (Leonhardt, 2000). Lopez and Runkle (2004) reported a decrease in time from visible inflorescence to flower opening in *Zygopetalum* (*Zygopetalum* Redvale 'Fire Kiss') when there was an increase in temperature (14 °C to 26 °C).

Many species in Orchidaceae need a period of vernalization after maturation to induce flowering. This is also true for tropical orchids (Hew and

Yong, 2004). The 'Lava Glow' clone of the hybrid *Doritaenopsis* (*Phalaenopsis* Buddha's Treasure x *Doritis pulcherrima*) remained vegetative at a 12 h day/night temperature of 25 °C /15 °C while all plants flowered at 15 °C /25 °C (Wang, 2004).

Flowering of many of the most commonly grown orchid genera is influenced by temperature and light. In particular, a relatively low temperature induces flowering, while a high temperature inhibits flowering (Lopez and Runkle, 2005). In some species and hybrids of *Dendrobium* and *Cattleya*, the combination of short photoperiod and low temperature induces flowering in the most complete, rapid and uniform manner (Lopez and Runkle, 2005).

Phalaenopsis plants with a young inflorescence can become an aerial shoot known as a keiki, in place of a flower bud when temperatures remain at 28 °C or higher (Lopez *et al*., 2005). Inflorescences did not emerge from *Phalaenopsis* Miva Smartissimo x Canberra '450' or Brother Goldsmith '720' plants within 20 weeks when grown at a 12 h day temperature of 29 °C and a night temperature of 17 °C, 23 °C or 29 °C (Blanchard and Runkle, 2006).

Flowering of a first generation *Phalaenopsis pulcherrima* hybrid is delayed by cool day temperatures of 25 °C and warm night temperatures of 30 °C (Wang, 2007). Cool day temperature of 20 °C and warm night of 25 °C induced flowering, whereas warm day of 25 ° C and cool night of 20 °C inhibit flowering. Flower induction begins as temperatures fall below 26 °C for four to five weeks.

Dendrobium Sea Mary 'Snow King' needs to be subjected to a specific amount of cooling for flowering (Yen *et al*., 2008). Temperature between 14 ^{0}C and 17 ^{0}C can be used to promote both inflorescence initiation and development in *Odontioda* orchids (Blanchard and Runkle, 2008b).

Interrupting an inflorescence initiating period (day/night temperatures of 20 °C /15 °C or 25 °C /20 °C) with one week at 30 °C delayed subsequent flowering of *Phalaenopsis* Taisuco Swin clone by upto three weeks (Tsai *et al.,* 2008). Inflorescence height of *Phalaenopsis* Miva Smartissimo x Canberra

'Mosella' increased by 19 per cent or 30 per cent by exposure to 4 or 8 h at 29 ºC compared with the height of inflorescences at constant 20 ºC (Newton and Runkle, 2009).

Runkle (2010) reported that once plants attained the capacity to flower (*i.e*. they are mature), temperature is the primary factor that controls inflorescence initiation and development of *Phalaenopsis*.

2.3.3 Relative humidity

Humid warm atmosphere is most essential for the growth of most of the tropical orchids, which do not have well established root system. Orchids in general prefer high humidity for their growth and flowering. Sympodial types like *Cattleya*, *Laelia* require 40 to 55 per cent relative humidity (Quyu, 1959). In the wild, majority of orchids flourish in regions of perpetual mist (Abraham and Vatsala, 1981).

Janous *et al*. (1996) stated that at high relative humidity (85 ± 5 per cent), chlorophyll content was higher than at lower relative humidity (55 ± 5 per cent). Shimizu *et al*. (1997) found that low relative humidity decreased the leaf area and relative growth rate (RGR) of wheat and increased the transpiration rate.

Samasya (2000) reported that in *Dendrobium* var. Sonia-17, the plantlets grown in the hardening chamber maintained at 50 per cent light intensity and 70 to 90 per cent relative humidity recorded maximum value of total chlorophyll, chlorophyll a and chlorophyll b among treatments.

2.3.4 Interaction between physical factors

Kubota and Yoneda (1992a, 1992b) reported that tissues of *Phalaenopsis* plants under a low Photosynthetic Photon Flux (PPF) had lower sugar and higher nitrogen levels than those under a higher PPF, which resulted in reduced spiking or no spiking at all. A continuous sugar supply to the apex of a reproductive bud is essential for continued floral development, whether induced by high light, low temperature, or gibberellins (Chen *et al*., 1994).

During plant development, the transition from vegetative to reproductive growth is triggered by a number of environmental and endogenous signals. These signals evoke a cascade of cellular processes that eventually lead to floral induction (Bernier *et al.,* 1993; Levy and Dean, 1998).

The growth and development of orchids is markedly influenced by the physical (temperature, light, humidity and topography), chemical (nature of substratum) and biotic (rhizosphere, associated vegetation, pollinators) factors and their avidity to specific ecological niches varies with species (Chada and Bhattacharjee, 1995).

Cho and Kwack (1996) reported that in *Cymbidium goeringii* leaves transpiration rate increased as leaf temperature increased; transpiration rate started to decline at temperatures >25 °C. Increasing wind speeds also increased the transpiration rate; transpiration rate started to decline at wind speeds >2.5 m s^{-1}.

Nobuoka *et al*. (1996) opined that transpiration rate of tomato increased with decrease in relative humidity and increased light intensity. Shimizu *et al*. (1997) reported an increase of transpiration rate in maize when subjected to low relative humidity.

Generally, orchids have a long juvenile phase that requires several years of growing before they flower (Kostenyuk *et al*., 1999; Duan and Yazawa, 1994). Many factors such as photoperiod, irradiance, temperature and hormonal control might affect flowering of orchids (Chia *et al*., 1999; Goh, 1984).

Dendrobium plantlets which were subjected to the treatment of 50 per cent light and below 70 per cent relative humidity had maximum plant height (Samasya, 2000).

In *Dendrobium*, Samasya (2000) reported that among treatments, the plantlets subjected to 50 per cent light level and less than 70 per cent relative

humidity as well as those subjected to 25 per cent light and less than 70 per cent relative humidity produced more number of leaves.

Among the different levels of light intensity and humidity, plantlets grown at 50 per cent light intensity and 70 to 90 per cent relative humidity exhibited higher CGR, NAR and RGR in *Dendrobium* 'Sonia-17'. Also these plantlets exhibited a marked increase in photosynthetic rate and decrease in transpiration rate (Samasya, 2000).

The influence of the temperature for blooming is around 60 per cent, light is at 30 per cent and other factors at 10 per cent. This ratio may be different for the setting values of greenhouse environment, different management techniques and various varieties (Chen, 2002).

Plants often respond to changes in photoperiod and temperature so that they naturally flower when environmental conditions are favorable for reproduction. Once flower buds have initiated, flower development time depends upon genotype and temperature (Lopez and Runkle, 2004). Typically a mature *Phalaenopsis* growing in a house establishes a rhythm of blooming, producing a new leaf and after a leaf a new flower spike and blooming again. This takes about ten to fourteen months (Rogers, 2012).

Sarntinoranont and Wannakrairoj (2010) reported that in the rainy season, the ready-to-bloom florets of *Dendrobium* Sonia 'Ear-Sakul' were the most sensitive to yellowing. The inflorescence with no opened florets showed the highest percentage of inflorescence with yellow unopened florets. Unopened floret yellowing was influenced by many environmental stimuli. It was found that higher cumulative hours of daytime without photosynthetic photon flux, low temperature, high moisture and rainfall from 3 d before unopened floret yellowing were the major environmental factors.

2.3.5 Influence of greenhouse conditions

Leonardi (1996) studied the effect of shading on green house grown pepper and suggested that shading reduced the transpiration.

Rajeevan (1997) described a system for cultivation of *Dendrobium* orchids in Kerala, which involved double layer roofing, the lower layer being at a height of about 2.5 m for the purpose of changing according to weather condition. The top layer of roofing material, which was permanently fitted to main structure, was a polythene sheet. The bottom roofing was provided with shade net (25 per cent) during summer months and with UV stabilized sheet (70 gsm) during rainy season. Polythene sheet improved sunlight during rainy season which lasts for over six months in this region. This further prevents direct impact of rainfall, which may otherwise lead to incidence and spread of pests and diseases. The platform method of planting practiced in the new system also took care of humidity conditions and sanitation. The performance of plants, quality of flowers after a period of 18 months was much superior as compared to those grown under conventional system.

Samasya (2000) in *Dendrobium* Sonia 17 reported that plantlets subjected to 50 per cent light intensity and less than 70 per cent relative humidity exhibited lesser transpiration rate. Kittas *et al*. (2003) succeeded to keep the internal greenhouse temperature at 28 ^{0}C level by using fan and pad system. By calculating the system efficiency to become 80 per cent, they obtained a 10 ^{0}C decrease with respect to the external temperature. The moisture content in the environment is an important point in determining efficiency of cooling with using fan and pad system.

Guo *et al*. (2003) studied the response and adaptation of two orchids and reported that, in conditions of shade less than 200 µmol photons m^{-2} s^1, the rate of transpiration (*E*) was decreased in *Tangtsinia nanchuanica* and *Cephalanthera falcate.*

Singh *et al*. (2005) monitored performance of gerbera crop in the two green houses (naturally ventilated and fan and pad-cooled greenhouse) and linked to the greenhouse temperature and humidity conditions. Seasonal average temperatures in the naturally ventilated greenhouse were generally close to the ambient air temperatures and were higher by about 0.5 ºC to 1.6 ºC only. Relative

humidity of naturally ventilated greenhouse was close (within 5 per cent) to the ambient relative humidity, whereas in case of fan-pad cooled greenhouse, the greenhouse temperatures were 3-4 ^{0}C lower than ambient during summer months. At other times of year, the temperatures in fan-pad cooled greenhouse were 10-30 per cent higher than ambient air values. The crop performance in naturally ventilated greenhouse was observed to be superior to that in the fan-pad cooled greenhouse. Higher relative humidity in fan-pad cooled greenhouse appears to be responsible for higher disease incidence and consequently poorer crop performance was observed.

The fan and pad systems which are properly designed and utilized can boost up the efficiency level in greenhouses to 85 per cent. When the external moisture indications reach 50 per cent level and the temperature rises up to 32 ^{0}C, a vapour cooling system can lower the temperature down to 24 ^{0}C (Yagcioglu, 2005).

A number of *Phalaenopsis* cultivars and hybrids showed a fairly consistent pattern of enhanced foliage biomass production (fresh and dry weights) under blue coloured netting despite reduced transmission of *PAR* compared with black and red nets. The red netting, in comparison with black and blue netting (all normal 30 per cent shade), induced earlier flowering of nine of 10 *Phalaenopsis* cultivars and hybrids (Leite *et al*., 2008).

Umesha *et al*. (2011) reported that in *Vanilla*, longest internodes (5.39 cm) under 50 per cent shade net, longest shoots (42.4 cm) and maximum number of roots (1.70) were recorded under poly house, whereas more number of leaves (9.4) was recorded under greenhouse with misting followed by poly house. Higher photosynthetic efficiency under greenhouse with mist, longest length of the root (29.2 cm) and maximum dry weight of the root (0.73 g) was recorded under natural shade house.

In *Dendrobium candidum*, regarding transpiration, plants grown under 75 per cent shade treatment showed significantly higher values of *E* (transpiration)

than those of any other treatment before 13.30 h. The highest *E* value in winter was found in plants exposed to 75 per cent of shade at about 10. 00 h (Zheng *et al*., 2012 a).

2.4 Microbial associations

2.4.1 Mycorrhiza

Alexander and Hardley (1983) observed that mycorrhizal infections in the orchid *Goodyera repens* brought about enhanced growth rate and increased P concentration within tissues. Orchid mycorrhiza showed improved resistance to drought and environmental stress (Allen and Boosalls, 1983). Tearashita (1982) and Masuhara and Katsuya (1992) observed that this adult orchid form mycorrhizal association often with *R. repens* and occasionally with *R. solani.*

Ogoshi *et al.* (1983) reported that some isolates of binucleate *Rhizoctonia* induce symbiotic germination of some of the Australian orchids. Warcup (1983) has shown that some *R. solani* isolates induced symbiotic germination of seeds of *Microtis unifolia, Prasophyllum regiium* and *Orchis moria*. Abbot and Robson (1984) reported that mycorrhizal inoculation increased the growth and yield of different crop plants by improving P uptake and yield, particularly when these nutrients are sparingly available. Orchid mycorrhizal fungi improved nitrogen nutrition in orchid plants by facilitating the use of certain nitrogen forms that were difficult for the non-mycorrhizal plants to exploit (Press, 1986).

It has been reported that mycorrhizal orchids can acquire more N, P and water than non-mycorrhizal controls (Alexander *et al*., 1984; Yoder *et al*., 2000; Cameron *et al*., 2006, 2007). Thus, understanding the relationship between orchids and mycorrhizal fungi is of great important. Rare and endangered species of orchids have been propagated symbiotically; with the purpose of excite conservation or reintroduction (Zettkler and McInnis, 1992).

Plant nutrition is often dependent on mutualistic associations with other organisms. Mycorrhizal associations (mutualistic interaction between vascular plant roots and fungi, whereby the roots benefit from enhanced water and nutrient uptake and the fungi gain ready access to translocating photosynthates) are likely to favour nutrient uptake in epiphytic plants (Lesica and Antibus, 1990).

Mycena sp. are orchid mycorrhizal fungi of *Gastrodia elata* (Xu *et al*., 2001) that can accelerate seed germination in the form of protocorms and enhance the yield of *Gastrodia elata* (Fan *et al*., 1996). Symbiotic fungi could improve orchid growth rate (Yu and Guo, 2000; Ramsay and Dixon 2003; Kang *et al*., 2007; Rasmussen, 2009). Fungus F-23 could form mycorrhizal associations with the roots of the *Dendrobium officinale*, and enhance the growth of seedlings and roots.

Association of orchid mycorrhiza and arbuscular mycorrhizal fungi in vanilla was studied in detailed by Madhaiyan (1999). It was observed that inoculation of orchid mycorrhiza and AMF significantly increased the shoot and root dry weight of vanilla.

Most terrestrial plants on earth have a symbiotic association in their roots with soil fungi, known as *mycorrhizae*, which are beneficial to the growth and health of plants and soil (Cruz *et al*., 2002; Hodge *et al*., 2001; Jeffries and Barea, 2002; Rausch *et al*., 2001).

Significant increase in shoot and root length of vanilla seedlings was observed due to the inoculation of mycorrhizal fungi, AMF or combination of both over control. Madhaiyan *et al.* (2003) observed the infection of orchid mycorrhiza and peletion formation in cortical cells, particularly in the outer cortical cells of vanilla seedlings inoculated with orchid mycorrhiza.

In mature orchids, mycorrhizae also have roles in nutrient uptake and translocation. Orchid mycorrhizas support orchid development and initial root development by delivering nutrients for germination, protocorm and initial root development (Peterson and Massicotte, 2004).

Endophytes promote the growth of plants in various ways, through secretion of plant growth regulators; *e.g*. IAA (Lee *et al.,* 2004), phosphate solubilizing activity (Wakelin *et al.,* 2004), by enhancing hyphal growth and mycorrhizal colonization (Will and Sylvia 1990), production of siderophores (Costa and Loper 1994) and by supplying biologically fixed nitrogen (James *et al.,* 1994). Other effects of endophyte infection on the host plant include osmotic adjustment, stomatal regulation, modification of root morphology, enhanced uptake of minerals and alteration of nitrogen accumulation and metabolism (Malinowski and Belesky, 1999; Belesky and Malinowski, 2000).

Zhang *et al.* (2011) isolated an endophytic fungus, F-23, from the roots of *Dendrobium officinale* Kimura et Migo, an endangered Chinese medicinal plant. The sequence of the ITS region indicated that the isolate belongs to the genus *Mycena*. They observed that the hyphae of F-23 penetrated the epidermal cells within the host roots and spread from cell to cell. The F-23 fungus can form mycorrhizal associations with the roots of its host plant, *Dendrobium officinale*, and enhance the growth of seedlings and roots. *Mycena* sp. was identified and shown to be a mycorrhizal fungus of the epiphytic orchid, *Dendrobium officinale*. This might be of potential use to the mass cultivation of *Dendrobium officinale* under artificial conditions.

2.4.2 Plant Growth Promoting Root Endophyte (PGPRE)

Previously, only mycorrhizal fungi were considered as mutualistic symbionts of plant roots. In this definition, fungi that colonize plants without causing visible disease symptoms at any specific moment (Petrini, 1991; Wilson, 1995) are called fungal endophytes. In all ecosystems, many plant parts are colonized by fungal endophytes.

Endophytes may enhance growth by producing phytohormones without any apparent facilitation of host nutrient uptake or stimulation of host nutrient metabolism. The endophytic fungi may enhance biomass by producing growth

hormones or inducing the host hormone production (Petrini, 1991; Schulz and Boyle, 2005).

Taken literally, the word endophyte means 'in the plant' (endon-within; phyton-plant). The usage of this term is as broad as its literal definition and is a spectrum of potential plant hosts and inhabitants, including bacteria (Kobayashi and Palumbo, 2000), fungi (Stone *et al.,* 2000), algae (Peters, 1991), and insects (Feller, 1995). Any organ of the host can be colonized. Equally variable is the life-history strategy of the symbiosis, ranging from facultatively saprobic, to parasitic, to exploitive, to mutualistic. However, common to all endophytic interactions is the provision of nutrients and a buffer from external environmental stresses and microbial competition. Unlike mycorrhizal fungi, endophytes reside entirely within host tissues and emerge during host senescence. These fungi comprise a phylogenetically diverse group that are members of the Dikarya (Schardl and Leuchtmann, 2005; Van Bael *et al.,* 2005; Girlanda *et al.,* 2006; Arnold and Lutzoni, 2007), while most endophytes belong to the Basidiomycota. Although these fungi are often grouped together, they can be discriminated into different functional groups just as has been done with mycorrhizal fungi (Brundrett, 2006).

2.4.3 *Piriformospora indica*

The root-colonizing fungal mutualist *Piriformospora indica* was discovered in the rhizosphere of the woody shrubs *Prosopsis juliflora* and *Zizyphus nummularia* in the Indian Thar desert and it was named according to its characteristic pear-shaped chlamydospores (Verma *et al*., 1998).

Depending on the ultra structure of hyphae (presence of dolipore septa) and 18s-rRNA gene sequence, *P. indica* was grouped in the class Hymenomycetes (Basidiomycota) (Verma *et al.,* 1998). Serological classification showed close antigenic properties with mycorrhizal fungi (Varma *et al.,* 2001). In contrast to mycorrhizal fungi, this fungus can be cultured axenically on various synthetic simple and complex media at 25-35 ^{o}C (Varma *et al*., 1999).

Morphologically, *P.indica* young mycelia were white and almost hyaline. Hyphae were thin - walled and of different diameters ranging from 0.7 to 3.5 µm. The septate hyphae often showed anastmosis. New branches emerged irregularly and the hyphal walls showed some external deposits at irregular intervals, perhaps polysaccharides and/or some hydrophobic proteins, which stained deeply with toluidine blue. Since septation was irregular, the single compartments could contain more than one nucleus. The chlamydospores appeared singly or in clusters and were distinctive due to their pear-shaped structure. The chlamydospores were 16-25 µm in length and 10-17 µm in width. The cytoplasm of the chlamydospores was densely packed with granular material and usually contained 8-25 nuclei. Neither clamp connections nor sexual structures could be observed. The new fungus produced chlamydospores at the apex of the undifferentiated hyphae. According to the ultrastructure of the septal pore and the molecular data, the fungus was placed within the Hymenomycetes (Basidiomycota) (Varma *et al*., 2001).

Piriformospora indica AM fungi – like fungus, showed prominent positive influence on a wide range of plants of agriculture, forestry and flori-horticultural importance. Fungus has a wide host range of monocots and dicots including legumes, terrestrial orchids (*Dactylorhiza maculata*) and members of the bryophytes (*Aneura pinguis*). The fungus showed potential as an agent for biological control of disease against soil-borne root pathogens. ^{32}P experiments suggest that this fungus is important for phosphorus acquisition by the roots, especially in the arid and semi-arid regions. Mycelium could utilize a wide variety of inorganic and organic phosphate chemicals and produced acid phosphatases at the tip of the hyphae (Singh *et al*., 2003a, b).

2.4.3.1 Growth promotional effects

Endophyte-infected plants often grow faster than non infected ones (Cheplick *et al*., 1989). This effect is at least in part due to the production of phytohormones such as IAA, cytokinins, and other plant growth promoting substances (Zou and Tan, 1999) and or partly owing to the fact that endophytes

could have enhanced the host's uptake of nutritional elements such as nitrogen and phosphorus (Gasoni and Gurfinkel, 1997; Malinowski and Belesky, 1999). Pronounced growth promotional effects were also seen with terrestrial orchids (Blechert *et al*., 1999; Singh and Varma, 2000; Singh *et al.,* 2000, 2002b).

Microbes such as *Piriformospora indica* (Verma *et al.,* 1998), *Fusarium* sp. and *Cladorrhinum foecundissimum* (Gasoni and Gurfinkel, 1997; Kuldau and Yates, 2000; Sieber, 2002) *Chaetomium* spp. (Vilich *et al.,* 1998) were shown to improve the growth of their hosts after root colonization. In these symbioses, fungi most probably benefit by obtaining a reliable nutritional source while hosts may acquire multiple advantages besides an improved growth. Various hosts inoculated with root endophytes displayed an increased tolerance to abiotic stresses and induced resistance. Many studies have indicated that mycorrhizal fungi can promote seed germination and seedling growth (Guo *et al*., 2000; Kang *et al.,* 2007; Jin *et al.*, 2009).

Piriformospora indica having a broad host spectrum shows pronounced growth promotional effects. It mobilizes the insoluble phosphates and translocates the phosphorus to the host in an energy-dependent process. The axenic cultivability of *P. indica* on economically viable synthetic media makes it suitable for mass scale inoculum production for application in agro-forestry and horticulture. Pronounced growth promotional effects were also seen with terrestrial orchids. The fungus promises to be a potential source for colonizing the orchids, their better growth and higher rate of survival of seeds. *P. indica* enters the root cortex and forms inter and intracellular hyphae. Within the cortical cells, the fungus often forms dense hyphal coils or branched structures intracellularly. *P. indica* also forms spore or vesicle-like structures within or between the cortical cells. Like AMF, hyphae multiply within the host cortical tissues and never traverse through the endodermis. Likewise, they also do not invade the aerial portion of the plant (stem and leaves) (Singh *et. al.,* 2000).

P. indica acts as plant growth promoter (auxin), biofertilizer (solid and liquid engineering), bioregulator, immunomodulator, phytoremediator, biological

hardening agent for micro propagated plantlets; imparts resistance against heavy metals, biocontrol against insects and pathogens, stress tolerance- both salt and temperature; works as stimulator with Plant Growth Promoting Rhizobacteria (PGPRs), antioxidant and drug enhancer, anti-ageing agent; promotes synthesis of anti-cancer drugs and possesses potential for its use in bionanomedicines (Varma *et al*., 1999; Rai *et al.,* 2004; Waller *et al.,* 2005; Deshmukh *et al*., 2006; Shahollari *et al.,* 2005, Serfling *et al.,* 2007; Sherameti *et al.*, 2008a, 2008b).

The differences in growth observed between inoculated and control plants may have been caused by greater absorption of water and mineral nutrients due to extensive colonization of root by *Piriformospora indica*. The ability of *P.indica* to continue improving growth of *Spilanthus calva* and *Withania somnifera* even during the hot March-June summer season (day temperature of above 40 ^{o}C) suggests that the fungus may improve drought tolerance. Positive influence of this fungus on plant growth clearly indicates the commercial potential for large-scale cultivation of medicinal plants (Rai *et al*., 2001; Rai and Varma, 2002).

Rai and Varma (2005) observed a profuse proliferation of root of *Adhatoda vasica* after inoculation of *P.indica* and root colonization of *A. vasica* by *P.indica* increased with time from 53 per cent after 2 months to 95 per cent after 6 months.

Shahollari *et al*. (2005) observed in the case of *Arabidopsis* colonized with *Piriformospora indica* that the fungus increases the phosphate uptake 2-3 times higher in *Arabidopsis* seedlings, and it was concluded that *P. indica* stimulates *Arabidopsis* growth in a fashion similar to that described for mycorrhizal symbiosis.

Inoculation dramatically enhanced the number and length of the adventitious roots in pelargonium and poinsettia. *P. indica* based biotechnology is proposed as a new tool for improving plant propagation systems of plant species or cultivars with low to moderate capacity of adventitious root formation (Druege *et al.,* 2007).

Dhinesh (2009) reported that in *Dendrobium* cv. Earsakul maximum plant height, number of leaves and girth of the shoots was obtained in the treatment combination of Package of Practices of KAU (POP) along with organic mixture, vermiwash, *Piriformospora indica* and bone meal.

Piriformospora indica is reported to help plants in growth promotion, salt tolerance, disease resistance and higher yield (Waller *et al*., 2005; Kumar *et al*., 2009). Yadav *et al.*(2010) suggested that *Piriformopsora indica* could be good candidate for use in sustainable agriculture to improve plant productivity in land deficient in phosphorous.

Yadav *et al*. (2010) reported that phosphate has an impact on the biomass of the maize plant colonized with *Piriformospora indica*.

2.4.3.2 Phosphate mobilization

Most adult orchids have coarse roots that were likely to remain much dependent upon mycorrhiza for mineral nutrient (Particularly phosphorus) uptake as was the pattern in other coarse- rooted plants (Baylis, 1975).

Studies on *P. indica* have shown fungal-mediated uptake of radio-labelled phosphorus from the medium and its translocation to the host in an energy-dependent process, evident by a sharp increase in its content in the shoot. *P. indica* produces significant amounts of acid phosphatases for the mobilization of broad range of insoluble, condensed or complex forms of phosphates, enabling the host plant the accessibility of adequate phosphorus from immobilized reserves in the soil (Singh *et al*., 2000).

2.4.3.3 Linkage between the host and *Piriformospora indica*

P. indica infests roots of a broad range of monocotyledonous and dicotyledonous plants (Verma *et al.,* 1998; Pham *et al*., 2004). Endophytic root colonization by this fungus confers enhanced growth to the host plant (Varma *et al*., 1999; Peskan-Bergheofer *et al.,* 2004) and provides protection against biotic

and abiotic stresses and it requires host cell death for barley root colonization (Deshmukh *et al*., 2006).

The interaction of *P. indica* with orchids differs fundamentally from the described interactions with other higher plants. Blechert *et al*. (1999) inoculated two year old asymbiotically grown *Dactylorhiza maculata* with *P. indica*. They found that pelotons as in orchid mycorrhiza were formed and that growth of the plants was significantly promoted.

Dearnaley (2007) reported that orchidmycorrhizal fungi (OMF's) can transfer carbon from neighboring trees to orchids and increase the nutrient absorption surface of the host plant root systems.

In vitro raised plantlets of *Feronia limonia* (L.) Swingle were colonized by an endosymbiotic root fungus *Piriformospora indica* during *in vitro* rooting and their *ex vitro* transfer. Improved growth has been observed in terms of higher shoot and root length, internode diameter, area and number of leaves and both fresh and dry weights in plants showing an association with this fungus. More than 90 per cent of such plants survived in the greenhouse and subsequently under a nursery shed (Vyas *et al*., 2008).

Stein *et al*. (2008) reported that *Arabidopsis* roots inoculated with *P. indica* detected hyphae on the root surface, intercellularly aligned to root cell walls, and, albeit less frequently, intracellularly. Hyphae were confined mostly to the rhizodermis, and newly formed chlamydospores could be observed from 10 to 14 days post-infection (dpi) on the root surface and inside rhizodermal cells.

Dhinesh (2009) reported that percentage of root colonization of *Piriformospora indica* was maximum in POP recommendations of KAU along with *P. indica* at 6 MAP and flower bud formation stage in *Dendrobium* cv. Earsakul.

Kumar *et al*. (2011) observed colonization of *P. indica* in maize plant (70 per cent at 20 days after inoculation) at low as well as at high phosphate

concentration and suggested that the colonization is independent of phosphate availability.

Karimi *et al*. (2011) reported that in barley, the hyphal penetration in roots and root colonization were observed by microscopic inspection. In the case of inoculated plants, the hyphal growth of *Piriformospora indica* was detected on the root surface between the outer cell layers of cortex and within the cortical cells. The presence of intracellular round bodies was also observed, but a typical arbuscule such as that developed by the AM fungi (Glomeromycota) was not detected in any root cells. The round bodies, might function as storage organs, as has been considered for the intraradical vesicles of the Glomeromycota (Varma *et al*., 1999). *Piriformospora indica* mycelium was detected in the central part of the roots beyond endodermis.

2.4.3.4 Disease resistance

As endophytic growth of *P. indica* is restricted to the root, the fungus is able to provide systemic protection due to a yet unknown mechanism of induced resistance. As *P. indica* can easily be cultured without a host plant (Varma *et al*., 1999), it is suitable as a model system to study compatible plant-microbe interactions.

2.5 Physiology of CAM plants

Hew and Khoo (1980) reported that thick leaved orchids have features that are characteristic of CAM plants. This includes leaf and cell succulence, diurnal fluctuation in titrable acidity and nocturnal CO_2 fixation and inverted stomatal physiology.

Arditti (1982) stated that thick leaved orchids have CAM pathway and a direct relationship exist between stomatal opening and CO_2 fixation in the dark. Studies of Khoo and Hew (1999) also revealed the existence of CAM in *Dendrobium*.

Greater CAM activity in the leaves than that in the roots (both white and green portions) was found by Hew *et al*. (1984) in the epiphytic orchid hybrids *Arachnis* 'Maggie Oei' and *Aranthera* 'James Storie', as well as by Motomura *et al*. (2008) in several species of *Phalaenopsis*.

Flowers of *Oncidium* Goldiana have high PEPC/RUBPC ratio, indicating that it can fix CO_2 primarily through β–carboxylation. Fluctuations in titrable acidity have been observed in flowers of CAM orchid *Dendrobium* (Hew, 1995).

2.6 Radioisotope studies

Asen *et al.* (1963) demonstrated that ^{32}P applied as a dip to *Chrysanthemum morifolium* leaves was absorbed and translocated basipetally to other plant parts.

Sheehan *et al*. (1967) reported that ^{32}P applied to the foliage was readily absorbed by *Cattleya* 'Trimose' plants and roots three to four years old absorbed as much ^{32}P as younger roots. There was an increase in ^{32}P content in the tissue with time.

Alexander *et al*. (1984) demonstrated that the inflow of ^{32}P orthophosphate to adult *Goodyera repens* plants was less by two orders of magnitude when the roots were treated with fungicide, relative to untreated plants. This provided circumstantial evidence that the mycorrhizal fungus was involved in P uptake and transfer.

Finlay and Read (1986a; 1986b) showed that ectomycorrhizal (ECM) hyphae were the principle route for ^{14}C and ^{32}P transfer between Pinus seedlings. Chiariello *et al*. (1982) observed the transfer of ^{32}P from *Plantago erecta* to other VAM-infected grassland plants.

The pattern of photoassimilates partitioning changes with the development. Developing inflorescences and fruit capsules become the major

sinks at a later stage of growth, as reported in other orchids (Clifford *et al*., 1992, 1994, 1995; Yong and Hew, 1995a, b).

In *Cymbidium sinense*, both the one- and two-year old roots can absorb ^{32}P though the ability to absorb phosphorus in the one-year-old root is stronger. Hence care should be given to both kinds of roots during cultivation. During vegetative growth, the highest amount of ^{32}P is accumulated in the bud, followed by the pseudocorm and leaf. During reproductive growth, most of the ^{32}P is accumulated in the flower bud with very little activity in the leaf (Liang and Pan, 1994).

Leaves on back shoots supplied significantly more ^{14}C assimilates to another shoot bearing an inflorescence than to the other plant parts within back shoot itself. The inflorescence on the current shoot obtained ^{14}C assimilates from the leaves of both the current shoot and back shoot. It is concluded that back shoots are an important source of photo assimilates for growth and flower production in *Dendrobium* (Wadasinghe and Hew, 1995).

Nair *et al*. (2002 a) conducted experiment on *Dendrobium* 'Sonia 28' using ^{32}P to assess the nature of translocation of nutrients from backbulb to the young shoots. For this, backbulb was injected with ^{32}P solution and samples from all the shoots were taken at a regular interval. The radioactive phosphorous which was injected to the back bulb of the plant was recovered in the younger shoots. Radioactivity was recovered from all the young shoots from the second day of injection. Maximum radioactivity was recovered in the shoots nearest to the back bulb to which radioactivity was applied. The amount of radioactivity recovered kept on increasing in the younger shoots as days progressed. Thus, it confirms that translocation occurs from the back bulb to younger shoots in *Dendrobium* during the course of development.

The mycorrhizal fungus supplies the orchid with organic nitrogen (N) (Cameron *et al.*, 2006) and a further study has demonstrated P transfer to juvenile protocorms (Smith, 1966).

Cameron *et al*. (2007) found that transfer of P from fungus-to-host can occur rapidly in mycorrhizal symbiosis. Finlay and Read (1986 a,b) showed extensive labelling of ecto-mycorrhizal networks and the co-associated *Pinus sylvestris* plants after as little as 82 h after the fungus had been supplied with ^{32}P, with the fungus transporting the P over distance of several decimeters. Extensive labelling of the fungus and associated fungus was observed over 7 days.

Experiments conducted to evaluate the fertilizer use efficiency and the residual effects of phosphatic and nitrogenous fertilizers using ^{32}P revealed that, P fertilizers have a better fertilizer use efficiency than the nitrogenous fertilizers under vegetable intercropping system (Kotur *et al*., 2010).

Kumar *et al.* (2011) reported that using bi-compartment assay for ^{32}P transportation, P transfer by *Piriformospora indica* to the host plant was analyzed and a considerable amount of ^{32}P was measured in maize plants, suggesting that hyphae were transporting P to host plant at P deprived condition.

2.7 Vase life

Maintaining continuous supply of exogenous sugars have been proved to prolong vase-life in many species, such as rose and chrysanthemum (Yakinova *et al*., 1996) and snapdragon (Ichimura and Hisamitsu, 1999).

Vase solutions containing sucrose increase longevity of many flowers by supplying substrate for respiration and thereby delay senescence (Eason *et al*., 1997).

Maximum vase life was observed in plants sprayed with nutrient solution containing higher ratio of P, K and lower ratio of N *i.e.* 10:30:30 NPK in *Dendrbium* 'Sonia 17' (Swapna, 2000).

Fernandez (2001) reported that in *Dendrobium* flower longevity was more in 50 per cent single (59.75 days) and double levels (59.85 days) of shade.

Jawaharlal *et al.* (2002) studied the effect of holding solutions on *Dendrobium* "Sonia 17". Stems were cut to a uniform length of 55 cm and kept in the holding solutions. The flower stalks placed in the holding solutions of 8-HQS 100 ppm + sucrose 2 per cent recorded the highest vase life of 31.33 days.

Dinesh Babu *et al.* (2002) observed that flower spikes of *Dendrobium* 'Sonia-17' dipped in 8-HQS 5 ppm recorded the highest vase life of 30.66 days. Rattanawisalanon *et al*., (2003) achieved the maximum increase in the vase-life of *Dendrobium* 'Jew Yuay Tew' inflorescences treated with a combination of 4 per cent glucose and 0.05 µM amino oxy acetic acid (AOA).

2.8 Pest and disease incidence

2.8.1. Pest incidence

Gough *et al*. (1994) reported that *Stethopachys formosa* Baly feed on 27 species of orchids and that orchids were the only hosts of this pest, most commonly *Dendrobium* sp. Gough and Montgomery (1994) attempted to control *Stethopachys formosa* pest and found that benthiocarb 0.4 g l^{-1}, carbaryl at 10 g l^{-1} and methidathion 0.5 g l^{-1} were the most effective sprays for rapid killing of the adults.

Kumari (1998) reported that among the insecticides tested, quinalphos produced the highest mean mortality of the nymphs of *Aleurodicus disperses* (48 per cent). In the case of slugs, 5 per cent metaldehyde bait and metaldehyde mixed with carbaryl bait (2.5 per cent) gave the highest mean mortality of 44.44 per cent within 24 h of treatment. Treatment with 1 g phorate showed the highest mortality of 66-67 per cent after 48 h of treatment.

2.8.2 Disease incidence

Uchida (1995) recommended Agribroom for the control of bacterial diseases of orchids. Yungchun *et al*. (1999) observed that the growth of *Erwinia*

chrysanthemi causing soft rot in *Oncidium* was inhibited by lincomycin (100 ppm) and streptomycin (125 ppm).

Antibiotic bactericide (oxytetracycline/streptomycin mixture WP) was most effective for controlling the bacterial black spot caused by *Burkholderia andropogonis* in orchid (Takahashi *et al*., 2004).

A bacterial black spot caused by *Burkholderia s*p. was observed by Takahashi *et al.* (2004) in orchids. The typical symptom on leaves was dark or black spots with yellow halo. A bacterial disease characterized by small to large leaf spots with or without water soaking or soft rots was observed on various orchid genera including *Dendrobium, Oncidium* and *Miltonia* spp. and hybrids. The pathogenic bacteria were identified as *Burkholderia gladioli* (Keith *et al*., 2005).

According to Akrapikulchart (2009), at first the spots of anthracnose of *Dendrobium* may occur on the leaves and vary from yellowish to light brown and will be more or less circular, soft and sunken. Lesion may coalesce quickly to form large necrotic areas that may contain small black fungal structures. The surface of the lesion becomes covered with the wet, gelatinous spores from acervulus with numerous setae.

Palmer (2011) explained the symptoms of fusarium wilt in orchids as severe yellowing of leaves, collapse of the leaf stalk and wilting of entire plant. The rhizome of infected orchid developed a pink discoloration which eventually spread through the whole rhizome and to the pseudobulb.

Materials and methods

3. MATERIALS AND METHODS

The present investigation on 'Growth and physiological response of *Dendrobium* cv. Earsakul in different growing conditions' was conducted at College of Horticulture, Vellanikkara, Kerala from April 2011 to March 2013. The main objective was to assess the response of combination of nutrients, plant growth regulators and plant growth promoting root endophyte (PGPRE) in two age groups of *Dendrobium* cv. Earsakul plants (six month old and three year old at planting time) under three growing systems *viz.,* two level shade house, top ventilated polyhouse and fan and pad system. Attempts were also made to examine the symbiotic association between the host and PGPRE. The materials used and methodology adopted for the studies are described in this chapter.

3.1 Experimental site

The present experiments were conducted for a period from April 2011 to March 2013 in three growing systems *viz.,* two level shade house, top ventilated polyhouse and fan and pad system at the orchidarium of the All India Coordinated Research Project on Floriculture (AICRP) in the Dept. of Pomology and Floriculture, College of Horticulture, Vellanikkara, Thrissur, Kerala.

3.1.1 Location

The College of Horticulture, Vellanikkara where the experiment was conducted is situated at a latitude of 10^{o} 31' N and longitude of 76^{o} 3' E. The area lies 22.25 m above MSL and enjoys the typical warm humid tropical climate of Kerala.

3.1.2 Climate

The climate is tropical humid climate. The climatalogical data during the period of investigation are given in Appendix 1-5.

3.2 Materials

3.2.1 Variety

Commercially cultivated orchid hybrid *Dendrobium* cv. Earsakul was used for the experiment.

3.2.2 Planting material

Tissue culture plants of commercially cultivated orchid hybrid *Dendrobium* cv. Earsakul in two stages of growth *viz.,* six months old and three year old plants were used for the study (Plate 1).

3.2.3 Type and size of pot

Mud pots were used for planting *Dendrobium* cv. Earsakul. Pot size of 16.00 cm (length), 16.00 cm (width) and 13.50 cm depth was used. Iron benches of 2.50 m length, 1.00 m width and 0.80 m height were used for keeping the pots.

3.2.4 Potting media

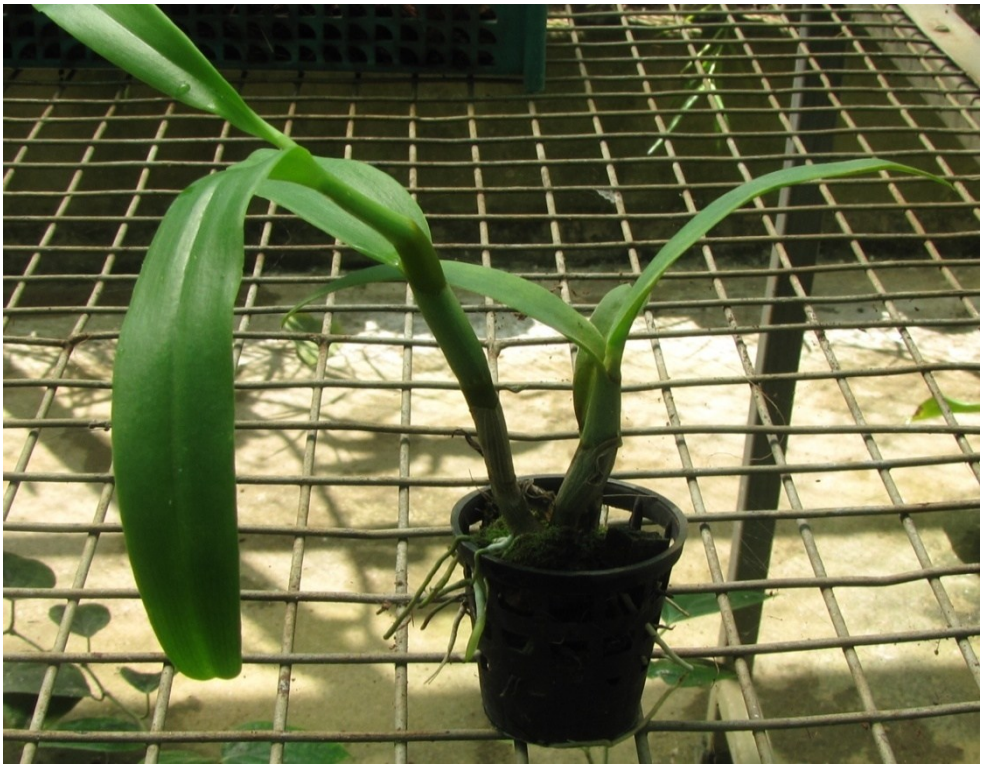
Tile bits, brick pieces, charcoal and coconut fibre pieces were used as the potting media.

3.2.5 Systems of growing

Three systems of growing *viz.,* two level shade house (S_1), top ventilated poly house (S_2), fan and pad system (S_3) were used for conducting the experiments.

3.2.5.1. Two level shade house

The size of the system is 21.00 m x 6.00 m x 3.50 m x 2.00 m, top one layer shade net, lower one layer poly film 200 micron with misting system. In this shade house, top and side walls along with the door are installed with agro shade net. The system has iron benches (mesh type) constructed with the support of cement pillars for keeping the plants. During rains, use of UV film protected the



Six month old plant

Three year old plant

Plate 1. Plant materials used for the study

plants from the adverse effects of rains (Plate 2). The shade level under the system is 50 per cent.

3.2.5.2 Top ventilated poly house

The size of the system was 21.00 m x 6.00 m x 3.50 m x 2.00 m and it was covered on top with poly film of 200 micron with one layer shade net below and misting system. Side and back walls were installed with agro shade net. This top ventilated poly house is designed to solve the problem of ventilation and humidity. The shade level under the system is 40 per cent (Plate 2).

3.2.5.3 Fan and pad system

The size of the growing system was 12.50 m x 8.00 m x 6.00 m x 4.00 m, poly film 200 micron covering, UV stabilized shade net with fan and pad for cooling system. Fan and pad system consisted of a greenhouse with its exhaust fans at one end of the greenhouse and a pump circulating water and over a porous pad installed at the opposite end of the greenhouse. The structure was made up of GI frames, covered on sides and top with poly ethylene film with a floor area of sand. The shade level under the system is 60-70 per cent (Plate 2).

3.2.6 Nutrients

3.2.6.1 Inorganic nutrients

The nutrients $N:P_2O_5:K_2O$ (3:1:1 during vegetative period and 1:2:2 during flowering period) were supplied through combinations made by using ammonium nitrate, orthophosphoric acid and potassium nitrate.

3.2.6.2 Organic manures

Organic manures such as organic mixture *viz.,* groundnut cake (N 6.5%, P 1.3% and K 1.5%), neem cake (N 5.5%, P 1.1% and K 1.5%), bone meal (N_2 to 4%, P 20 to 25%), cowdung slurry (N 0.5%, P 0.3% and K 0.9%) and vermiwash (N 200 ppm, P 70 ppm and K 1000 ppm) were used for the study.

Plate 2. Systems of growing

Two level shade house (S_1)

Inside view of two level shade house

Top ventilated polyhouse (S_2)

View of top ventilation

Fan and pad system (S_3)

Inside view of fan and pad system

Plate 3. Plants inside the three growing systems

Plants inside the two level shade house

Plants inside the top ventilated polyhouse

Plants inside the fan and pad system

3.2.6.3 Plant growth promoting root endophyte (PGPRE)

Culture of *Piriformospora indica* collected form Dept. of Agricultural Microbiology, College of Agriculture, Vellayani, Thiruvananthapuram was used (Plate 4).

3.2.6.4 Growth regulators

Growth regulators *viz.,* BA and GA_3 were used for the experiments.

3.3 Methods

Experiment I: Optimization of nutrients and growth regulator combinations in two stages of crop growth under three growing systems.

3.3.1 Design of the experiment

The experiment was laid out in Completely Randomised Design (CRD) with six treatments and three replications. Five plants per replication was selected for recording observations. .

3.3.2 Treatments

Plant growth promoters having a combination of organic manures, inorganic nutrients, growth regulators and *Piriformospora indica* (PGPRE) were used for the study. Details of the treatments are furnished in Table 1.

Table 1. Details of the treatments

Sl. No.	Treatments	Notations
1	POP recommendation of KAU	T_1
2	POP + PGPRE + Bone meal	T_2
3	POP + OM + VW + PGPRE + Bone meal	T_3
4	POP + OM + VW + PGPRE + Bone meal + GR	T_4
5	NPK + GR	T_5
6	NPK + GR + OM + VW + PGPRE + Bone meal	T_6

3.3.2.1 Package of Practices Recommendations of KAU (POP)

Plants were sprayed with supernatent liquid of cow dung slurry (1 kg of fresh cow dung in 5 l of water), foliar feeding was given with fertilizer mixture of $N:P_2O_5:K_2O$ 3:1:1 during vegetative period and 1:2:2 during flowering period (dose of the mixture was 2-3 g per litre of water, sprayed weekly twice). Nutrient combinations were made using ammonium nitrate, ortho-phosphoric acid and potassium nitrate.

3.3.2.2 Organic mixture (OM)

Organic manures *viz.,* bone meal, neem cake and groundnut cake 100 g each, soaked in water for 3-4 days and diluted to 10-15 times with water, filtered and sprayed over the plants at 15 days interval.

3.3.2.3 Vermiwash (VW)

Vermiwash was diluted to 3 per cent concentration and sprayed at 15 days interval.

3.3.2.4 Plant growth promoting root endophyte (PGPRE)

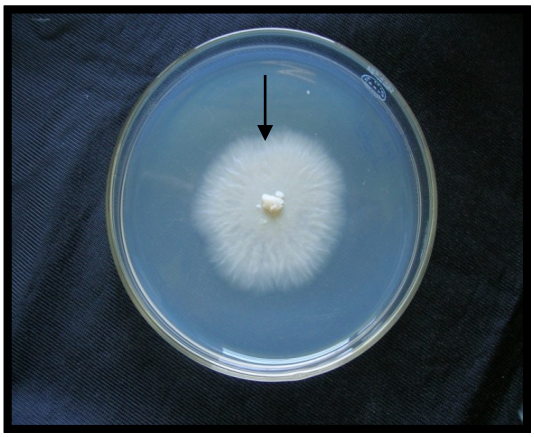
Piriformospora indica mycelium was mixed with vermiculite @ 1g per 100 g of vermiculite and applied near the root zone at the time of planting.

3.3.2.5 Bone meal

Bone meal was applied @ 15 g per plant near the root zone at the time of planting.

3.3.2.6 NPK

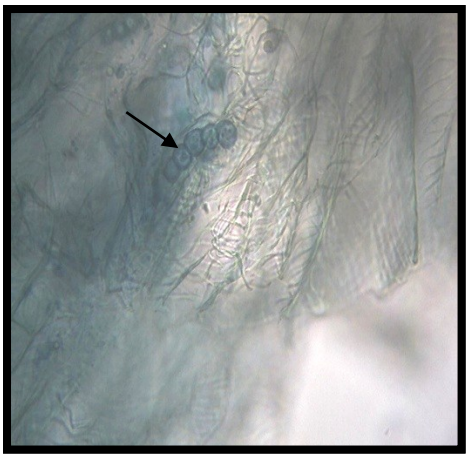
A combination of NPK in the ratio of 10:20:10 at 0.2 per cent was sprayed weekly twice. NPK in the form of ammonium nitrate, ortho-phosphoric acid and potassium nitrate were used for the study.



Piriformospora indica culture in PDA media

Piriformospora indica culture in PDB media

Piriformospora indica culture in vermiculite



Pear shaped chlamydospores of the fungus

Plate 4. Culture of *Piriformospora indica* (a plant growth promoting root endophyte)

3.3.2.7 Growth regulators (GR)

Benzyl adenine (BA) 50 mg l^{-1} (dissolved in 40 per cent 5 N NaoH) and GA_3 10 mg l^{-1} (dissolved in ethyl alcohol) were sprayed at monthly intervals.

3.3.3 Stages of growth

3.3.3.1 Six month old plants

Six month old tissue cultured planting materials were used for the experiment.

3.3.3.2 Three year old plants

Three-year-old plants were used for the experiment.

3.4 Plant protection

Streptomycin sulphate (0.2 g l^{-1}) was applied once in two to three months for the control of the bacterial soft rot disease. Other diseases caused by fungus are managed by the spray of mancozeb @ 2.5 g l^{-1} and carbendazim @ 1 g l^{-1}. Snails were controlled by application of metaldehyde bait 2.5 per cent. Thrips, aphids and spider mites were controlled by the sprays of systemic insecticides.

Experiment II

3.5 Study on symbiotic interactions

3.5.1 Anatomical studies

Roots from the treated plants were washed thoroughly in running tap water, cut into 1.0 cm pieces and treated overnight with 10 per cent KOH solution at room temperature and the root segments were boiled for 10 minutes. Thereafter, the root segments were washed 3-5 times with sterilized distilled water and then treated with 1 per cent HCl for 3-4 minutes before staining with 0.05 per cent trypan blue in lactophenol (Phillips and Hayman, 1970). Then the root bits were de-stained with fresh lactophenol and fine thin, transparent, cross

and longitudinal section of the root segments were put on a glass slide and gently pressed with cover slip, examined microscopically (40X and 100X), photographed and the growth and nature of attachment of hyphae in root cells was observed and the information on structural linkage between the host and *Piriformospora indica* (PGPRE) was recorded.

3.6 Radioisotope labelling (^{32}P)

Radioisotope labelling (^{32}P) was carried out to study the functional linkage between the host and *Piriformospora indica* (PGPRE).

Table 2. Treatments for the radioisotope study

Sl. No.	Treatments	Notations
1	Labelled $KH_2{}^{32}PO_4$ applied to the roots inoculated with non-labelled fungus (1.7 µCi concentration)	T_1
2	Labelled $KH_2{}^{32}PO_4$ applied to the roots without fungus (1.7 µCi concentration)	T_2
3	Labelled 1:2:2 $N:P_2O_5:K_2O$ nutrient solution applied to the roots inoculated with non-labelled fungus (2.4 µCi concentration)	T_3
4	Labelled fungus applied to the roots (1.29 µCi concentration)	T_4
5	Labelled fungus applied to the roots (1.94 µCi concentration)	T_5
6	Labelled fungus applied to the roots (2.58 µCi concentration)	T_6

3.6.1 Labelled $KH_2{}^{32}PO_4$ applied to the roots inoculated with non-labelled fungus (T_1)

The concentration of 1.7 µCi of ^{32}P was mixed to the 1000 ml of 1000 ppm of KH_2PO_4 and 25 ml was applied to the roots of the plant. For this treatment, the fungus was inoculated to the plant before application of labelled $KH_2{}^{32}PO_4$.

Application of ^{32}P to the plants

Plants after inoculation

Plate 5. Radioisotope labelling (^{32}P) at Radiotracer Laboratory

3.6.2 Labelled $KH_2{}^{32}PO_4$ applied to the roots without fungus (T_2)

Roots of the plant was applied with labelled $KH_2{}^{32}PO_4$ (1.7 μCi concentration) without fungus inoculation.

3.6.3 Labelled nutrient solution applied to the roots inoculated with non-labelled fungus (T_3)

For this treatment, 2.4 μCi ^{32}P was taken and mixed with 100 ml 1:2:2 $N:P_2O_5:K_2O$ nutrient solution and applied to the roots of the plants. In this case also plants were inoculated with *Piriformospora indica* fungus before applying the labelled nutrient solution.

3.6.4 Labelled fungus applied to the roots with three concentrations

Pure culture of *Piriformospora indica* fungus from Potato Dextrose Agar (PDA) media was taken and sub-cultured in Martin's Rose Bengal media. The fungus was labelled with ^{32}P with three concentrations *viz*., 1.29 μCi (T_4), 1.94 μCi (T_5) and 2.58 μCi (T_6) in the broth culture *i.e.* in Martin's Rose Bengal media each treated separately and kept for fungus development at Radio Tracer Laboratory.

After proper growth of the fungus in the Martin's Rose Bengal media, radioactivity present in the growth media was removed by centrifugation before inoculation of labelled fungus into the plant in order to assure whether the radio activity detected in inoculated plant is either from the *P. indica* fungus or from the media *i.e.* ^{32}P should reach the plant from the fungus. For this, the broth culture (Martin's Rose Bengal media) was centrifuged in centrifuge tubes at 5000 rpm for 15 minutes. After each centrifugation, the supernatent was removed and the fungus pelleted at the bottom of the centrifuge tube was re-suspended in sterile distilled water and centrifuged again for removing the radioactivity from the Martin's Rose Bengal media. The process of centrifugation was repeated thrice and the supernatent obtained was tested for the presence of radioactivity in a scintillation unit. Centrifugation and re-suspension in fresh sterile distilled water was repeated until the supernatant was totally free of radioactivity. Finally, the

labelled fungus was re-suspended in 25 ml sterile distilled water and used for root inoculation of the *Dendrobium* cv. Earsakul plants.

3.6.5 Root inoculation

After completion of centrifugation and final testing of radioactivity in scintillation unit, the fungal suspension (25 ml) was taken in small plastic tubes and the tip of the root was dipped carefully in the fungal suspension for root inoculation.

3.6.6 Autoradiography

Three weeks after application of labelled $KH_2{}^{32}PO_4$ (T_1 and T_2) and labelled 1:2:2 nutrient solution (T_3), the plants were uprooted carefully from the pots. The plants were then arranged in X-ray films in between sheets of an absorbent paper in their original position, labelled and secured with adhesive tape. The specimens sandwiched between absorbent sheets were then pressed in herbarium press and allowed to dry at room temperature in the dark room. After drying, the plant specimens were taken for autoradiography. The plants were removed and the X-ray film was developed and fixed by using a commercial X-ray film developer/ fixer solution.

3.6.7 Counting of ^{32}P in a scintillation unit

After autoradiography, the dried plant parts were ground into fine powder, digested with diacid mixture made up to 100 ml and filtered solution was taken in vials and kept in a scintillation unit for counts per minute (CPM) and data was recorded.

3.7 Observations

The observations were taken from three sample plants in each treatment, each replication and the data was recorded.

3.7.1 Growth characters

Following growth characters were recorded at monthly intervals.

3.7.1.1 Plant height

The height of the plant was measured and recorded from the base of the plant to tip and was expressed in cm.

3.7.1.2 Number of leaves per plant

Number of leaves on each shoot of the plant was counted and recorded.

3.7.1.3 Number of shoots per plant

Number of all shoots per plant was counted and recorded.

3.7.1.4 Girth of the shoot

Girth of the 5^{th} internode on tallest shoot of the plant was measured and expressed in cm.

3.7.1.5 Internodal length

The length of the 5^{th} internode on the tallest shoot of the plant was measured and expressed in cm.

3.8 Flower characters

The following flower characters were observed and recorded during the period of study from April 2011 to March 2013.

3.8.1 Days to flowering

Total number of days taken for flowering during the period of study was recorded.

3.8.2 Days to first flower opening

Total number of days taken for the first flower to open in a plant was recorded.

3.8.3 Days to last flower opening

Total number of days taken for the last flower to open in a plant was recorded.

3.8.4 Length of the spike

Length of spike was measured from the point of emergence to the tip of flower pedicel and expressed in cm.

3.8.5 Number of flowers per spike

Total number of flowers per spike was counted and recorded.

3.8.6 Size of flower

Size of individual flowers was recorded by noting down the length and breadth of the flowers and expressed in cm.

3.8.7 Number of spikes per plant

Number of spikes initiated in each plant, during the period of observation was counted and recorded.

3.8.8 Vase life

The number of days that the flowers can be kept fresh, after removing from the plant was observed and recorded.

3.9 Physiological parameters

The observations on physiological parameters were recorded at six months after planting.

3.9.1 Leaf area

The length and breadth of leaf was measured and the area of leaf was computed by using the following regression equation developed as part of the present study (R^2)

Leaf area (a) = - 25.857 + 8.95 x breadth + 2.184 x length

3.9.2 Chlorophyll content

The chlorophyll content of the leaves was determined using 80 per cent acetone (Porra, 2002). The most recent, fully developed leaf was taken and cut into small pieces (100 mg), the leaf sample pieces digested in 10 ml acetone and ground well using mortar and pestle. Then ground material was poured into centrifuge tube and centrifuged at 5000 rpm for 10 minutes. The supernatent solution was poured into vial (cuvette). The absorbance was read at 646.6 nm and 663.6 nm using distilled water as blank with spectrophotometer. Chlorophyll a, b and total chlorophyll was calculated using the formula, and expressed in mg g^{-1} fresh weight.

Chlorophyll a = 12.25 ($A_{663.6}$) – 2.55 ($A_{646.6}$) x 10 ml acetone / 100 mg leaf tissue

Chlorophyll b = 20.31 ($A_{646.6}$) – 4.91 ($A_{663.6}$) x 10 ml acetone / 100 mg leaf tissue

Total chlorophyll = 17.76 ($A_{646.6}$) + 7.34 ($A_{663.6}$) x 10 ml acetone / 100 mg leaf tissue

3.9.3 Relative growth rate

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

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

Where, W_1 and W_2 are the dry weight of the whole plant at time t_1 and t_2, respectively.

3.9.4 Net assimilation rate

Net assimilation rate (NAR) refers to the change in dry weight of the plant per unit leaf area per unit time. NAR can be determined by measuring plant dry weight and leaf area periodically during the growth and is commonly expressed in g m^{-2} day^{-1} (Williams, 1946).

$$NAR = \frac{W_2 - W_1}{(LA_2 - LA_1)} \times \frac{\text{Loge } W_2 - \text{Loge } W_1}{t_2 - t_1}$$

Where, LA_1 and LA_2 are the leaf area of plant and W_1 and W_2 are the whole plant dry weight at time t_1 and t_2 respectively.

3.9.5 Crop growth rate

Crop growth rate (CGR) was calculated using the formula of Yaduraju and Ahuja (1996) and expressed in g m^{-2} day^{-1}.

$$CGR = \frac{W_2 - W_1}{T_2 - T_1}$$

3.9.6 Dry matter production

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

3.9.7 Stomatal characters

Stomatal impressions were taken at three different areas using glue (quick fix). The number of stomata per square millimeter of microscopic field (0.11 mm^2) was counted and recorded as per square millimeter (number of stomata / 0.11 mm^2).

3.9.8 Diffusive resistance

Diffusive resistance of the leaf was measured using Infra Red Gas Analyzer (IRGA) and expressed as S cm^{-1}.

3.9.9 Rate of photosynthesis

Photosynthetic rate of the leaf was recorded by using Infra Red Gas Analyzer (IRGA) during the night (6 pm to 11 pm) and expressed as µmol CO_2 m^{-2} s^{-1}

3.9.10 Rate of transpiration

Transpiration rate of the leaf was recorded by using Infra Red Gas Analyzer (IRGA) during the night (6 pm to 11 pm) and day time also and expressed as µmol m^{-2} s^{-1}

3.10 Nutrient analysis

Nutrient analysis was conducted at the time of flower bud formation. Most recent and fully developed leaves were collected from the plant and analysed for nutrient composition (Naik and Barman, 2007). Leaf samples were washed and dried in shade for one week and then dried in hot air oven at 70 ^oC. The dried samples were ground, mixed with diacid mixture and then used for analysis for major nutrients *viz*., N, P and K.

3.10.1 Nitrogen

Dried, finely powdered leaf sample of 0.2 g was digested using concentrated sulphuric acid, oxidized using 30 per cent H_2O_2 and the N content was estimated by Microkjeldahl method (Jackson, 1958).

3.10.2 Phosphorus

The leaf sample (0.5 g) was digested using diacid mixture of nitric acid and perchloric acid taken in the ratio of 9:4 (Johnson and Ulrich, 1959). Finally phosphorus was estimated using vanadomolybdophosphoric yellow colour method. The intensity of yellow colour was read in Spectronic-20 at 470 nm.

3.10.3 Potassium

From the digested sample as mentioned above, an aliquote was prepared and K content was estimated using a Flame photometer (Jackson, 1958).

3.11 Root parameters

Root parameters were recorded at the time of flower bud formation.

3.11.1 Number of roots

Total number of roots per plant was counted and expressed in number.

3.11.2 Root length

Length of the longest root was measured and recorded after uprooting the plant and expressed in cm.

3.11.3 Root volume

Root volume was measured after uprooting the plant and expressed in m^3.

3.11.4 Root colonization

The method proposed by Giovannetti and Mosse (1980) was followed for assessment of root colonization of *Piriformospora indica*. The root segments (1.0

cm) were selected at random from the stained samples and observed under light and binocular microscope (40X and 100X). Fifteen root segments were examined under the microscope and the percentage colonization was calculated as follows

$$\text{Percentage colonization} = \frac{\text{Number of root segments colonized}}{\text{Total number of segments observed}} \times 100$$

3.12 Incidence of pest and diseases

Incidence of pest and diseases was also observed during the period of study and proper control measures were taken.

3.13 Statistical analysis

The experimental data were analysed by the ANOVA (Analysis of Variance technique (Panse and Sukhatme, 1985). MSTATC and MS-Excel software were used for computation of data. Canonical correlation was done to find the relationship of growth parameters and yield characters of the plant.

Results

4. RESULTS

The results of the study pertaining to influence of plant growth promoters (treatments) on plants under three systems of growing are presented under seven captions *viz*.,

1. Growth characters
2. Flower characters
3. Physiological parameters
4. Content of nutrients
5. Root parameters
6. Study on symbiotic interactions
7. Pest and disease incidence

4.1 Growth characters

Various observations on growth at different combinations of plant growth promoters (Treatments-T) under three growing systems *viz*., two level shade house (S_1), top ventilated poly house (S_2) and fan and pad system (S_3) of plants in two stages of plant growth *viz*., six month old and three year old plants were recorded, analyzed and the results are presented in Tables 3a to 7b.

4.1.1 Plant height

The data depicting the plant height of the six month and three year old plants are presented in Tables 3a and 3b.

In six month old plants, response of treatments to plant height was significant. No significant difference in plant height was noticed up to 9 MAT. At 12 MAT, treatment T_3 and T_2 recorded a plant height of 19.56 cm each, which was on par with T_4 (19.43 cm), T_1 (19.06 cm) and T_6 (16.79 cm). At 15 MAT, T_3 recorded the maximum plant height of 21.16 cm which was on par with all other treatments except T_5 (16.26 cm). The same trend was observed on plant height at 18 MAT. At 24 MAT, the treatment T_3 recorded highest plant height of 22.42 cm

which was on par with T_2 (21.53 cm), T_1 (18.26 cm) and T_4 (18.72 cm). The treatment T_5 recorded lowest plant height of 15.94 cm. In three year old plants, plant height was significantly influenced by treatments during 18 MAT, 21 MAT and 24 MAT. At 18 MAT, treatment T_3 recorded maximum plant height of 25.15 cm which was on par with T_2 (23.90 cm), T_1 (22.81 cm) and T_4 (20.39 cm). The treatment T_3 recorded highest plant height of 27.05 cm at 21 MAT which was on par with T_2 (23.80 cm) and T_1 (23.91 cm). At 24 MAT, highest plant of 26.49 cm was recorded in T_3 which was on par with T_2 (22.80 cm).

It is inferred that the treatment combination POP + OM + VW + PGPRE + Bone meal (T_3) recorded maximum plant height when compared to all the treatments in six month old and three year old plants, except in 3rd month after transplanting in six month old plant and in 6th and 9th MAT in three year old plant.

Plant height was significantly influenced by growing systems in all stages of growth except at 9 MAT in six month old plants. In general, among growing systems, significantly higher plant height was recorded in S_2 (Fig. 8). At 21 MAT, highest plant height of 22.36 cm was recorded in S_2 which was on par with S_1 (20.06 cm). In three year old plants, height of the plant was significantly influenced by the growing systems at all stages of growth except at 6 MAT and 9 MAT. In general, from 12 MAT, highest plant height was recorded in S_2 which was on par with S_1 in all stages of growth except in 15 MAT and 21 MAT.

It is concluded that top ventilated polyhouse (S_2) had the maximum influence on plant height irrespective of the age of the plants.

Interaction of various plant inputs and systems of growing did not have significant influence on plant height irrespective of the age of the plants.

4.1.2 Number of leaves per plant

Data on number of leaves per plant of six month old and three year old plants is presented in Tables 4a and 4b.

Table 3a. Influence of plant growth promoters (T), growing systems (S) and TxS interactions on plant height (cm) in six month old plants of *Dendrobium* cv. Earsakul at quarterly intervals

Treatments		Plant height (cm)							
		Months after treatments (MAT)							
		3	6	9	12	15	18	21	24
Plant growth promoters (T)	T_1	15.54	19.20	19.41	19.06^{xy}	19.61^{xy}	21.28^{x}	19.49	18.26^{xy}
	T_2	14.97	18.66	19.60	19.56^{x}	18.80^{xy}	21.30^{x}	20.67	21.53^{x}
	T_3	14.97	18.70	19.57	19.56^{x}	21.16^{x}	23.55^{x}	20.99	22.42^{x}
	T_4	13.94	18.16	19.20	19.43^{x}	19.33^{xy}	21.57^{x}	18.37	18.72^{xy}
	T_5	14.78	18.49	16.64	15.43^{y}	16.26^{y}	17.66^{y}	16.27	15.94^{y}
	T_6	14.99	18.60	19.09	16.79^{xy}	18.61^{xy}	20.79^{x}	19.35	18.97^{xy}
CD (0.05)		NS	NS	NS	3.62	3.87	3.50	NS	3.80
Growing systems (S)	S_1	14.48^{m}	18.54^{lm}	19.45	17.42^{m}	20.02^{m}	23.09^{m}	20.06^{l}	20.05^{m}
	S_2	15.96^{l}	19.73^{l}	19.47	20.84^{l}	23.85^{l}	25.50^{l}	22.36^{l}	23.33^{l}
	S_3	14.17^{m}	17.64^{m}	17.83	16.64^{m}	13.01^{n}	14.49^{n}	15.16^{m}	14.54^{n}
CD (0.05)		1.34	1.57	NS	2.56	2.73	2.48	2.91	2.68
T x S	T_1S_1	14.17	17.97	18.06	16.75	19.05	22.98	19.44	18.42
	T_2S_1	14.62	19.02	19.54	19.33	20.36	23.54	22.57	22.93
	T_3S_1	15.67	19.27	19.38	17.86	21.90	26.73	23.42	24.60
	T_4S_1	13.84	18.74	19.71	19.23	23.08	21.97	21.58	20.14
	T_5S_1	14.34	18.21	20.15	14.45	18.12	20.49	14.11	15.53
	T_6S_1	14.21	17.97	19.85	16.88	17.57	22.78	19.21	18.66
	T_1S_2	16.92	20.35	20.06	20.52	23.13	24.80	22.23	20.45
	T_2S_2	15.40	18.63	19.48	19.07	24.62	27.53	26.05	27.57
	T_3S_2	14.86	19.05	20.86	23.00	25.61	27.77	23.60	25.70
	T_4S_2	15.16	19.36	20.66	22.13	23.34	26.17	17.63	21.62
	T_5S_2	16.85	20.77	16.11	18.18	21.64	20.45	20.13	19.36
	T_6S_2	16.52	20.16	19.60	22.13	24.76	26.26	24.47	25.23
	T_1S_3	15.54	19.26	20.08	19.88	16.63	16.07	16.80	15.90
	T_2S_3	14.90	18.32	19.75	20.27	11.41	12.81	13.37	14.08
	T_3S_3	14.36	17.75	18.45	17.78	15.97	16.14	15.96	16.96
	T_4S_3	12.82	16.35	17.22	16.91	11.54	16.54	15.88	14.37
	T_5S_3	13.16	16.46	13.65	13.63	9.02	12.03	14.56	12.93
	T_6S_3	14.24	17.66	17.81	11.34	13.48	13.30	14.35	13.00
CD (0.05)		NS	NS	NS	NS	NS	NS	NS	NS

1. Figures with same alphabets/no superscripts form a homogenous group
2. All comparisons along the column based on DMRT
3. Use super script x, y, z,..... for comparison of treatments
4. Use super script l, m, n,..... for comparison of growing systems
5. Use super script a, b, c,..... for comparison of interactions

Table 3b. Influence of plant growth promoters (T), growing systems (S) and TxS interactions on plant height (cm) in three year plants of *Dendrobium* cv. Earsakul at quarterly intervals

Treatments		Plant height (cm)							
		Months after treatments (MAT)							
		3	6	9	12	15	18	21	24
Plant growth promoters (T)	T_1	17.94	21.13	19.70	18.68	20.89	22.81^{xy}	23.91^{xy}	21.05^{yz}
	T_2	19.37	22.89	23.81	19.78	20.40	23.90^{x}	23.80^{xy}	22.80^{xy}
	T_3	19.28	22.64	22.93	22.77	22.43	25.15^{x}	27.05^{x}	26.49^{x}
	T_4	20.85	24.36	21.42	18.51	19.79	20.39^{xyz}	19.64^{yz}	19.57^{yz}
	T_5	19.71	22.26	20.40	15.15	17.05	16.88^{z}	14.30^{z}	14.06^{z}
	T_6	21.77	25.19	19.18	19.01	15.72	17.80^{yz}	19.52^{yz}	17.72^{z}
CD (0.05)		NS	NS	NS	NS	NS	5.00	5.64	4.18
Growing systems (S)	S_1	19.47^{lm}	22.61	23.04	20.71^{l}	19.27^{m}	22.88^{l}	23.26^{l}	21.43^{l}
	S_2	21.63^{l}	24.97	20.53	21.54^{l}	23.31^{l}	23.89^{l}	22.37^{lm}	23.70^{l}
	S_3	18.38^{m}	21.66	20.15	14.69^{m}	15.56^{n}	16.69^{m}	18.47^{m}	15.72^{m}
CD (0.05)		2.97	NS	NS	4.43	3.61	3.54	3.99	2.96
T x S	T_1S_1	14.17	20.78	21.05	20.58	22.56	26.13	25.64	17.03
	T_2S_1	14.62	24.21	25.66	16.56	17.13	23.19	23.83	22.96
	T_3S_1	15.67	20.75	21.08	19.70	22.67	27.81	28.62	28.30
	T_4S_1	13.84	24.03	25.79	24.53	22.84	26.44	24.77	23.90
	T_5S_1	14.34	21.82	22.25	19.60	16.24	19.57	15.80	17.11
	T_6S_1	14.21	24.06	22.36	23.28	14.13	14.14	20.89	19.25
	T_1S_2	16.92	24.15	18.51	20.45	22.82	22.53	24.37	25.28
	T_2S_2	15.40	23.93	25.24	26.47	28.07	30.81	28.54	27.76
	T_3S_2	14.86	21.48	20.93	24.93	24.24	26.54	29.92	31.00
	T_4S_2	15.16	24.88	20.10	21.58	24.20	21.94	20.94	22.57
	T_5S_2	16.85	26.94	22.85	15.71	21.68	18.73	14.82	15.67
	T_6S_2	16.52	28.38	15.55	20.08	18.85	22.79	15.64	19.91
	T_1S_3	15.54	18.43	19.52	14.98	17.27	19.76	21.71	20.82
	T_2S_3	14.90	20.53	20.53	16.30	16.00	17.70	19.01	17.69
	T_3S_3	14.36	25.66	26.76	23.66	20.37	21.08	22.61	20.17
	T_4S_3	12.82	24.14	18.37	9.41	12.31	12.78	13.22	12.24
	T_5S_3	13.16	18.01	16.10	10.13	13.21	12.34	12.27	9.41
	T_6S_3	14.24	23.10	19.62	13.65	14.16	16.46	22.01	14.00
CD (0.05)		NS	NS	NS	NS	NS	NS	NS	NS

1. Figures with same alphabets/no superscripts form a homogenous group
2. All comparisons along the column based on DMRT
3. Use super script x, y, z,..... for comparison of treatments
4. Use super script l, m, n,..... for comparison of growing systems
5. Use super script a, b, c,..... for comparison of interactions

Table 4a.Influence of plant growth promoters (T), growing systems (S) and TxS interactions on number of leaves per plant in six month old plants of *Dendrobium* cv. Earsakul at quarterly intervals

Treatments		Number of leaves per plant							
		Months after treatments (MAT)							
		3	6	9	12	15	18	21	24
Plant growth promoters (T)	T_1	9.48^{xy}	6.22^{y}	5.52^{xy}	4.00^{y}	5.37^{xy}	3.67^{z}	3.44^{z}	3.37^{z}
	T_2	9.93^{xy}	7.74^{xy}	5.96^{xy}	4.26^{y}	6.63^{xy}	4.00^{yz}	4.19^{yz}	4.48^{z}
	T_3	9.96^{xy}	6.89^{xy}	6.44^{xy}	5.56^{x}	6.96^{x}	4.33^{yz}	5.03^{xy}	5.85^{y}
	T_4	11.11^{x}	8.70^{x}	8.07^{x}	5.93^{x}	6.89^{x}	5.44^{x}	5.89^{x}	6.96^{x}
	T_5	8.93^{y}	5.70^{y}	5.06^{z}	3.78^{y}	5.63^{xy}	4.74^{xy}	3.96^{yz}	3.85^{z}
	T_6	9.63^{xy}	7.52^{xy}	6.59^{y}	3.96^{y}	5.14^{y}	4.89^{xy}	4.41^{yz}	6.30^{xy}
CD (0.05)		1.60	1.92	1.36	1.15	1.48	0.97	1.00	0.80
Growing systems (S)	S_1	9.22^{m}	7.26	4.59^{n}	5.24^{m}	5.93^{m}	4.57^{l}	4.91^{l}	5.72^{m}
	S_2	11.00^{l}	7.69	7.73^{l}	6.19^{l}	8.33^{l}	5.11^{l}	5.15^{l}	6.83^{l}
	S_3	9.30^{m}	6.44	6.50^{m}	2.31^{n}	4.06^{n}	3.85^{m}	3.41^{m}	2.85^{n}
CD (0.05)		1.13	NS	0.95	0.81	1.04	0.68	0.71	0.57
T x S	T_1S_1	9.00	7.33	4.11	4.89	6.11	3.44^{b}	3.44^{c}	3.44^{def}
	T_2S_1	9.78	8.00	4.89	4.89	6.44	3.56^{b}	4.33^{abc}	5.78^{bcdef}
	T_3S_1	8.89	6.11	4.78	6.00	6.44	4.11^{b}	5.33^{abc}	6.44^{abcd}
	T_4S_1	10.56	9.33	6.67	7.33	5.55	5.89_{ab}	7.22^{ab}	7.78^{abc}
	T_5S_1	8.89	5.11	2.78	4.56	6.22	5.44^{ab}	4.66^{abc}	4.67^{cdef}
	T_6S_1	8.22	7.67	4.33	3.78	4.77	5.00^{ab}	4.44^{abc}	6.22^{abcde}
	T_1S_2	9.78	6.00	6.89	5.44	7.22	4.33^{ab}	3.89^{bc}	4.56^{cdef}
	T_2S_2	10.33	6.78	6.00	5.22	8.44	4.00^{b}	4.56^{abc}	5.00^{cdef}
	T_3S_2	11.78	7.89	8.33	7.67	9.00	4.89^{ab}	5.56^{abc}	8.11^{abc}
	T_4S_2	13.33	10.33	10.67	8.11	11.22	7.33^{a}	7.56^{a}	9.89^{a}
	T_5S_2	9.56	6.89	6.17	4.67	6.89	4.67^{ab}	3.56^{c}	4.44^{cdef}
	T_6S_2	11.22	8.22	8.33	6.00	7.22	5.44^{ab}	5.78^{abc}	9.00^{ab}
	T_1S_3	9.67	5.33	5.56	1.67	2.78	3.22^{b}	3.00^{c}	2.11^{f}
	T_2S_3	9.67	8.44	7.00	2.67	5.00	4.44^{ab}	3.67^{c}	2.67^{def}
	T_3S_3	9.22	6.67	6.22	3.00	5.44	4.00^{b}	4.22^{abc}	3.00^{def}
	T_4S_3	9.44	6.44	6.89	2.33	3.89	3.11^{b}	2.89^{c}	3.22^{def}
	T_5S_3	8.33	5.11	6.22	2.11	3.78	4.11^{b}	3.67^{c}	2.44^{ef}
	T_6S_3	9.44	6.67	7.11	2.11	3.44	4.22^{b}	3.00^{c}	3.67^{def}
CD (0.05)		NS	NS	NS	NS	NS	1.67	1.74	1.40

1. Figures with same alphabets/no superscripts form a homogenous group
2. All comparisons along the column based on DMRT
3. Use super script x, y, z,..... for comparison of treatments
4. Use super script l, m, n,..... for comparison of growing systems
5. Use super script a, b, c, d, e, f ..... for comparison of interactions

Table 4b. Influence of plant growth promoters (T), growing systems (S) and TxS interactions on number of leaves per plant in three year old plants of *Dendrobium* cv. Earsakul at quarterly intervals

Treatments		Number of leaves per plant							
		Months after treatments (MAT)							
		3	6	9	12	15	18	21	24
Plant growth promoters (T)	T_1	5.30	5.59	4.26^{xy}	3.74	5.51	5.41	3.81^{y}	3.33^{z}
	T_2	6.30	6.41	5.19^{x}	4.22	6.03	4.85	4.19^{xy}	5.04^{y}
	T_3	6.37	5.88	5.00^{x}	4.15	5.48	5.59	5.44^{x}	5.89^{xy}
	T_4	6.59	7.17	5.33^{x}	3.96	6.52	5.93	4.85^{xy}	6.22^{x}
	T_5	6.15	5.07	3.37^{y}	4.00	4.89	4.70	4.74^{xy}	4.04^{z}
	T_6	6.93	5.19	3.56^{y}	4.67	5.89	5.93	4.44^{y}	6.22^{x}
CD (0.05)		NS	NS	1.35	NS	NS	NS	1.40	0.96
Growing systems (S)	S_1	5.28^{m}	6.59^{l}	3.14^{m}	3.83^{m}	5.76^{m}	5.43	4.07^{m}	5.03^{m}
	S_2	8.24^{l}	5.70^{lm}	6.67^{l}	6.07^{l}	8.09^{l}	5.85	6.09^{l}	6.92^{l}
	S_3	5.29^{m}	5.37^{m}	3.53^{m}	2.46^{n}	3.46^{n}	4.93	3.57^{m}	3.40^{n}
CD (0.05)		1.07	1.03	0.95	0.96	0.94	NS	0.99	0.67
T x S	T_1S_1	4.78	6.89	3.11	3.33	5.22	4.56	3.22	3.22^{c}
	T_2S_1	6.33	6.89	3.11	4.33	7.00	5.33	3.67	5.78^{bc}
	T_3S_1	3.67	5.78	3.22	3.67	6.00	4.89	4.67	4.89^{bc}
	T_4S_1	5.33	7.89	4.22	3.00	6.11	6.00	4.33	6.33^{abc}
	T_5S_1	6.00	6.89	2.89	3.67	4.67	5.33	4.56	4.00^{c}
	T_6S_1	5.56	5.22	2.33	5.00	5.56	6.44	4.00	6.00^{abc}
	T_1S_2	7.00	5.11	6.11	5.33	7.78	6.22	4.67	4.00^{c}
	T_2S_2	6.89	5.89	7.78	6.44	8.56	4.67	6.00	6.00^{abc}
	T_3S_2	8.67	6.00	6.89	5.56	7.67	6.89	7.11	8.33^{ab}
	T_4S_2	9.67	7.56	9.00	7.78	10.33	6.89	7.11	9.55^{a}
	T_5S_2	8.44	4.44	4.89	5.89	6.88	5.22	5.89	5.44^{bc}
	T_6S_2	8.78	4.89	5.33	5.44	7.33	5.22	5.78	8.22^{ab}
	T_1S_3	4.11	4.78	3.56	2.56	3.22	5.44	3.56	2.78^{c}
	T_2S_3	5.67	6.44	4.67	1.89	3.77	4.56	2.89	3.33^{c}
	T_3S_3	6.78	5.89	4.89	3.22	2.77	5.00	4.56	4.44^{c}
	T_4S_3	4.78	5.78	2.78	1.11	3.11	4.89	3.11	2.78^{c}
	T_5S_3	4.00	3.89	2.33	2.44	3.11	3.56	3.78	2.67^{c}
	T_6S_3	6.44	5.44	3.00	3.55	4.77	6.11	3.56	4.44^{c}
CD (0.05)		NS	NS	NS	NS	NS	NS	NS	1.66

1. Figures with same alphabets/no superscripts form a homogenous group
2. All comparisons along the column based on DMRT
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4. Use super script l, m, n,..... for comparison of growing systems
5. Use super script a, b, c,..... for comparison of interactions

Two level shade house (S_1)

Two level shade house (S_1)

Top ventilated polyhouse(S_2)

Top ventilated polyhouse(S_2)

Fan and pad system (S_3)

Fan and pad system (S_3)

Plate 6. Influence of growing systems on number of leaves per plant

Response of treatments on number of leaves per plant was significant in all stages of growth in six months old plants. In general, the treatment T_4 recorded significantly higher number of leaves per plant in all stages of growth. During 24 MAT, the treatment T_4 recorded significantly higher number of leaves per plant (6.96) which was on par with T_6 (6.30). In three year old plants, response of treatments on the production of leaves per plant was significant at 9, 21 and 24 MAT. At 9 MAT, treatment T_4 recorded the maximum number of leaves per plant (5.33) which was on par with T_1 (4.26), T_2 (5.19) and T_3 (5.00). At 21 MAT, treatment T_3 recorded the maximum number of leaves per plant (5.44) which was on par with T_4 (4.85), T_5 (4.74) and T_2 (4.19). At 24 MAT, treatment T_4 recorded maximum number of leaves per plant (6.22) which was on par with T_6 (6.22) and T_3 (5.89).

It is inferred that the combination of POP + OM + VW + PGPRE + Bone meal + GR (T_4) recorded maximum number of leaves per plant irrespective of the age of the plants.

Growing systems showed significant influence on number of leaves per plant at all stages of growth except 6 MAT in six month old plants. Among growing systems, S_2 recorded significantly higher number of leaves per plant at all stages of growth (Plate 6). However, number of leaves per plant under S_1 and S_2 were on par at 18 MAT and 21 MAT. In three year old plants, production of leaves per plant was significantly influenced by different growing systems in all stages of growth except 18 MAT. Plants grown in S_2 produced significantly higher number of leaves per plant at all stages of growth.

It is concluded that top ventilated polyhouse (S_2) had significant influence on production of leaves per plant irrespective of the age of the plants.

In six month old plants, interaction of plant inputs and systems of growing had significant influence on production of number of leaves per plant between 18 MAT and 24 MAT. In 18 MAT, the interaction T_4S_2 recorded significantly higher number of leaves per plant (7.33) which was on par with T_4S_1 (5.89), T_5S_1 (5.44),

T_6S_1 (5.00), T_1S_2 (4.33), T_3S_2 (4.89), T_5S_2 (4.67), T_6S_2 (5.44) and T_2S_3 (4.44). At 21 MAT, T_4S_2 recorded the maximum number of leaves per plant (7.56) which was on par with T_2S_1 (4.33), T_3S_1 (5.33), T_4S_1 (7.22), T_5S_1 (4.66), T_6S_1 (4.44), T_2S_2 (4.56), T_3S_2 (5.56), T_6S_2 (5.78) and T_3S_3 (4.22). At 24 MAT, T_4S_2 recorded maximum number of leaves per plant (9.89) which was on par with T_3S_1 (6.44), T_4S_1 (7.78), T_6S_1 (6.22), T_3S_2 (8.11) and T_6S_2 (9.00). Interaction of plant inputs and systems of growing on number of leaves per plant did not vary significantly at all stages of growth except during 24 MAT in three year old plants. Significantly higher number of leaves per plant (9.55) was recorded in T_4S_2 which was on par with T_3S_2 (8.33), T_6S_2 (8.22) T_4S_1 (6.33), T_6S_1 (6.00) and T_2S_2 (6.00).

It is inferred that the combination of POP + OM + VW + PGPRE + Bone meal + GR T_4) and top ventilated polyhouse (S_2) recorded significantly higher number of leaves per plant irrespective of age of the plant.

4.1.3 Number of shoots per plant

Data pertaining to number of shoots per plant of the six month old and three year old plants is presented in Tables 5a and 5b.

Production of number of shoots per plant was significantly influenced by the treatments in all stages of growth except during 15, 18 and 21 MAT in six month old plants. In general, the treatment T_3 recorded higher number of shoots per plant up to 12 MAT. At 24 MAT, the treatment T_4 recorded significantly higher number of shoots per plant (8.78) which was on par with T_3 (8.44) and T_6 (8.26). Production of shoots per plant was significantly influenced by the treatments only at 3, 6 and 12 MAT in three year old plants. The treatment T_2 recorded maximum number of shoots per plant (4.37) at 3 MAT which was on par with T_4 (4.11), T_3 (4.04) and T_6 (3.85). At 6 MAT, highest number of shoots per plant was recorded in T_2 (5.04) which was on par with all other treatments except T_5 (3.93). At 12 MAT also, same trend was observed as above in production of shoots per plant.

It is inferred that the combination of POP + OM + VW + PGPRE + Bone meal (T_3) recorded maximum number of shoots per plant in six month old plants whereas in three year old plants, the combination of POP + PGPRE + Bone meal (T_2) recorded maximum number of shoots per plant.

Number of shoots per plant was significantly influenced by growing systems in all stages of growth in six months old plants. In general, significantly higher number of shoots per plant was produced under S_2 at all stages of growth except during 15 MAT and 18 MAT. At 15 MAT and 18 MAT, significantly higher number of shoots per plant was recorded under S_1. Minimum number of shoots per plant was recorded in S_3 in all stages of growth. In three year old plants, production of number of shoots per plant was significantly influenced by the growing systems. Growing system S_2 recorded significantly higher number of shoots per plant at all stages of growth. Upto 15 MAT, number of shoots per plant was higher in S_2. At 18 MAT, system S_2 recorded highest number of shoots per plant which was on par with S_1. In 21 MAT and 24 MAT, system S_3 recorded the lowest number of shoots per plant.

It is concluded that top ventilated polyhouse (S_2) had significant influence on production of number of shoots per plant irrespective of the age of the plants.

Interaction of plant inputs and systems of growing had significant effect on production of number of shoots per plant only at 12 MAT in six month old plants. Significantly higher number of shoots per plant (6.22) was recorded in treatment combination T_3S_2 which was on par with all other interactions except T_5S_1, T_1S_3 and T_6S_3. Interaction of plant inputs and systems of growing on production of number of shoots per plant was significant only up to 9 MAT in three year old plants. In 3 MAT, significantly higher number of shoots per plant was recorded in T_2S_1 (5.22) which was on par with all other interactions except T_5S_1 (2.67), T_6S_1 (2.78), T_1S_3 (3.00) and T_5S_3 (2.78). In 6 MAT, T_4S_2 and T_6S_2 recorded significantly higher number of shoots per plant (6.22) which was on par with all other interactions except T_5S_1 (2.78) and T_6S_1 (3.33). At 9 MAT, T_4S_2

Table 5a. Influence of plant growth promoters (T), growing systems (S) and TxS interactions on number of shoots per plant in six month old plants of *Dendrobium* cv. Earsakul at quarterly intervals

Treatments		Number of shoots per plant							
		Months after treatments (MAT)							
		3	6	9	12	15	18	21	24
Plant growth promoters (T)	T_1	3.48^{z}	3.89^{z}	4.30^{z}	4.74^{y}	5.44	5.96	7.44	7.19^{z}
	T_2	4.11^{y}	4.74^{xy}	5.15^{xy}	5.56^{x}	6.44	6.74	7.78	7.93^{yz}
	T_3	4.56^{x}	5.04^{x}	5.52^{x}	5.78^{x}	6.52	7.04	8.41	8.44^{xy}
	T_4	4.11^{y}	4.70^{xy}	5.30^{x}	5.74^{x}	6.30	6.85	8.11	8.78^{x}
	T_5	3.41^{z}	3.85^{z}	4.37^{z}	5.00^{y}	5.85	6.48	7.74	7.70^{yz}
	T_6	4.07^{y}	4.37^{yz}	4.70^{yz}	4.96^{y}	5.78	6.22	7.78	8.26^{xy}
CD (0.05)		0.39	0.50	0.49	0.47	NS	NS	NS	0.74
Growing systems (S)	S_1	4.18^{l}	4.54^{l}	4.85^{m}	5.39^{m}	6.89^{l}	7.46^{l}	7.98^{m}	8.06^{m}
	S_2	4.35^{l}	4.78^{l}	5.56^{l}	5.87^{l}	6.11^{m}	6.59^{m}	8.96^{l}	9.59^{l}
	S_3	3.33^{m}	3.98^{m}	4.26^{n}	4.63n	5.17^{n}	5.59^{n}	6.69^{n}	6.50^{n}
CD (0.05)		0.27	0.35	0.34	0.34	0.60	0.72	0.58	0.52
T x S	T_1S_1	3.56	4.11	4.56	5.67^{abc}	7.44	8.11	8.56	7.89
	T_2S_1	4.67	5.22	5.56	5.67^{abc}	7.11	7.22	7.89	7.89
	T_3S_1	5.11	5.33	5.67	5.78^{abc}	7.11	7.44	7.89	8.11
	T_4S_1	4.22	4.55	5.00	5.78^{abc}	6.78	7.44	8.11	8.67
	T_5S_1	3.33	3.67	3.89	4.56^{bcde}	6.78	7.56	7.78	7.89
	T_6S_1	4.22	4.33	4.44	4.89^{abcde}	6.11	7.00	7.67	7.89
	T_1S_2	4.00	4.22	4.78	5.00^{abcde}	5.00	5.44	8.00	8.22
	T_2S_2	4.22	4.78	5.44	5.89^{abc}	6.11	6.22	8.56	9.22
	T_3S_2	4.78	5.33	6.11	6.22^{a}	6.55	7.67	9.78	10.11
	T_4S_2	4.33	5.11	6.00	6.11^{ab}	6.55	7.33	9.78	11.33
	T_5S_2	4.00	4.22	5.22	6.00^{abc}	6.33	6.78	8.44	8.556
	T_6S_2	4.77	5.00	5.78	6.00^{abc}	6.11	6.11	9.22	10.11
	T_1S_3	2.89	3.33	3.56	3.56^{e}	3.89	4.33	5.78	5.44
	T_2S_3	3.44	4.22	4.44	5.11^{abcde}	6.11	6.78	6.89	6.67
	T_3S_3	3.78	4.44	4.78	5.33^{abcd}	5.89	6.00	7.56	7.11
	T_4S_3	3.78	4.44	4.89	5.33^{abcd}	5.56	5.78	6.44	6.33
	T_5S_3	2.89	3.67	4.00	4.44^{cde}	4.44	5.11	7.00	6.67
	T_6S_3	3.22	3.78	3.89	4.00^{de}	5.11	5.56	6.44	6.78
CD (0.05)		NS	NS	NS	0.85	NS	NS	NS	NS

1. Figures with same alphabets/no superscripts form a homogenous group
2. All comparisons along the column based on DMRT
3. Use super script x, y, z,..... for comparison of treatments
4. Use super script l, m, n,..... for comparison of growing systems
5. Use super script a, b, c, d, e, f ..... for comparison of interactions

Table 5b. Influence of plant growth promoters (T), growing systems (S) and TxS interactions on number of shoots per plant in three year old plants of *Dendrobium* cv. Earsakul at quarterly intervals

Treatments		Number of shoots per plant							
		Months after treatments (MAT)							
		3	6	9	12	15	18	21	24
Plant growth promoters (T)	T_1	3.59^{yz}	4.48^{xy}	4.67	5.26^{xy}	6.00	6.41	7.63	7.48
	T_2	4.37^{x}	5.04^{x}	5.37	5.70^{x}	6.30	6.59	8.11	8.00
	T_3	4.04^{xy}	4.70^{x}	5.11	5.59^{xy}	6.11	6.59	7.56	8.15
	T_4	4.11^{xy}	4.85^{x}	5.15	5.52^{xy}	6.07	6.48	8.63	8.89
	T_5	3.22^{z}	3.93^{y}	4.33	4.63^{y}	5.67	6.26	7.63	7.78
	T_6	3.85^{xy}	4.85^{x}	5.37	5.81^{x}	6.41	7.33	8.70	8.52
CD (0.05)		0.54	0.68	NS	0.96	NS	NS	NS	NS
Growing systems (S)	S_1	3.69^{m}	4.09^{m}	4.35^{m}	4.63^{m}	5.91^{m}	6.65^{l}	7.91^{m}	8.33^{m}
	S_2	4.50^{l}	5.63^{l}	6.19^{l}	6.83^{l}	7.09^{l}	7.48^{l}	9.67^{l}	9.76^{l}
	S_3	3.41^{m}	4.20^{m}	4.46^{m}	4.80^{m}	5.28^{m}	5.70^{m}	6.56^{n}	6.31^{n}
CD (0.05)		0.38	0.49	0.54	0.68	0.79	0.92	1.24	1.23
T x S	T_1S_1	3.78^{abcd}	4.22^{abc}	4.33^{abcd}	4.78	6.44	6.78	7.44	7.44
	T_2S_1	5.22^{a}	5.67^{ab}	6.00^{abc}	6.22	7.66	8.11	9.56	9.56
	T_3S_1	3.89^{abcd}	4.67^{abc}	4.89^{abcd}	5.11	5.78	6.44	7.22	8.00
	T_4S_1	3.78^{abcd}	3.89^{abc}	4.22^{abcd}	4.44	5.11	5.56	7.78	8.44
	T_5S_1	2.67^{d}	2.78^{c}	2.89^{d}	3.22	5.67	6.67	7.67	8.56
	T_6S_1	2.78^{cd}	3.33^{bc}	3.78^{cd}	4.00	4.78	6.33	7.78	8.00
	T_1S_2	4.00^{abcd}	5.22^{abc}	5.67^{abc}	6.56	6.67	6.89	9.00	9.11
	T_2S_2	4.22^{abcd}	5.33^{abc}	5.78^{abc}	6.33	6.44	6.56	9.11	8.89
	T_3S_2	4.89^{ab}	5.56^{ab}	6.44^{abc}	7.33	7.78	8.22	9.78	10.89
	T_4S_2	4.78^{abc}	6.22^{a}	6.78^{a}	7.22	7.56	8.00	11.33	11.67
	T_5S_2	4.22^{abcd}	5.22^{abc}	5.78^{abc}	6.22	6.44	7.00	8.56	8.33
	T_6S_2	4.89^{ab}	6.22^{a}	6.67^{ab}	7.33	7.67	8.22	10.22	9.67
	T_1S_3	3.00^{bcd}	4.00^{abc}	4.00^{bcd}	4.44	4.89	5.56	6.44	5.89
	T_2S_3	3.67^{abcd}	4.11^{abc}	4.33^{abcd}	4.56	4.78	5.11	5.67	5.56
	T_3S_3	3.33^{abcd}	3.89^{abc}	4.00^{bcd}	4.33	4.78	5.11	5.67	5.56
	T_4S_3	3.78^{abcd}	4.44^{abc}	4.44^{abcd}	4.89	5.56	5.89	6.78	6.56
	T_5S_3	2.78^{cd}	3.78^{abc}	4.33^{abcd}	4.44	4.89	5.11	6.67	6.44
	T_6S_3	3.89^{abcd}	5.00^{abc}	5.67^{abc}	6.11	6.78	7.44	8.11	7.89
CD (0.05)		0.94	1.20	1.32	NS	NS	NS	NS	NS

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4. Use super script l, m, n,..... for comparison of growing systems
5. Use super script a, b, c, d, e, f ..... for comparison of interactions

Two level shade house (S_1)

Two level shade house (S_1)

Top ventilated polyhouse (S_2)

Top ventilated polyhouse (S_2)

Fan and pad system (S_3)

Fan and pad system (S_3)

Plate 7. Influence of growing systems on number of shoots per plant

recorded maximum number of shoots per plant (6.78) which was on par with all other interactions except T_5S_1(2.89), T_6S_1 (3.78) and T_3S_3 (4.00).

It is inferred that the combination of POP + OM + VW + PGPRE + Bone meal (T_3) and top ventilated polyhouse (S_2) in six months old plants recorded maximum number of shoots per plant, whereas in three year old plants, the combination of POP + OM + VW + PGPRE + Bone meal + GR (T_4) and top ventilated polyhouse (S_2) recorded significantly higher number of shoots per plant.

4.1.4 Girth of shoot

Data on girth of shoot of six month old and three year old plants is presented in Tables 6a and 6b.

Girth of the shoot was significantly influenced by the treatments only in 9 and 18 MAT in six months old plants. In 9 MAT, treatment T_1 was found to be beneficial in increasing the girth of the shoot which was on par with T_2 (3.20 cm), T_3 (3.29 cm) and T_4 (3.10 cm). At 18 MAT, T_3 recorded the maximum girth of 3.77 cm which was on par with T_2 (3.50 cm), T_1 (3.38 cm) and T_6 (3.16 cm). In three year old plants, influence of treatments on girth of shoot was significant only in 24 MAT. The treatment T_3 recorded highest shoot girth of 4.05 cm which was on par with all other treatments except T_5 (2.72 cm).

It is inferred that the treatment combination POP + OM + VW + PGPRE + Bone meal (T_3) recorded maximum girth of the shoot in both stages of plants.

Girth of the shoot was significantly influenced by the growing systems in all stages of growth in six months old plants. Up to 9 MAT, highest girth of shoot was registered in S_3. Between 12 and 24 MAT, S_2 registered maximum girth of shoot which was on par with plants in S_1. Between 12 and 24 MAT, lowest girth was observed in plants grown in S_3. Girth of shoot was significantly influenced by growing systems in all growth stages except at 12 MAT in three year old plants. Upto 9 MAT, S_1 and S_3 recorded the higher girth of shoot and were on par.

Between 15 and 24 MAT, S_1 and S_2 recorded significantly higher girth of shoot and were on par. S_3 recorded lowest girth in all stages of growth between 15 and 24 MAT.

It is concluded that top ventilated polyhouse (S_2) in six months old plants and two level shade house (S_1) in three year old plants had the maximum influence on girth of shoot.

Interaction of plant inputs and systems of growing did not have significant influence on girth of shoot.

4.1.5 Internodal length

The data that depict the internodal length of six month old and three year old plants is presented in Tables 7a and 7b.

Internodal length did not vary significantly among different treatments in six months old plants. In three year old plants, length of internode was significantly influenced by treatments at 9 and 24 MAT. At 9 MAT, highest internodal length of 4.23 cm was recorded in T_2 which was on par with all other treatments except T_5 (3.21 cm) and T_6 (3.23 cm). At 24 MAT, T_3 recorded the highest internodal length of 5.23 cm which was on par with all other treatments except T_5 (3.00 cm).

It is concluded that in six month old plants, the internodal length did not vary significantly among different treatments, whereas in three year old plants, combination of POP + OM + VW + PGPRE + Bone meal (T_3) recorded maximum internodal length at later stage of crop growth.

Length of internode was significantly influenced by growing systems in all stages of growth except 9 MAT in six months old plants. S_2 recorded highest internodal length which was on par with S_1 in stages of growth between 12 and 24 MAT. Lowest internodal length was recorded in S_3 between 12 and 24 MAT. In three year old plants, length of the internode was significantly influenced by the

Table 6a. Influence of plant growth promoters (T), growing systems (S) and TxS interactions on girth of shoot (cm) in six month old plants of *Dendrobium* cv. Earsakul at quarterly intervals

Treatments		Girth of shoot (cm)							
		Months after treatments (MAT)							
		3	6	9	12	15	18	21	24
Plant growth promoters (T)	T_1	2.03	3.39	3.30^{x}	3.09	3.27	3.38^{xy}	3.41	3.75
	T_2	2.49	3.73	3.20^{xy}	3.33	3.33	3.50^{xy}	3.61	3.89
	T_3	2.52	3.74	3.29^{x}	3.09	3.50	3.77^{x}	3.62	3.81
	T_4	2.40	3.62	3.10^{xyz}	3.08	3.00	2.89^{y}	3.49	3.68
	T_5	2.28	3.57	2.72^{z}	2.79	2.77	3.07y	3.75	3.57
	T_6	2.37	3.71	2.86^{yz}	2.49	3.24	3.16^{xy}	3.38	3.60
CD (0.05)		NS	NS	0.37	NS	NS	0.62	NS	NS
Growing systems (S)	S_1	1.56^{n}	3.16^{n}	3.39^{l}	3.17^{l}	3.33^{l}	3.51^{l}	3.92^{l}	3.96^{l}
	S_2	2.45^{m}	3.59^{m}	2.58^{m}	3.30^{l}	3.63^{l}	3.83^{l}	3.89^{l}	4.01^{l}
	S_3	3.03^{l}	4.12^{l}	3.27^{l}	2.48^{m}	2.60^{m}	2.54^{m}	2.82^{m}	3.19^{m}
CD (0.05)		0.27	0.31	0.26	0.56	0.41	0.44	0.40	0.30
T x S	T_1S_1	1.24	2.96	3.50	3.60	3.21	3.34	3.68	4.01
	T_2S_1	1.96	3.51	3.59	3.24	3.64	3.68	4.11	4.11
	T_3S_1	1.77	3.28	3.56	2.89	3.40	3.87	4.30	4.20
	T_4S_1	1.51	3.11	3.17	3.13	3.31	3.53	3.69	3.77
	T_5S_1	1.39	2.98	3.40	3.53	3.30	3.78	4.63	4.13
	T_6S_1	1.50	3.12	3.07	2.59	3.12	3.04	3.11	3.51
	T_1S_2	2.28	3.31	3.07	3.29	3.53	3.79	3.73	3.80
	T_2S_2	2.51	3.61	2.95	3.29	3.83	4.04	4.01	4.61
	T_3S_2	2.39	3.47	2.54	3.35	3.74	4.04	4.38	4.04
	T_4S_2	2.66	3.66	2.47	3.46	3.71	3.69	3.78	4.23
	T_5S_2	2.57	3.81	2.23	3.03	3.32	3.62	3.61	3.54
	T_6S_2	2.31	3.66	2.21	3.32	3.65	3.80	3.81	3.82
	T_1S_3	2.55	3.87	3.32	2.38	3.06	3.00	2.83	3.45
	T_2S_3	3.00	4.06	3.06	3.46	2.51	2.77	2.71	2.96
	T_3S_3	3.40	4.44	3.76	3.03	3.36	3.41	2.17	3.20
	T_4S_3	3.04	4.08	3.63	2.64	1.97	1.45	3.00	3.03
	T_5S_3	2.86	3.92	2.52	1.78	1.69	2.00	3.00	3.03
	T_6S_3	3.30	4.35	3.28	1.56	2.96	2.61	3.21	3.46
CD (0.05)		NS	NS	NS	NS	NS	NS	NS	NS

1. Figures with same alphabets/no superscripts form a homogenous group
2. All comparisons along the column based on DMRT
3. Use super script x, y, z,..... for comparison of treatments
4. Use super script l, m, n,..... for comparison of growing systems
5. Use super script a, b, c,..... for comparison of interactions

Table 6b. Influence of plant growth promoters (T), growing systems (S) and TxS interactions on girth of shoot (cm) in three year old plants of *Dendrobium* cv. Earsakul at quarterly intervals

Treatments		Girth of shoot (cm)							
		Months after treatments (MAT)							
		3	6	9	12	15	18	21	24
Plant growth promoters (T)	T_1	2.07	3.14	2.91	2.59	3.13	3.29	3.51	3.51^{xy}
	T_2	2.08	3.28	3.09	3.21	2.98	3.26	3.26	4.04^{x}
	T_3	2.01	3.19	3.12	3.51	3.22	3.26	3.82	4.05^{x}
	T_4	1.95	3.15	2.99	2.44	2.90	3.24	3.01	3.25^{xy}
	T_5	2.04	3.29	2.79	2.12	2.73	3.00	2.72	2.72^{y}
	T_6	2.14	3.21	2.62	2.95	2.76	2.76	3.40	3.80^{x}
CD (0.05)		NS	NS	NS	NS	NS	NS	NS	0.82
Growing systems (S)	S_1	2.27^{l}	3.44^{l}	3.36^{l}	3.00	3.12^{l}	3.40^{l}	3.81^{l}	4.07^{l}
	S_2	1.65^{m}	3.01^{m}	2.45^{m}	2.99	3.28^{l}	3.39^{l}	3.32^{l}	3.62^{l}
	S_3	2.23^{l}	3.18^{m}	2.95^{l}	2.41	2.49^{m}	2.63^{m}	2.74^{m}	2.99^{m}
CD (0.05)		0.18	0.17	0.48	NS	0.62	0.53	0.66	0.58
T x S	T_1S_1	2.23	3.30	3.16	2.36	3.17	3.40	3.81	3.83
	T_2S_1	2.24	3.33	3.17	2.81	3.30	3.69	3.36	4.02
	T_3S_1	2.32	3.48	3.44	3.43	3.53	3.66	3.90	4.47
	T_4S_1	2.26	3.51	3.42	3.36	3.42	3.94	3.74	4.14
	T_5S_1	2.30	3.63	3.44	2.88	3.10	3.49	3.91	3.68
	T_6S_1	2.25	3.36	3.52	3.17	2.15	2.21	4.11	4.26
	T_1S_2	1.61	2.87	2.20	3.07	3.15	3.37	3.42	3.38
	T_2S_2	1.70	3.12	3.21	3.26	3.43	3.76	3.99	4.11
	T_3S_2	1.49	2.91	2.76	3.47	3.46	3.52	3.89	4.07
	T_4S_2	1.49	2.83	2.51	3.05	3.18	3.35	3.29	3.52
	T_5S_2	1.63	3.12	2.58	1.88	3.14	3.22	2.11	3.20
	T_6S_2	1.94	3.20	1.42	3.25	3.28	3.12	3.23	3.44
	T_1S_3	2.38	3.25	3.37	2.34	3.08	3.11	3.31	3.32
	T_2S_3	2.28	3.37	2.89	3.56	2.23	2.34	2.42	3.97
	T_3S_3	2.20	3.16	3.15	3.64	2.67	2.62	3.67	3.60
	T_4S_3	2.11	3.10	3.02	.91	2.11	2.45	2.017	2.10
	T_5S_3	2.16	3.10	2.35	1.60	1.94	2.30	2.13	1.26
	T_6S_3	2.23	3.07	2.91	2.42	2.86	2.96	2.86	3.67
CD (0.05)		NS	NS	NS	NS	NS	NS	NS	NS

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2. All comparisons along the column based on DMRT
3. Use super script x, y, z,..... for comparison of treatments
4. Use super script l, m, n,..... for comparison of growing systems
5. Use super script a, b, c,..... for comparison of interactions

Table 7a. Influence of plant growth promoters (T), growing systems (S) and TxS interactions on internodal length (cm) in six month old plants of *Dendrobium* cv. Earsakul at quarterly intervals

Treatments		Internodal length (cm)							
		Months after treatments (MAT)							
		3	6	9	12	15	18	21	24
Plant growth promoters (T)	T_1	2.78	4.18	4.00	3.50	3.58	3.99	4.10	4.33
	T_2	2.83	4.26	4.03	4.02	3.41	3.95	3.98	3.96
	T_3	2.90	4.32	3.70	3.50	3.88	4.41	4.10	4.27
	T_4	2.53	4.03	3.70	3.11	3.40	3.37	4.15	4.06
	T_5	2.89	4.20	3.35	3.22	3.20	3.68	4.29	4.15
	T_6	2.91	4.40	3.73	2.93	3.96	3.68	4.33	3.95
CD (0.05)		NS	NS	NS	NS	NS	NS	NS	NS
Growing systems (S)	S_1	2.42^{m}	4.01^{m}	3.84	3.50^{l}	3.79^{l}	4.09^{l}	4.56^{l}	4.21^{l}
	S_2	2.93^{l}	4.44^{l}	3.57	3.96^{l}	4.15^{l}	4.57^{l}	4.57^{l}	4.55^{l}
	S_3	3.09^{l}	4.26^{l}	3.85	2.69^{m}	2.78^{m}	2.89^{m}	3.36^{m}	3.60^{m}
CD (0.05)		0.23	0.21	NS	0.66	0.50	0.54	0.44	0.48
T x S	T_1S_1	2.30	3.83	3.79	3.74	3.65	3.99	4.41^{ab}	4.52
	T_2S_1	2.42	4.08	3.92	3.85	3.93	4.16	4.76^{a}	4.24
	T_3S_1	2.62	4.31	3.90	3.22	3.92	4.67	4.96^{a}	4.68
	T_4S_1	2.16	3.93	3.90	3.33	3.92	3.99	4.15^{ab}	3.98
	T_5S_1	2.52	3.82	3.70	3.83	3.56	4.18	4.73^{a}	4.15
	T_6S_1	2.51	4.04	3.83	3.03	3.76	3.57	4.31^{ab}	3.70
	T_1S_2	2.94	4.35	4.14	3.81	4.04	4.81	4.42^{ab}	4.15
	T_2S_2	3.18	4.66	4.32	4.25	4.16	4.93	4.64^{a}	5.25
	T_3S_2	2.76	4.16	3.30	4.16	4.34	4.84	4.88^{a}	4.55
	T_4S_2	2.47	4.11	3.57	3.87	4.21	4.19	4.11^{ab}	4.49
	T_5S_2	2.98	4.47	2.85	3.89	4.01	4.49	4.36^{ab}	4.27
	T_6S_2	3.20	4.86	3.22	3.77	4.14	4.16	4.96^{a}	4.60
	T_1S_3	3.11	4.36	4.05	2.97	3.04	3.18	3.46^{ab}	4.31
	T_2S_3	2.90	4.04	3.85	3.98	2.16	2.76	2.55^{b}	2.38
	T_3S_3	3.33	4.50	3.91	3.11	3.37	3.71	2.46^{b}	3.57
	T_4S_3	2.96	4.04	3.64	2.14	2.06	1.95	4.20^{ab}	3.71
	T_5S_3	3.17	4.31	3.51	1.96	2.04	2.38	3.77^{ab}	4.05
	T_6S_3	3.04	4.31	4.14	1.98	4.00	3.33	3.71^{ab}	3.56
CD (0.05)		NS	NS	NS	NS	NS	NS	1.10	NS

1. Figures with same alphabets/no superscripts form a homogenous group
2. All comparisons along the column based on DMRT
3. Use super script x, y, z,..... for comparison of treatments
4. Use super script l, m, n,..... for comparison of growing systems
5. Use super script a, b, c,..... for comparison of interactions

Table 7b. Influence of plant growth promoters (T), growing systems (S) and TxS interactions on internodal length (cm) in three year old plants of *Dendrobium* cv. Earsakul at quarterly intervals

Treatments		Internodal length (cm)							
		Months after treatments (MAT)							
		3	6	9	12	15	18	21	24
Plant growth promoters (T)	T_1	2.71	4.11	3.99^{xy}	3.39	4.34	4.55	4.82	4.46^{x}
	T_2	2.77	4.24	4.23^{x}	3.67	4.02	4.25	4.36	4.95^{x}
	T_3	2.58	3.97	3.86^{xy}	4.22	3.95	4.44	5.04	5.23^{x}
	T_4	2.54	3.95	4.03^{xy}	3.04	3.48	4.10	4.13	3.98^{xy}
	T_5	2.48	3.80	3.21^{y}	2.57	3.17	3.87	3.29	3.00^{y}
	T_6	2.63	4.01	3.23^{y}	3.41	3.16	3.54	4.19	4.14^{xy}
CD (0.05)		NS	NS	0.89	NS	NS	NS	NS	1.21
Growing systems (S)	S_1	2.37^{m}	4.09	4.32^{l}	3.63	3.72	4.14^{lm}	4.60	4.52
	S_2	2.57^{m}	3.88	3.25^{m}	3.69	4.03	4.55^{l}	4.58	4.47
	S_3	2.92^{l}	4.07	3.71^{lm}	2.82	3.32	3.69^{m}	3.72	3.88
CD (0.05)		0.25	NS	0.63	NS	NS	0.74	NS	NS
T x S	T_1S_1	2.79	4.46	4.46	3.20	4.20	4.69	5.07	4.16
	T_2S_1	2.33	4.09	4.06	3.47	4.18	4.33	4.06	4.98
	T_3S_1	2.21	3.98	3.89	3.91	4.16	4.82	5.13	5.36
	T_4S_1	2.42	4.28	5.06	4.00	3.97	4.63	4.72	4.89
	T_5S_1	2.19	3.82	4.14	3.80	3.22	3.96	4.50	3.80
	T_6S_1	2.26	3.93	4.43	3.41	2.60	2.43	4.16	3.94
	T_1S_2	2.39	3.81	3.18	3.70	4.05	4.55	4.72	4.61
	T_2S_2	2.84	4.26	4.13	4.43	4.79	5.20	5.61	5.25
	T_3S_2	2.61	3.74	3.79	4.14	4.37	4.73	5.24	5.26
	T_4S_2	2.53	3.75	3.36	4.07	3.87	4.09	4.59	4.34
	T_5S_2	2.46	3.75	2.99	1.87	3.69	4.45	2.78	3.53
	T_6S_2	2.69	4.00	2.05	3.95	3.41	4.29	4.55	3.83
	T_1S_3	2.98	4.06	4.34	3.28	4.78	4.43	4.67	4.60
	T_2S_3	3.13	4.37	4.56	3.10	3.10	3.22	3.39	4.60
	T_3S_3	2.94	4.21	3.89	4.60	3.32	3.79	4.76	5.06
	T_4S_3	2.68	3.82	3.72	1.04	2.60	3.60	3.07	2.71
	T_5S_3	2.82	3.83	2.51	2.03	2.62	3.21	2.60	1.67
	T_6S_3	2.97	4.12	3.21	2.87	3.49	3.90	3.87	4.63
CD (0.05)		NS	NS	NS	NS	NS	NS	NS	NS

1. Figures with same alphabets/no superscripts form a homogenous group
2. All comparisons along the column based on DMRT
3. Use super script x, y, z,..... for comparison of treatments
4. Use super script l, m, n,..... for comparison of growing systems
5. Use super script a, b, c,..... for comparison of interactions

growing systems at 3, 9 and 18 MAT. In 3 MAT, highest internodal length of 2.92 cm was recorded in S_3. In 9 MAT, highest internodal length of 4.32 cm was recorded in S_1 but at 18 MAT, significantly higher internodal length of 4.55 cm was observed in S_2.

It is concluded that top ventilated polyhouse (S_2) had the maximum internodal length irrespective of the age of the plants.

Interaction of plant inputs and systems of growing significantly influenced the internodal length only at 21 MAT in six months old plants. The treatment combination of T_3S_1 and T_6S_2 recorded highest internodal length of 4.96 cm which was on par with all other interactions except T_2S_3 (2.55 cm) and T_3S_3 (2.46 cm). In three year old plants, interaction of plant inputs and systems of growing was not significantly influenced the internodal length in all stages of growth.

It is concluded that in the interaction of plant inputs and systems of growing, NPK + GR + OM + VW + PGPRE + Bone meal (T_6) in top ventilated polyhouse recorded maximum internodal length. But in three year old plants, interaction was not explicit in all stages of growth.

4.2 Flower characters

Various observations on flower characters at different plant input management under three growing systems *viz*., two level shade house (S_1), top ventilated poly house (S_2) and fan and pad system (S_3) of plants in two stages of plant growth *viz*., six month old and three year old plants were recorded, analyzed and the results are presented in Tables 8 to 9.

4.2.1 Days to flowering

Analysis of the data corresponding to days to flowering in six month old and three year old plants is presented in Tables 8 and 9.

The days to flowering did not vary significantly among different treatments in six month old plant. In three year old plants, response of treatments

on days to flowering was significant. The treatment T_4 took minimum duration of 283.91 days for flowering which was on par with T_5 (285.12 days), T_6 (305.93 days) and T_1 (348.13 days). The treatment T_3 took maximum duration of 380.09 days for flowering which was on par with all other treatments except T_5 and T_4.

It is inferred that the treatment combination POP + OM + VW + PGPRE + Bone meal + GR (T_4) recorded early flowering in three year old plants. But in six months old plants, days to flowering did not vary significantly among the different treatments.

Days to flowering was significantly influenced by growing systems in six months old plants. Under S_2, flowering started in 252.95 days and under S_3 flowering was observed in 427.03 days. In three year old plants, flowering was earlier (225.42 days) under S_2. The system S_3 took maximum duration for flowering (405.83 days).

It is concluded that top ventilated polyhouse (S_2) had significant influence on days to flowering irrespective of the age of the plants.

T x S interaction had significant influence on days to flowering in six month old plants. Minimum days for flowering were observed in interaction T_3S_2 (128.06 days) which was on par with T_2S_2 (138.06 days) and T_6S_2 (250.75 days). Maximum duration of 434.50 days was observed in T_5S_3. In three year old plants, T x S interaction had significant influence on days to flowering. The interaction of T_4S_2 took minimum time of 118.08 days for flowering which was on par with T_5S_2 (127.89 days) and T_6S_2 (217.83 days). The combination T_3S_3 recorded maximum duration of 476.94 days for flowering.

It is inferred that, in six month old plants, the combination of POP + OM + VW + PGPRE + Bone meal (T_3) and top ventilated polyhouse (S_2) recorded minimum time for days to flowering. However in three year old plants, POP + OM + VW + PGPRE + Bone meal + GR (T_4) took minimum days for flowering in top ventilated polyhouse (S_2).

4.2.2 Days to first flower opening

The data that depict the days to first flower opening in six month old and three year old plants is presented in Tables 8 and 9.

Days to first flower opening was significantly influenced by treatments in six months old plants. The treatment T_6 took minimum days of 14.52 for first flower opening which was on par with T_4 (15.42 days), T_2 (16.06 days), T_3 (16.64 days) and T_5 (16.84 days). The treatment T_1 recorded longest period of 20.06 days to first flower opening. Days to first flower opening did not vary significantly among the different treatments in three year old plants.

It is inferred that the combination of NPK + GR + OM + VW + PGPRE + Bone meal (T_6) took minimum days for first flower opening in six month old plants.

Among growing systems, days to first flower opening did not vary significantly in both stages of plant growth.

It is concluded that days to first flower opening was not significantly influenced by growing systems irrespective of the age of the plants.

TxS interaction showed significant influence on days to first flower opening in six month old plants. In T_6S_1, minimum time of 12.76 days was required for first flower opening which was on par with all other treatments except T_1S_3. The interaction T_1S_3 recorded maximum period of 23.39 days for first flower opening. T x S interaction was not significantly influenced by the days to first flower opening in three year old plants.

It is concluded that the combination of NPK + GR + OM + VW + PGPRE + Bone meal (T_6) and two level shade house (S_1) took minimum days for first flower opening in six month old plants.

4.2.3 Days to last flower opening

Analysis of the data pertaining to days to last flower opening in six month old and three year old plants is presented in Tables 8 and 9.

Days to last flower opening did not vary significantly among the different treatments in six months old plants. Response of treatments on days to last flower opening was significant in three year old plants. Treatment T_4 recorded significantly minimum period of 10.98 days for last flower opening which was followed by T_6 (11.28 days). Treatment T_5 showed maximum duration of 15.11 days for last flower opening which was followed by T_1 (14.62 days).

It is inferred that the combination of POP + OM + VW + PGPRE + Bone meal + GR (T_4) took minimum days for last flower opening in three year old plants.

In six months old plants, no significant difference in days to last flower opening was noticed among different growing systems. Days to last flower opening was significantly influenced by growing systems in three year old plants. Plants under S_1 took minimum period of 12.58 days for last flower opening which was on par with S_2 (12.69 days).

It is concluded that plants grown in two level shade house (S_1) recorded minimum days for last flower opening in three year old plants.

T x S interaction was significant in six month old plants. Minimum time of 9.62 days for last flower opening was registered under T_6S_2 which was on par with all other treatments except T_1S_1 and T_6S_3. T_6S_3 interaction recorded maximum duration of 17.67 days for last flower opening. In three year old plants, the T x S interaction had significant effect on days to last flower opening. Minimum days for last flower opening (9.15 days) was registered under T_6S_2 and maximum duration in T_5S_1 (19.23 days).

It is inferred that the combination of NPK + GR + OM + VW + PGPRE + Bone meal (T_6) and top ventilated polyhouse (S_2) took minimum days for last flower opening in both stages of plants.

4.2.4 Length of the spike

The data that depict length of the spike in six months old and three year old plants is presented in Tables 8 and 9.

Length of the spike was significantly influenced by treatments in six months old plants. The treatment T_4 recorded significantly higher spike length of 31.34 cm which was on par with T_3 (29.01 cm) and T_6 (28.71 cm). Lowest spike length of 23.84 cm was recorded in T_5 which was on par with T_1 (24.18 cm), T_2 (24.38 cm) and T_6 (28.71 cm). Response of treatments on spike length was significant in three year old plants. The treatment T_6 recorded significantly higher spike length of 30.46 cm which was on par with T_2 (28.14 cm), T_3 (27.49 cm) and T_5 (25.65 cm). The treatment T_1 recorded lowest spike length of 23.47 cm which was on par with all other treatments except T_6.

It is inferred that the combination of POP + OM + VW + PGPRE + Bone meal + GR (T_4) in six month old plants and the combination of NPK + GR + OM + VW + PGPRE + Bone meal (T_6) in three year old plants recorded significantly higher spike length.

Length of the spike was significantly influenced by growing systems in six months old plants. The system S_2 recorded significantly higher spike length of 29.79 cm (Plate 8) which was on par with S_1 (28.02 cm). The system S_3 recorded lowest spike length of 22.92 cm. In three year old plants, the growing system S_2 recorded significantly higher spike length of 29.50 cm (Plate 8) which was on par with S_1 (27.88 cm). Lowest spike length of 22.66 cm was recorded under S_3.

It is concluded that top ventilated polyhouse (S_2) had significant influence on length of the spike irrespective of the age of the plants.

T x S interaction had significant effect on spike length in six month old plants. Highest spike length of 36.05 cm was recorded in T_4S_2 which was on par with T_4S_1 (33.16 cm), T_3S_2 (31.21 cm), T_6S_2 (30.98 cm), T_6S_1 (29.51 cm), T_3S_1 (28.91 cm), T_2S_2 (28.48 cm) and T_5S_1 (27.64 cm). Minimum spike length of 17.79

Table 8. Influence of plant growth promoters (T), growing systems (S) and T x S interaction on flower characters in six month old plants of *Dendrobium* cv. Earsakul

Treatments	Days to flowering				Days to first flower opening				Days to last flower opening				Length of the spike (cm)			
	S_1	S_2	S_3	Mean	S_1	S_2	S_3	Mean	S_1	S_2	S_3	Mean	S_1	S_2	S_3	Mean
T_1	406.87	282.92	477.33	389.04	17.45	19.33	23.39	20.06	17.48	15.26	12.50	15.08	22.03	26.06	24.45	24.18
T_2	381.44	138.06	407.70	309.06	15.22	16.50	16.44	16.06	14.85	11.50	13.90	13.42	26.88	28.48	17.79	24.38
T_3	382.75	128.06	433.28	314.69	15.18	15.58	19.17	16.64	12.07	10.35	13.17	11.86	28.91	31.21	26.92	29.01
T_4	318.25	373.44	381.45	357.71	14.87	16.29	15.11	15.42	10.76	12.63	12.44	11.94	33.16	36.05	24.82	31.34
T_5	347.98	344.50	434.50	375.66	16.76	18.39	15.39	16.84	11.02	13.02	12.33	12.12	27.64	25.96	17.90	23.84
T_6	341.76	250.75	427.94	340.15	12.76	13.04	17.75	14.52	11.37	9.62	17.67	12.89	29.51	30.98	25.65	28.71
Mean	363.17	252.95	427.03		15.37	16.52	17.88		12.93	12.06	13.67		28.02	29.79	22.92	
CD (0.05)	T: NS S: 56.56 T x S: 145.90				T: 4.38 S: NS T x S: 7.58				T: NS S: NS T x S: 6.27				T: 5.14 S: 3.63 T x S: 8.90			

Treatments	Number of flowers per spike				Size of the flower (cm) lxb				Number of spikes per plant				Vase life (days)			
	S_1	S_2	S_3	Mean	S_1	S_2	S_3	Mean	S_1	S_2	S_3	Mean	S_1	S_2	S_3	Mean
T_1	3.85	3.54	3.83	3.74	7.70x6.87	7.97x6.60	7.80x6.90	7.82x6.79	2.22	2.22	1.17	1.87	22.81	22.14	19.12	21.36
T_2	4.70	4.42	2.50	3.87	8.01x7.05	7.65x6.22	5.49x5.00	7.05x6.08	2.56	2.89	0.67	2.04	24.37	24.37	20.56	23.09
T_3	5.11	8.11	4.28	5.07	7.25x6.60	8.16x7.06	8.01x6.93	7.81x6.86	2.22	3.22	1.33	2.26	25.88	26.55	23.30	25.24
T_4	7.19	5.81	4.33	6.54	8.46x7.36	8.49x7.28	7.81x7.17	8.25x7.23	3.33	3.56	0.67	2.52	30.72	33.06	26.22	30.00
T_5	4.48	5.07	2.00	3.85	7.78x6.85	8.14x7.03	5.45x4.97	7.12x6.28	1.89	2.00	1.22	1.70	26.74	28.07	22.33	25.72
T_6	6.07	6.44	3.67	5.39	8.09x6.91	8.16x7.17	8.18x7.67	8.14x7.29	3.22	3.30	1.33	2.62	30.41	32.07	24.33	28.94
Mean	5.24	5.57	3.44		7.88x6.90	8.09x6.89	7.12x6.44		2.57	2.86	1.07		26.82	27.71	22.64	
CD (0.05)	T: 0.74 S: 0.53 T x S:1.29				T: NS x NS S: NS x NS T x S: NS x NS				T: 0.35 S: 0.25 T x S: 0.61				T: 0.55 S: 0.39 T x S: 0.96			

Two level shade house (S_1)

Two level shade house (S_1)

Top ventilated polyhouse (S_2)

Top ventilated polyhouse (S_2)

Fan and pad system (S_3)

Fan and pad system (S_3)

Plate 8. Influence of growing systems on length of the spike (cm)

cm was recorded in T_2S_3. In three year old plants, T x S interaction had significant influence on spike length. T_6S_2 interaction recorded significantly highest spike length of 34.80 cm which was on par with all other treatment combinations except T_3S_1, T_1S_1, T_1S_2, T_1S_3, T_5S_3 and T_4S_3. Lowest spike length of 9.52 cm was recorded in T_4S_3.

It is inferred that the combination of POP + OM + VW + PGPRE + Bone meal + GR (T_4) and top ventilated polyhouse (S_2) in six month old plants and the combination of NPK + GR + OM + VW + PGPRE + Bone meal (T_6) and top ventilated polyhouse (S_2) in three year old plants recorded significantly higher spike length.

4.2.5 Number of flowers per spike

The data that depict number of flowers per spike in six months old and a three year old plant is presented in Tables 8 and 9.

Number of flowers per spike was significantly influenced by treatments in six months old plants. The treatment T_4 recorded significantly higher number of flowers (6.54) which was followed by T_6 (5.39). Number of flowers per spike was lesser in T_1 (3.74) which was on par with T_5 (3.85) and T_2 (3.87). In three year old plants, treatments showed significant influence on number of flowers per spike. The treatment T_6 recorded significantly higher flower number (5.08) which was on par with T_3 (4.75) and T_4 (4.49). Lowest number of flowers (3.84) was recorded by T_1 which was on par with T_5 (4.22), T_2 (4.25) and T_4 (4.49).

The inference of the results is that the combination of POP + OM + VW + PGPRE + Bone meal + GR (T_4) in six month old plants and the combination of NPK + GR + OM + VW + PGPRE + Bone meal (T_6) in three year old plants recorded significantly higher number of flowers.

Growing systems showed significant influence on number of flowers per spike in six months old plants. The system S_2 recorded significantly higher number of flowers (5.57) (Plate 9) which was on par with S1 (5.24). Lowest flower count (3.44) was recorded under S_3. Response of growing system was significat on production of

Two level shade house (S_1)

Two level shade house (S_1)

Top ventilated polyhouse (S_2)

Top ventilated polyhouse (S_2)

Fan and pad system (S_3)

Fan and pad system (S_3)

Plate 9. Influence of growing systems on number of flowers per spike

flowers per spike in three year old plants. S_2 recorded significantly higher number of flowers per spike (5.47) (Plate 9). S_3 recorded lowest number of flowers (3.04) per spike.

It is concluded that top ventilated polyhouse (S_2) had significant influence on number of flowers per spike irrespective of the age of the plants.

T x S interaction had significant effect on number of flowers per spike in six month old plants. T_3S_2 interaction recorded higher number of flowers (8.11) which was on par with T_4S_1 (7.19). Lowest number of flowers per spike was registered in T_5S_3 (2.00). In three year old plants, T_6S_2 interaction recorded significantly higher number of flowers (6.46) which was on par with T_4S_2 (6.33), T_4S_1 (5.89), T_5S_2 (5.46) and T_3S_2 (5.40). The interaction T_4S_3 registered lowest flower count of 1.25 flowers per spike.

It is inferred that the combination of POP + OM + VW + PGPRE + Bone meal (T_3) and top ventilated polyhouse (S_2) recorded maximum number of flowers in six month old plants. In three year old plants, the combination of NPK + GR + OM + VW + PGPRE + Bone meal (T_6) and top ventilated polyhouse (S_2) recorded significantly higher number of flowers.

4.2.6 Size of the flower

The data pertaining to size of the flower in six month old and three year old plants is presented in Tables 8 and 9.

Size of the flower did not vary significantly among different treatments, growing systems and interactions in both six month old and three year old plants.

4.2.7 Number of spikes per plant

The data that depict number of spikes per plant in six months old and three year plants is presented in Tables 8 and 9.

The influence of treatments on production of spikes per plant was significant in six months old plants. The treatment T_6 recorded significantly higher number of spikes per plant (2.62) which was on par with T_4 (2.52). Lowest number of spikes per plant

was registered in T_5 (1.70) which was on par with T_1 (1.87) and T_2 (2.04). Number of spikes per plant was significantly influenced by various treatments in three year old plants. The treatment T_4 recorded significantly higher number of spikes (2.63) which was on par with T_3 (2.19). The minimum number of spikes was registered in T_2 (1.67) which was on par with all other treatments except T_4.

The inference of the results is that the combination of NPK + GR + OM + VW + PGPRE + Bone meal (T_6) in six month old plants and the combination of POP + OM + VW + PGPRE + Bone meal + GR (T_4) in three year old plants recorded significantly higher number of spikes per plant.

In six months old plants, different growing systems had significant effect on production of number of spikes per plant. The system S_2 recorded significantly higher number of spikes per plant (2.86) which was followed by S_1 (2.57). S_3 recorded lowest number of spikes (1.07) per plant. Different growing systems had significant influence on production of spikes per plant in three year old plants. S_2 recorded significantly higher number of spikes per plant (2.53) which was on par with S_1 (2.31). Lowest number of spikes per plant was recorded under S_3 (1.08).

It is concluded that top ventilated polyhouse (S_2) recorded significantly higher number of spike per plant irrespective of the age of the plants.

T x S interaction was significant on production of number of spikes per plant in six month old plants. T_4S_2 interaction recorded significantly higher number of spikes per plant (3.56) which was on par with T_6S_1 (3.33), T_4S_1 (3.33), T_6S_2 (3.30) and T_3S_2 (3.22). Lowest number of spikes (0.67) was recorded in T_4S_3. In three year old plants, T_4S_1 recorded significantly higher number of spikes per plant (3.22) which was on par with T_4S_2 (3.00), T_3S_2 (2.78), T_2S_2 (2.56), T_1S_2 (2.56), T_3S_1 (2.44), T_5S_2 (2.39) and T_6S_1 (2.33). Lowest number of spikes was recorded in T_2S_3 (0.50).

It is concluded that the treatment POP + OM + VW + PGPRE + Bone meal + GR (T_4) and top ventilated poly house (S_2) in six month old plants and POP + OM + VW + PGPRE + Bone meal + GR (T_4) and two level shade house (S_1) in three year old plants recorded significantly higher number of spikes per plant.

4.2.8 Vase life

The data pertaining to vase life in six month old and three year old plants is presented in Tables 8 and 9.

Treatments had significant influence on vase life in six months old plants. T_4 recorded significantly higher value for vase life (30.00 days) which was followed by T_6 (28.94 days) and was on par with T_5 (25.72 days) and T_3 (25.24 days). Lowest vase life was registered in T_1 (21.36 days). In three year old plants, different treatments had significant influence on vase life. T_4 recorded significantly higher vase life of 28.26 days and lowest vase life was registered in T_1 (18.90 days).

The inference of the results is that the combination of POP + OM + VW + PGPRE + Bone meal + GR (T_4) recorded significantly higher vase life.

Vase life was significantly influenced by growing systems in six months old plants. S_2 recorded significantly higher vase life of 27.71 days and lowest vase life was recorded under S_3 (22.64 days). In three year old plants, vase life was significantly influenced by growing systems. In S_2, significantly higher vase life of 26.17 days was recorded. Lowest vase life of 21.72 days was recorded under S_3.

It is concluded that top ventilated polyhouse (S_2) recorded significantly higher vase life irrespective of the age of the plants.

T x S interaction on vase life was significant in six month old plants. T_4S_2 interaction had maximum vase life of 33.06 days which was on par with T_6S_2 (32.07 days). Lowest vase life was recorded in T_1S_3 (19.12 days). In three year old plants, T_4S_2 recorded significantly higher vase life of 30.44 days which was on par with T_6S_1 (29.22 days) and T_6S_2 (29.17 days). Lowest vase life of 17.89 days was recorded in T_1S_3.

It is inferred that the combination of POP + OM + VW + PGPRE + Bone meal + GR (T_4) and top ventilated polyhouse (S_2) recorded significantly higher vase life.

Table 9. Influence of plant growth promoters (T), growing systems (S) and T x S interaction on flower characters in three year old plants of *Dendrobium* cv. Earsakul

Treatments	Days to flowering				Days to first flower opening				Days to last flower opening				Length of the spike (cm)			
	S_1	S_2	S_3	Mean	S_1	S_2	S_3	Mean	S_1	S_2	S_3	Mean	S_1	S_2	S_3	Mean
T_1	361.87	271.83	410.70	348.13	21.46	18.36	16.67	18.83	12.53	16.67	14.67	14.62	23.74	23.66	23.02	23.47
T_2	297.59	362.00	427.55	362.38	18.15	17.22	16.00	17.12	10.19	14.47	13.50	12.72	27.15	27.55	29.72	28.14
T_3	408.50	254.86	476.94	380.09	14.95	15.60	18.75	16.43	14.02	12.32	12.22	12.85	25.59	28.29	28.59	27.49
T_4	369.98	118.08	363.68	283.91	13.47	15.39	15.17	14.68	9.16	11.86	11.92	10.98	32.90	32.26	9.52	24.89
T_5	313.00	127.89	414.46	285.12	16.64	16.52	15.56	16.24	19.23	11.67	14.44	15.11	30.60	30.44	15.89	25.65
T_6	358.31	217.83	341.63	305.93	13.74	14.20	14.67	14.20	10.35	9.15	14.33	11.28	27.34	34.80	29.23	30.46
Mean	351.54	225.42	405.83		16.40	16.22	16.13		12.58	12.69	13.51		27.88	29.50	22.66	
CD (0.05)	T: 74.17 S: 52.45 T x S: 128.47				T: NS S: NS T x S: NS				T: 0.29 S: 1.00 T x S: 0.46				T: 5.00 S: 3.54 T x S: 8.68			

Treat-ments	Number of flowers per spike				Size of the flower (cm) lxb				Number of spikes per plant				Vase life (days)			
	S_1	S_2	S_3	Mean	S_1	S_2	S_3	Mean	S_1	S_2	S_3	Mean	S_1	S_2	S_3	Mean
T_1	3.84	4.01	3.67	3.84	7.69x6.85	7.38x6.55	7.55x6.58	7.54x6.66	1.67	2.56	1.33	1.85	18.57	20.24	17.89	18.90
T_2	4.28	5.14	3.33	4.25	7.34x6.49	7.46x6.68	7.93x7.30	7.58x6.82	1.94	2.56	0.50	1.67	26.19	25.52	19.89	23.86
T_3	4.80	5.40	4.11	4.75	8.06x7.11	7.80x6.86	8.09x7.50	7.98x7.16	2.44	2.78	1.33	2.19	25.67	26.33	22.63	24.88
T_4	5.89	6.33	1.25	4.49	8.31x7.19	8.13x7.30	7.93x6.97	8.13x7.13	3.22	3.00	1.67	2.63	28.44	30.44	25.89	28.26
T_5	4.91	5.46	2.28	4.22	8.38x7.28	7.57x6.93	5.36x4.97	7.10x6.39	2.22	2.39	0.67	1.76	25.33	25.33	20.33	23.67
T_6	5.11	6.46	3.67	5.08	8.29x7.27	7.63x6.65	8.04x6.57	7.98x6.83	2.33	1.89	1.00	1.74	29.22	29.17	23.67	27.35
Mean	4.80	5.47	3.04		8.01x7.03	7.66x6.82	7.48x6.65		2.31	2.53	1.08		25.57	26.17	21.72	
CD (0.05)	T: 0.72 S: 0.51 T x S: 1.24				T: NS x NS S: NS x NS T x S: NS x NS				T: 0.53 S: 0.37 T x S: 0.91				T: 0.75 S: 0.53 T x S: 1.30			

S_1- Two level shade house, S_2- Top ventilated poly house, S_3- Fan and pad system

4.3 Physiological parameters

Various observations on physiological parameters at different combination of plant growth promoters (Treatments-T) under three growing systems *viz*., two level shade house (S_1), top ventilated poly house (S_2) and fan and pad system (S_3) of plants in two stages of plant growth *viz*., six month old and three year old plants were recorded, analyzed and the results are presented in Tables 10 to 12. The data on physiological parameters were recorded at six months after treatments.

4.3.1 Leaf area

Analysis of data corresponding to leaf area in six month old and three year old plants is presented in Tables 10 and 11.

Leaf area was significantly influenced by treatments. In six month old plants, T_4 recorded significantly higher leaf area (29.99 cm^2) which was on par with T_3 (29.33 cm^2) and T_2 (27.43 cm^2). The lowest leaf area of 21.81 cm^2 was recorded in T_5 which was on par with T_6 (22.06 cm^2). In three year old plants, the treatment T_4 recorded significantly higher leaf area (30.58 cm^2) which was followed by T_3 (27.17 cm^2). The Treatment T_3 was on par with T_2 (26.13 cm^2). The lowest leaf area of 19.49 cm^2 was recorded in T_6 which was on par with T_5 (21.22 cm^2).

It is inferred that the combination of POP + OM + VW + PGPRE + Bone meal + GR (T_4) recorded significantly higher leaf area irrespective of the age of the plants.

Response of growing systems on leaf area was significant. Significantly higher leaf area was recorded in S_2 (28.92 cm^2) which was followed by S_3 (24.94 cm^2). The leaf area in S_3 was on par with S_1 (23.97 cm^2). The growing systems had no significant influence on production of leaf area in three year old plants.

It is concluded that top ventilated polyhouse (S_2) had maximum influence on leaf area in six month old plants.

T x S interaction on leaf area was significant in six month old plants. Significantly higher leaf area of 34.41 cm^2 was recorded under the combination T_3S_2

which was on par with T_4S_1 (31.25 cm^2) and T_4S_2 (30.46 cm^2). Lowest leaf area was recorded in T_5S_3 (16.51 cm^2). T x S interaction on leaf area was significant in three year old plants. T_4S_1 interaction recorded significantly higher leaf area (32.73 cm^2) which was on par with T_3S_3 (31.53 cm^2) and T_3S_2 (31.41 cm^2). Lowest leaf area of 18.66 cm^2 was recorded in T_1S_3.

It is inferred that the combination of POP + OM + VW + PGPRE + Bone meal (T_3) and top ventilated polyhouse (S_2) in six month old plants and POP + OM + VW + PGPRE + Bone meal + GR (T_4) and two level shade house (S_1) in three year old plants recorded significantly higher leaf area.

4.3.2 Dry matter production

Analysis of data corresponding to dry matter production (DMP) in six month old and three year old plants is presented in Tables 10 and 11.

The results indicated that different treatments markedly influenced the DMP. In six month old plants, treatment T_3 recorded significantly higher DMP (14.27 g $plant^{-1}$) which was followed by T_6 (10.28 g $plant^{-1}$) and this was on par with T_4 (9.43 g $plant^{-1}$) and T_2 (8.82 g $plant^{-1}$). The lowest DMP of 7.43 g $plant^{-1}$ was recorded in T_5 which was on par with T_1 (7.53 g $plant^{-1}$) and T_2 (8.82 g $plant^{-1}$). Different treatments had significant influence on DMP in three year old plants. The treatment T_4 recorded significantly higher DMP of 20.92 g $plant^{-1}$ which was followed by T_3 (18.09 g $plant^{-1}$), T_6 (14.41 g $plant^{-1}$), T_2 (11.77 g $plant^{-1}$) and T_5 (9.51 g $plant^{-1}$). The lowest DMP of 7.38 g $plant^{-1}$ was recorded in T_1.

It is inferred that the combination of POP + OM + VW + PGPRE + Bone meal (T_3) in six month old plants and POP + OM + VW + PGPRE + Bone meal + GR (T_4) in three year old plant recorded significantly higher DMP.

Different growing systems had significant influence on DMP. Significantly higher DMP was recorded in S_2 (11.92 g $plant^{-1}$). S_3 recorded lowest DMP of 8.11 g $plant^{-1}$ which was on par with S_1 (8.84 g $plant^{-1}$). In three year old plants, growing systems had significant influence on DMP. Significantly higher DMP of 16.78 g

plant^{-1} was recorded under S_2 which was followed by S_1 (13.70 g plant^{-1}). Lowest DMP of 10.56 g plant^{-1} was recorded in S_3.

It is concluded that top ventilated polyhouse (S_2) had maximum influence on DMP irrespective of age of the plants.

T x S interaction had significant influence on DMP in six month old plants. T_3S_2 interaction recorded significantly higher DMP of 16.07 g plant^{-1} which was on par with T_4S_2 (15.47 g plant^{-1}), T_6S_1 (14.80 g plant^{-1}), T_3S_1 (13.93 g plant^{-1}) and T_3S_3 (12.80 g plant^{-1}). Lowest DMP of 5.10 g plant^{-1} was recorded in T_5S_1. T x S interaction had significant influence on DMP in three year old plants. T_4S_2 interaction recorded significantly highest DMP of 26.66 g plant^{-1} which was on par with T_3S_2 (24.33 g plant^{-1}). Lowest DMP of 6.76 g plant^{-1} was recorded in T_1S_1.

It is inferred that the combination of POP + OM + VW + PGPRE + Bone meal (T_3) and top ventilated polyhouse (S_2) in six month old plants and POP + OM + VW + PGPRE + Bone meal + GR (T_4) and top ventilated polyhouse (S_2) in three year old plants recorded higher DMP.

4.3.3 Crop growth rate

Analysis of data corresponding to crop growth rate (CGR) in six month old and three year old plants is presented in Tables 10 and 11.

Influence of treatments had significant effect on CGR in six month old plants. The treatment T_3 recorded significantly higher CGR of 0.131 g m^{-2} day^{-1} which was on par with T_6 (0.125 g m^{-2} day^{-1}), T_4 (0.091 g m^{-2} day^{-1}), T_1 (0.090 g m^{-2} day^{-1}) and T_2 (0.085 g m^{-2} day^{-1}). The lowest CGR of 0.078 g m^{-2} day^{-1} was recorded in T_5 which was on par with all other treatments except T_3. In three year old plants, the treatment T_4 recorded significantly higher CGR of 0.148 g m^{-2} day^{-1} which was followed by T_3 (0.123 g m^{-2} day^{-1}) and this was on par with all other treatments.

It is inferred that the combination of POP + OM + VW + PGPRE + Bone meal (T_3) in six month old plants and POP + OM + VW + PGPRE + Bone meal + GR (T_4) in three year old plant recorded significantly higher CGR.

Different growing systems had significant influence on CGR in six month old plants. Significantly higher CGR was recorded in S_2 (0.115 g m^{-2} day^{-1}). Lowest CGR was recorded in S_3 (0.078 g m^{-2} day^{-1}) which was on par with S_1 (0.107 g m^{-2} day^{-1}). In three year old plants, significantly higher CGR of 0.125 g m^{-2} day^{-1} was recorded in S_1. Lowest CGR was recorded in S_3 (0.089 g m^{-2} day^{-1}).

It is concluded that top ventilated polyhouse (S_2) in six month old plants and two level shade house (S_1) in three year old plants recorded maximum CGR.

T x S interaction on CGR was significant. In six month old plants, significantly higher CGR was recorded in T_6S_1 (0.179 g m^{-2} day^{-1}) which was on par with T_3S_1 (0.169 g m^{-2} day^{-1}), T_6S_2 (0.147 g m^{-2} day^{-1}), T_3S_2 (0.130 g m^{-2} day^{-1}) and T_4S_2 (0.116 g m^{-2} day^{-1}). The lowest value for CGR was recorded in T_6S_3 (0.011 g m^{-2} day^{-1}). In three year old plants, highest CGR was recorded in T_4S_1 (0.180 g m^{-2} day^{-1}) which was on par with T_4S_2 (0.159 g m^{-2} day^{-1}), T_3S_1 (0.156 g m^{-2} day^{-1}) and T_5S_2 (0.128 g m^{-2} day^{-1}). The lowest CGR of 0.065 g m^{-2} day^{-1} was recorded in T_2S_3.

It is inferred that the combination of NPK + GR + OM + VW + PGPRE + Bone meal (T_6) and two level shade house (S_1) in six month old plants and POP + OM + VW + PGPRE + Bone meal + GR (T_4) and two level shade house (S_1) in three year old plants recorded higher CGR.

4.3.4 Relative growth rate

Analysis of data corresponding to relative growth rate (RGR) in six month old and three year old plants is presented in Tables 10 and 11.

Treatments had significant effect on RGR. In six month old plants, the treatment T_4 recorded significantly higher RGR (0.013 g g^{-1} day^{-1}) which was on par with T_2 (0.011 g g^{-1} day^{-1}) and T_3 (0.010 g g^{-1} day^{-1}). Lowest RGR of 0.007 g g^{-1} day^{-1} was recorded in T_6 which was on par with T_5 (0.008 g g^{-1} day^{-1}), T_1 (0.009 g g^{-1} day^{-1}) and T_3 (0.010 g g^{-1} day^{-1}). In three year old plants, the different treatments had no significant effect on RGR.

It is inferred that the combination of POP + OM + VW + PGPRE + Bone meal + GR (T_4) recorded significantly higher RGR in six month old plants.

Growing systems had no significant effect on RGR in both stages of plants.

T x S interaction had significant influence on RGR. In six month old plants, highest RGR of 0.019 g g^{-1} day^{-1} was recorded in T_4S_3 which was on par with T_4S_1 (0.018 g g^{-1} day^{-1}). Lowest RGR was recorded in T_6S_3 (0.006 g g^{-1} day^{-1}). In three year old plants, significantly higher RGR was recorded in T_6S_1 (0.039 g g^{-1} day^{-1}). The lowest RGR of 0.007 g g^{-1} day^{-1} was recorded in T_5S_3 and T_6S_3.

It is concluded that the combination of POP + OM + VW + PGPRE + Bone meal + GR (T_4) and fan and pad system (S_3) in six month old plants and NPK + GR + OM + VW + PGPRE + Bone meal (T_6) and two level shad house (S_1) in three year old plants recorded maximum RGR.

4.3.5 Net assimilation rate

Analysis of data corresponding to net assimilation rate (NAR) in six month old and three year old plants is presented in Tables 10 and 11.

Treatments had no significant effect on NAR at both stages of plant growth.

Growing systems had significant influence on NAR. In six month old plants, significantly higher NAR of 0.009 g m^{-2} day^{-1} was recorded in S_2. Lowest NAR was recorded in S_3 (0.004 g m^{-2} day^{-1}) which was on par with S_1 (0.006 g m^{-2} day^{-1}). In three year old plants, significantly higher NAR was recorded in S_1 (0.013 g m^{-2} day^{-1}) which was on par with S_2 (0.012 g m^{-2} day^{-1}). Lowest NAR of 0.004 g m^{-2} day^{-1} was recorded in S_3.

It is concluded that top ventilated polyhouse (S_2) in six month old plants and two level shade house (S_1) in three year old plants recorded higher NAR.

T x S interaction had significant effect on NAR. In six month old plants, highest NAR was recorded under the combination T_6S_2 (0.011 g m^{-2} day^{-1}) which was on par with all other treatments except T_5S_3 (0.003 g m^{-2} day^{-1}) and T_6S_3 (0.002 g m^{-2}

day^{-1}). The lowest value for NAR was recorded under the combination T_6S_3 (0.002 g m^{-2} day^{-1}). In three year old plants, highest NAR was recorded under combination of T_6S_1 (0.028 g m^{-2} day^{-1}) which was on par with T_6S_2 (0.017 g m^{-2} day^{-1}), T_5S_2 (0.014 g m^{-2} day^{-1}), T_4S_2 (0.014 g m^{-2} day^{-1}), T_2S_1 (0.013 g m^{-2} day^{-1}), T_2S_2 (0.012 g m^{-2} day^{-1}) and T_3S_1 (0.012 g m^{-2} day^{-1}). Lowest NAR was recorded under the combination of T_2S_3 (0.003 g m^{-2} day^{-1}).

It is inferred that the combination of NPK + GR + OM + VW + PGPRE + Bone meal (T_6) had more influence on NAR in top ventilated poly house (S_2) in six month old plants and two level shade house (S_1) in three year old plants.

4.3.6 Number of stomata

Analysis of data corresponding to number of stomata in six month old and three year old plants is presented in Tables 10 and 11.

Different treatments had significant effect on number of stomata. In six month old plants, T_4 recorded significantly higher number of stomata (41.14 per mm^2) which was on par with T_2 (38.70 per mm^2) and T_6 (38.21 per mm^2). The lowest stomatal count of 31.46 per mm^2 was recorded in T_1 which was on par with T_5 (34.91 per mm^2). In three year old plants, T_3 recorded significantly higher number of stomata (39.86 per mm^2) which was on par with T_2 (38.68 per mm^2), T_4 (38.36 per mm^2) and T_6 (38.02 per mm^2). The lowest number of stomata of 34.98 per mm^2 was recorded in T_1 which was on par with T_5 (36.16 per mm^2) and T_6 (38.02 per mm^2).

The inference of the results is that the combination of POP + OM + VW + PGPRE + Bone meal + GR (T_4) in six month old plants and POP + OM + VW + PGPRE + Bone meal (T_3) in three year old plants recorded higher number of stomata.

Growing systems had significant influence on number of stomata. In six month old plants, highest number of stomata was recorded under S_3 (38.34 per mm^2) which

Table 10. Influence of plant growth promoters (T), growing systems (S) and T x S interaction on physiological parameters in six month old plants of *Dendrobium* cv. Earsakul at six months after treatment

Treatm-ents	Leaf area (cm^2)				Dry matter production (g plant^{-1})				Crop growth rate (g m^{-2} day^{-1})				Relative growth rate (g g^{-1} day^{-1})			
	S_1	S_2	S_3	Mean	S_1	S_2	S_3	Mean	S_1	S_2	S_3	Mean	S_1	S_2	S_3	Mean
T_1	19.26	26.88	28.73	25.03	5.38	9.27	7.93	7.53	0.076	0.104	0.089	0.090	0.009	0.010	0.007	0.009
T_2	23.71	29.66	28.94	27.43	7.10	12.43	6.92	8.82	0.067	0.107	0.080	0.085	0.012	0.012	0.009	0.011
T_3	24.85	34.41	28.95	29.33	13.93	16.07	12.80	14.27	0.169	0.130	0.093	0.131	0.011	0.011	0.008	0.010
T_4	31.25	30.46	28.27	29.99	6.72	15.47	6.12	9.43	0.084	0.116	0.075	0.091	0.018	0.013	0.019	0.013
T_5	21.49	27.42	16.51	21.81	5.10	10.25	6.93	7.43	0.071	0.085	0.079	0.078	0.008	0.009	0.007	0.008
T_6	23.25	25.72	18.23	22.06	14.80	8.05	7.98	10.28	0.179	0.147	0.011	0.125	0.007	0.008	0.006	0.007
Mean	23.97	28.92	24.94		8.84	11.92	8.11		0.107	0.115	0.078		0.010	0.010	0.008	
CD (0.05)	T: 2.71 S: 1.91 T x S: 4.69				T: 1.95 S: 1.38 T x S: 3.38				T: 0.040 S: 0.028 T x S: 0.069				T: 0.003 S: NS T x S: 0.005			

Treatments	Net assimilation rate (g m^{-2} day^{-1})				Number of stomata				Rate of photosynthesis (µmol CO_2 m^{-2} s^{-1})				Rate of transpiration (Night) (µmol m^{-2} s^{-1})				Rate of transpiration (Day) (µmol m^{-2} s^{-1})			
	S_1	S_2	S_3	Mean	S_1	S_2	S_3	Mean	S_1	S_2	S_3	Mean	S_1	S_2	S_3	Mean	S_1	S_2	S_3	Mean
T_1	0.004	0.009	0.004	0.006	34.32	31.80	28.26	31.46	4.24	8.86	3.73	5.61	0.14	0.23	0.11	0.16	1.73	4.40	3.15	3.09
T_2	0.006	0.009	0.004	0.006	31.80	44.92	39.38	38.70	4.83	6.10	3.49	4.81	0.16	0.45	0.18	0.26	3.81	5.27	3.11	4.06
T_3	0.007	0.009	0.005	0.007	34.82	34.33	39.38	36.17	4.94	9.73	4.41	6.36	0.14	0.23	0.10	0.16	8.83	7.77	3.09	6.56
T_4	0.009	0.009	0.006	0.008	40.33	41.38	41.72	41.14	3.62	6.01	3.26	4.29	0.21	0.46	0.07	0.25	3.88	5.39	3.24	4.17
T_5	0.006	0.006	0.003	0.005	28.55	37.85	38.35	34.91	2.48	6.90	3.88	4.42	0.10	0.37	0.12	0.19	4.46	9.19	2.47	5.37
T_6	0.004	0.011	0.002	0.006	32.29	39.36	43.00	38.21	4.20	3.58	2.58	3.45	0.15	0.14	0.15	0.15	2.41	3.95	2.96	3.10
Mean	0.006	0.009	0.004		33.68	38.27	38.34		4.05	6.86	3.55		0.15	0.32	0.12		4.18	6.00	3.00	
CD (0.05)	T: NS S: 0.002 T x S: 0.007				T: 3.41 S: 2.41 T x S: 5.91				T: 1.72 S: 1.21 T x S: 2.98				T: 0.032 S: 0.023 T x S: 0.056				T: 1.29 S: 0.91 T x S:2.23			

Table 11. Influence of plant growth promoters (T), growing systems (S) and T x S interaction on physiological parameters in three year old plants of *Dendrobium* cv. Earsakul at six months after treatment

Treatments	Leaf area (cm^2)				Dry matter production (g $plant^{-1}$)				Crop growth rate (g m^{-2} day^{-1})				Relative growth rate (g g^{-1} day^{-1})			
	S_1	S_2	S_3	Mean	S_1	S_2	S_3	Mean	S_1	S_2	S_3	Mean	S_1	S_2	S_3	Mean
T_1	20.72	25.66	18.66	22.36	6.76	8.46	6.93	7.38	0.105	0.106	0.090	0.100	0.016	0.011	0.008	0.011
T_2	25.43	27.52	24.01	26.13	12.33	13.33	9.66	11.77	0.092	0.108	0.065	0.088	0.014	0.013	0.010	0.012
T_3	25.05	31.41	31.53	27.17	17.66	24.33	12.30	18.09	0.156	0.122	0.091	0.123	0.012	0.012	0.009	0.011
T_4	32.73	26.30	23.80	30.58	22.33	26.66	13.76	20.92	0.180	0.159	0.104	0.148	0.011	0.015	0.014	0.012
T_5	22.15	19.36	23.48	21.22	7.88	11.78	8.88	9.51	0.098	0.128	0.086	0.104	0.010	0.010	0.007	0.009
T_6	18.84	20.81	20.81	19.49	15.25	16.16	11.81	14.41	0.117	0.114	0.100	0.110	0.039	0.009	0.007	0.018
Mean	24.15	25.18	24.14		13.70	16.78	10.56		0.125	0.123	0.089		0.017	0.012	0.008	
CD (0.05)	T: 2.28 S: NS T x S: 3.96				T: 1.64 S: 1.16 T x S: 2.84				T: 0.033 S: 0.023 T x S: 0.057				T: NS S: NS T x S: 0.021			

Treatments	Net assimilation rate (g m^{-2} day^{-1})				Number of stomata				Rate of photosynthesis (µmol CO_2 m^{-2} s^{-1})				Rate of transpiration (Night) (µmol m^{-2} s^{-1})				Rate of transpiration (day time) (µmol m^{-2} s^{-1})			
	S_1	S_2	S_3	Mean	S_1	S_2	S_3	Mean	S_1	S_2	S_3	Mean	S_1	S_2	S_3	Mean	S_1	S_2	S_3	Mean
T_1	0.011	0.007	0.004	0.007	32.79	34.80	37.35	34.98	3.72	5.92	4.49	4.71	0.12	0.09	0.26	0.15	2.40	2.33	3.56	2.76
T_2	0.013	0.012	0.003	0.009	40.39	37.33	38.33	38.68	3.78	3.58	3.22	3.53	0.19	0.12	0.04	0.12	3.88	6.15	3.28	4.44
T_3	0.012	0.010	0.004	0.009	38.37	38.86	42.36	39.86	3.71	3.63	4.93	4.09	0.15	0.09	0.05	0.10	3.14	6.71	2.64	4.16
T_4	0.007	0.014	0.005	0.009	30.33	44.92	39.85	38.36	2.82	3.51	8.72	5.01	0.22	0.06	0.29	0.19	7.20	1.42	1.96	3.53
T_5	0.009	0.014	0.004	0.009	34.32	37.85	36.33	36.16	2.87	2.96	6.58	4.14	0.11	0.20	0.23	0.17	4.05	0.57	3.10	2.57
T_6	0.028	0.017	0.004	0.016	35.83	38.86	39.38	38.02	2.95	3.98	3.26	3.40	0.16	0.06	0.22	0.14	8.73	3.06	3.40	5.06
Mean	0.013	0.012	0.004		35.34	38.77	38.93		3.30	3.93	5.20		0.16	0.10	0.18		4.90	3.37	2.98	
CD (0.05)	T: NS S: 0.007 T x S: 0.017				T: 3.22 S: 2.28 T x S: 5.57				T: NS S: 1.84 T x S: 4.51				T: NS S: NS T x S: 0.301				T: 0.81 S: 0.57 T x S: 1.41			

was on par with S_2 (38.27 per mm^2). Lowest number of stomata (33.68 per mm^2) was recorded in S_1. In three year old plants, higher number of stomata was recorded under S_3 (38.93 per mm^2) which was on par with S_2 (38.77 per mm^2). Lowest number of stomata (35.34 per mm^2) was recorded in S_1.

It is concluded that fan and pad system (S_3) recorded highest number of stomata in both the stages of plants.

T x S interaction had significant influence on number of stomata. In six month old plants, the combination of T_2S_2 recorded significantly higher number of stomata (44.92 per mm^2) which was on par with T_6S_3 (43.00 per mm^2), T_4S_3 (41.72 per mm^2), T_4S_2 (41.38 per mm^2), T_4S_1 (40.33 per mm^2), T_3S_3 (39.38 per mm^2), T_2S_3 (39.38 per mm^2), T_6S_2 (39.36 per mm^2) and T_5S_3 (38.35 per mm^2). Lowest number of stomata (28.26 per mm^2) was recorded in combination T_1S_3. In three year old plants, the combination T_4S_2 recorded significantly higher number of stomata (44.92 per mm^2) which was on par with T_3S_3 (42.36 per mm^2), T_2S_1 (40.39 per mm^2), T_4S_3 (39.85 per mm^2) and T_6S_3 (39.38 per mm^2). Minimum number of stomata was recorded under T_4S_1 (30.33 per mm^2).

It is concluded that the combination of POP + PGPRE + Bone meal (T_2) and top ventilated poly house (S_2) in six month old plants and POP + OM + VW + PGPRE + Bone meal + GR (T_4) and top ventilated poly house (S_2) in three year old plants recorded higher number of stomata.

4.3.7 Rate of photosynthesis

Analysis of data pertaining to rate of photosynthesis in six month old and three year old plants is presented in Tables 10 and 11.

The influence of treatments on photosynthetic rate was significant. In six month old plants, the treatment T_3 recorded significantly higher rate of photosynthesis (6.36 µmol CO_2 m^{-2} s^{-1}) which was on par with T_1 (5.61 µmol CO_2 m^{-2} s^{-1}) and T_2 (4.81 µmol CO_2 m^{-2} s^{-1}). The lowest rate of photosynthesis of 3.45 µmol CO_2 m^{-2} s^{-1} was recorded in T_6 which was on par with T_4 (4.29 µmol CO_2 m^{-2} s^{-1}), T_5 (4.42 µmol CO_2 m^{-2} s^{-1}) and

T_2 (4.81 µmol CO_2 m^{-2} s^{-1}). In three year old plants, different treatments had no significant influence on photosynthetic rate.

It is inferred that the combination of POP + OM + VW + PGPRE + Bone meal (T_3) in six month old plants recorded significantly higher rate of photosynthesis.

Growing systems had significant influence on rate of photosynthesis. In six month old plants, highest photosynthetic rate was recorded under S_2 (6.86 µmol CO_2 m^{-2} s^{-1}) which was followed by S_1 (4.05 µmol CO_2 m^{-2} s^{-1}) and this was on par with S_3 (3.55 µmol CO_2 m^{-2} s^{-1}). In three year old plants, highest photosynthetic rate was recorded under S_3 (5.20 µmol CO_2 m^{-2} s^{-1}) which was on par with S_2 (3.93 µmol CO_2 m^{-2} s^{-1}). Rate of photosynthesis in S_2 was on par with S_1 (3.30 µmol CO_2 m^{-2} s^{-1}).

It is concluded that top ventilated polyhouse (S_2) in six month old plants and fan and pad system (S_3) in three year old plants recorded highest photosynthetic rate.

T x S interaction on photosynthetic rate was significant. In six month old plants, the combination T_3S_2 recorded significantly higher rate of photosynthesis (9.73 µmol CO_2 m^{-2} s^{-1}) which was on par with T_1S_2 (8.86 µmol CO_2 m^{-2} s^{-1}) and T_5S_2 (6.90 µmol CO_2 m^{-2} s^{-1}). Lowest photosynthetic rate of 2.48 µmol CO_2 m^{-2} s^{-1} was recorded in the combination T_5S_1. In three year old plants, combination of T_4S_3 recorded significantly higher rate of photosynthesis (8.72 µmol CO_2 m^{-2} s^{-1}) which was on par with T_5S_3 (6.58 µmol CO_2 m^{-2} s^{-1}), T_1S_2 (5.92 µmol CO_2 m^{-2} s^{-1}), T_3S_3 (4.93 µmol CO_2 m^{-2} s^{-1}) and T_1S_3 (4.49 µmol CO_2 m^{-2} s^{-1}). Lowest photosynthetic rate of 2.82 µmol CO_2 m^{-2} s^{-1} was recorded in treatment combination T_4S_1.

The inference of the result is that the combination of POP + OM + VW + PGPRE + Bone meal (T_3) and top ventilated polyhouse (S_2) in six month old plants and POP + OM + VW + PGPRE + Bone meal + GR (T_4) and fan pad system (S_3) in three year old plants recorded maximum rate of photosynthesis.

4.3.8 Rate of transpiration (at day time)

Analysis of data pertaining to rate of transpiration in six month old and three year old plants is presented in Tables 10 and 11.

Different treatments had significant influence on rate of transpiration. In six month old plants, the treatment T_3 recorded significantly higher rate of transpiration (6.56 µmol m^{-2} s^{-1}) which was on par with T_5 (5.37 µmol m^{-2} s^{-1}). The lowest rate of transpiration of 3.09 µmol m^{-2} s^{-1} was recorded in T_1 which was on par with T_6 (3.10 µmol m^{-2} s^{-1}), T_2 (4.06 µmol m^{-2} s^{-1}) and T_4 (4.17 µmol m^{-2} s^{-1}). In three year old plants, the treatment T_6 recorded significantly higher rate of transpiration (5.06 µmol m^{-2} s^{-1}) which was on par with T_2 (4.44 µmol m^{-2} s^{-1}). The lowest rate of transpiration of 2.57 µmol m^{-2} s^{-1} was recorded in T_5 which was on par with T_1 (2.76 µmol m^{-2} s^{-1}).

It is inferred that the combination of POP + OM + VW + PGPRE + Bone meal (T_3) in six month old plants and NPK + GR + OM + VW + PGPRE + Bone meal (T_6) in three year old plants recorded significantly higher rate of transpiration during day time.

Growing systems had significant influence on rate of transpiration. In six month old plants, highest transpiration rate of 6.00 µmol m^{-2} $s^{-1}$was recorded under S_2. Lowest rate of transpiration was recorded in S_3 (3.00). In three year old plants, significantly higher rate of transpiration was recorded under S_1 (4.90 µmol m^{-2} s^{-1}) which was followed by S_2 (3.37 µmol m^{-2} s^{-1}) and this was on par with S_3 (2.98 µmol m^{-2} s^{-1}).

It is concluded that top ventilated polyhouse (S_2) in six month old plants and two level shade house (S_1) in three year old plants recorded maximum rate of transpiration during day time.

T x S interaction had significant effect on rate of transpiration. In six month old plants, combination of T_5S_2 recorded significantly higher rate of transpiration (9.19 µmol m^{-2} s^{-1}) which was on par with T_3S_1 (8.83 µmol m^{-2} s^{-1}) and T_3S_2 (7.77 µmol m^{-2} s^{-1}). Lowest transpiration rate of 1.73 µmol m^{-2} s^{-1} was recorded in combination T_1S_1. In three year old plants, combination of T_6S_1 recorded significantly higher rate of transpiration (8.73 µmol m^{-2} s^{-1}). Lowest transpiration rate of 0.57 µmol m^{-2} s^{-1} was recorded in combination T_5S_2.

It is inferred that the combination of NPK + GR (T_5) and top ventilated polyhouse (S_2) in six month old plants and NPK + GR + OM + VW + PGPRE + Bone

meal (T_6) and two level shade house (S_1) recorded significantly higher rate of transpiration during day time.

4.3.9 Rate of transpiration (at night)

Analysis of the data pertaining to rate of transpiration in six month old and three year plants is presented in Tables 10 and 11.

Rate of transpiration varied significantly among treatments. In six month old plants, the treatment T_2 recorded significantly higher rate of transpiration (0.26 µmol m^{-2} s^{-1}) which was on par with T_4 (0.25 µmol m^{-2} s^{-1}). The lowest rate of transpiration of 0.15 µmol m^{-2} s^{-1} was recorded in T_6 which was on par with T_1 (0.16 µmol m^{-2} s^{-1}) and T_3 (0.16 µmol m^{-2} s^{-1}). The treatments had no significant that the combination of POP + PGPRE + Bone meal (T_2) in six month old plants recorded highest rate of transpiration during night.

Growing systems had significant influence on rate of transpiration. In six month old plants, highest transpiration rate was recorded under S_2 (0.32 µmol m^{-2} s^{-1}). Lowest rate of transpiration was recorded in S_3 (0.12 µmol m^{-2} s^{-1}). Growing systems did not showed significant influence on rate of transpiration in three year old plants.

It is concluded that top ventilated polyhouse (S_2) recorded highest rate of transpiration in six month old plants.

T x S interaction had significant influence on rate of transpiration. In six month old plants, combination of T_4S_2 recorded significantly higher rate of transpiration (0.46 µmol m^{-2} s^{-1}) which was on par with T_2S_2 (0.45 µmol m^{-2} s^{-1}). Lowest transpiration rate of 0.07 µmol m^{-2} s^{-1} was recorded in the combination T_4S_3. In three year old plants, T_4S_3 recorded significantly higher rate of transpiration (0.29 µmol m^{-2} s^{-1}) which was on par with all other interactions except T_4S_2 (0.06 µmol m^{-2} s^{-1}), T_6S_2 (0.06 µmol m^{-2} s^{-1}), T_3S_3 (0.05 µmol m^{-2} s^{-1}) and T_2S_3 (0.04 µmol m^{-2} s^{-1}). Lowest transpiration rate of 0.04 µmol m^{-2} s^{-1} was recorded in combination T_2S_3.

It is concluded that the treatment POP + OM + VW + PGPRE + Bone meal + GR (T_4) and top ventilated poly house (S_2) in six month old plants, POP + OM + VW + PGPRE + Bone meal + GR (T_4) and fan and pad system (S_3) in three year old plants recorded higher transpiration rate during night time.

4.3.10 Diffusive resistance

Analysis of data pertaining to diffusive resistance in six month old and three year old plants is presented in Tables 12 and 13.

Different treatments had significant effect on diffusive resistance. In six month old plants, the treatment T_6 recorded significantly higher diffusive resistance (13.66 S cm^{-1}) which was followed by T_5 (10.03 S cm^{-1}) and this was on par with T_2 (9.70 S cm^{-1}) and T_4 (8.42 S cm^{-1}). The lowest diffusive resistance of 6.62 S cm^{-1} was recorded in T_1 which was on par with T_3 (7.28 S cm^{-1}) and T_4 (8.42 S cm^{-1}). In three year old plants, the treatment T_5 recorded significantly higher diffusive resistance (18.51 S cm^{-1}) which was on par with T_4 (16.77 S cm^{-1}), T_3 (13.56 S cm^{-1}) and T_1 (13.23 S cm^{-1}). The lowest diffusive resistance of 9.48 S cm^{-1} was recorded in T_2 which was on par with all other treatments except T_4 and T_5.

It is concluded that treatment NPK + GR + OM + VW + PGPRE + Bone meal (T_6) in six month old plants and NPK + GR (T_5) in three year old plants recorded significantly higher diffusive resistance.

Growing systems had significant influence on diffusive resistance. In six month old plants, highest diffusive resistance of 10.98 S cm^{-1} was recorded under S_1. Lowest diffusive resistance of 8.38 S cm^{-1} was recorded in S_3 which was on par with S_2 (8.48 S cm^{-1}). In three year old plants, significantly higher diffusive resistance was recorded under S_2 (18.30 S cm^{-1}) which was followed by S_1 (13.37 S cm^{-1}) and was on par with S_3 (9.74 S cm^{-1}).

It is concluded that two level shade house (S_1) in six month old plants and top ventilated polyhouse (S_2) in three year old plants recorded higher diffusive resistance.

T x S interaction had significant influence on diffusive resistance. In six month old plants, combination of T_6S_1 recorded significantly higher diffusive resistance (16.17 S cm^{-1}) which was on par with T_2S_1 (13.24 S cm^{-1}), T_6S_2 (12.51 S cm^{-1}) and T_6S_3 (12.29 S cm^{-1}). Lowest diffusive resistance of 4.07 S cm^{-1} was recorded in combination of T_1S_3. In three year old plants, combination of T_5S_2 recorded significantly higher diffusive resistance (34.81S cm^{-1}) which was followed by T_4S_2 (22.80 S cm^{-1}) and which was on par with T_3S_1 (21.27 S cm^{-1}), T_6S_2 (17.83 S cm^{-1}), T_1S_2 (17.03 S cm^{-1}), T_1S_1 (16.00 S cm^{-1}), T_4S_3 (14.90 S cm^{-1}) and T_5S_1 (13.55 S cm^{-1}). Lowest diffusive resistance of 6.07 S cm^{-1} was recorded in the combinthat the treatment NPK + GR + OM + VW + PGPRE + Bone meal (T_6) and two level shade house (S_1) in six month old plants and NPK + GR (T_5) and top ventilated polyhouse (S_2) in three year old plants had significant influence on diffusive resistance.

4.3.11 Chlorophyll content

Analysis of the data pertaining to chlorophyll ‘a’ ‘b’ and total chlorophyll content in six month old and three year plants is presented in Tables 12 and 13.

The effect of treatments on chlorophyll ‘a’ content was not significant in both stages of plants.

The effect of growing systems on chlorophyll ‘a’ content was not significant in six month old plants. Growing systems had significant influence on chlorophyll ‘a’ content in three year old plants. The system S_2 recorded significantly higher chlorophyll ‘a’ content (0.31 mg g^{-1}). Lowest chlorophyll ‘a’ content was recorded in S_3 (0.09 mg g^{-1}) which was on par with S_1 (0.13 mg g^{-1}).

It is concluded that top ventilated polyhouse (S_2) had significant influence on chlorophyll ‘a’ content only in three year old plants.

T x S interaction had significant influence on chlorophyll ‘a’ content. In six month old plants, interaction T_6S_1 recorded maximum chlorophyll ‘a’ content (0.25 mg g^{-1}) which was on par with all other combinations except T_5S_1. In three year old plants,

the combination of T_3S_2 recorded significantly higher chlorophyll 'a' content (0.40 mg g^{-1}) which was on par with T_6S_2 (0.31 mg g^{-1}), T_5S_2 (0.30 mg g^{-1}), T_4S_2 (0.29 mg g^{-1}) and T_1S_2 (0.29 mg g^{-1}). Lowest chlorophyll 'a' content of 0.08 mg g^{-1} was recorded by T_1S_3.

It is inferred that the combination of NPK + GR + OM + VW + PGPRE + Bone meal (T_6) and two level shade house (S_1) in six month old plants and POP + OM + VW + PGPRE + Bone meal (T_3) and top ventilated polyhouse (S_2) in three year old plants recorded significantly higher chlorophyll 'a' content.

Treatments had no significant influence on chlorophyll ''b' content of six month old plants, while there was significant effect on chlorophyll 'b' content in three year old plants. The treatment T_5 recorded significantly higher chlorophyll 'b' content (0.19 mg g^{-1}) which was on par with all other treatments except T_2. Lowest chlorophyll 'b' content (0.13 mg g^{-1}) was recorded in T_2.

It is concluded that NPK + GR (T_5) recorded significantly higher chlorophyll 'b' content in three year old plants.

Growing systems had significant influence on chlorophyll 'b' content in six month old plants. The system S_1 recorded significantly higher chlorophyll 'b' content (0.47 mg g^{-1}). Lowest chlorophyll 'b' content was recorded in S_3 (0.06 mg g^{-1}) which was on par with S_2 (0.10 mg g^{-1}). In three year old plants, S_1 recorded significantly higher chlorophyll 'b' content of 0.20 mg g^{-1} and lowest chlorophyll 'b' content was recorded in S_3 (0.11 mg g^{-1}) which was on par with S_2 (0.13 mg g^{-1}).

It is concluded that two level shade house had maximum influence on chlorophyll 'b' content irrespective of the age of the plants.

T x S interactions had significant influence on chlorophyll 'b' content. In six month old plants, the combination of T_4S_1 recorded significantly higher chlorophyll 'b' content (0.75 mg g^{-1}) which was on par with T_2S_1 (0.51 mg g^{-1}), T_3S_1 (0.50 mg g^{-1}) and T_5S_1 (0.49 mg g^{-1}). Lowest value was recorded in T_3S_3 (0.01 mg g^{-1}). In three year old plants, the interaction T_5S_1 recorded significantly higher chlorophyll 'b' content (0.28

mg g^{-1}) which was on par with T_6S_1 (0.25 mg g^{-1}), T_3S_2 (0.20 mg g^{-1}) and T_3S_1 (0.20 mg g^{-1}). Lowest chlorophyll 'b' content was recorded in T_6S_2 (0.08 mg g^{-1}).

It is inferred that the treatment POP + OM + VW + PGPRE + Bone meal + GR (T_4) and NPK + GR (T_5) had more influence in two level shade house (S_1) in both stages of the plants.

Treatments had no significant effect on total chlorophyll content in both stages of growth.

Growing systems had significant influence on total chlorophyll content in six month old plants. The system S_1 recorded significantly higher total chlorophyll content of 0.68 mg g^{-1}. Lowest total chlorophyll content was recorded in S_3 (0.24 mg g^{-1}) which was on par with S_2 (0.32 mg g^{-1}). In three year old plants, the system S_2 recorded significantly higher total chlorophyll content of 0.44 mg g^{-1} whereas lowest total chlorophyll content of 0.20 mg g^{-1} was recorded in S_3.

It is concluded that two level shade house in six month old plants (S_1) and top ventilated polyhouse (S_2) in three year old plants recorded significantly higher total chlorophyll content.

T x S interaction on total chlorophyll content was significant in six month old plants. The combination of T_4S_1 recorded significantly higher total chlorophyll content of 0.96 mg g^{-1} which was on par with T_2S_1 (0.73 mg g^{-1}) and T_3S_1 (0.71 mg g^{-1}). Lowest total chlorophyll content of 0.22 mg g^{-1} was recorded in T_4S_3. In three year old plants, interaction T_3S_2 recorded significantly higher total chlorophyll content of 0.60 mg g^{-1} which was on par with T_5S_1 (0.47 mg g^{-1}) and T_5S_2 (0.44 mg g^{-1}). Lowest total chlorophyll content of 0.19 mg g^{-1} was recorded in T_6S_3.

It is inferred that the treatment POP + OM + VW + PGPRE + Bone meal + GR (T_4) and two level shade house (S_1) in six month old plants and POP + OM + VW + PGPRE + Bone meal(T_3) and top ventilated polyhouse (S_2) in three year old plants recorded significantly higher total chlorophyll content.

Table 12. Influence of plant growth promoters (T), growing systems (S) and T x S interaction on diffusive resistance and chlorophyll content in six month old plants of *Dendrobium* cv. Earsakul at six months after treatment

Treatments	Diffusive resistance (S cm^{-1})				Chlorophyll a (mg g^{-1} leaf weight)				Chlorophyll b (mg g^{-1} leaf weight)				Total chlorophyll (mg g^{-1} leaf weight)			
	S_1	S_2	S_3	Mean	S_1	S_2	S_3	Mean	S_1	S_2	S_3	Mean	S_1	S_2	S_3	Mean
T_1	11.33	4.47	4.07	6.62	0.22	0.19	0.17	0.19	0.28	0.10	0.09	0.16	0.50	0.30	0.26	0.34
T_2	13.24	7.04	8.82	9.70	0.21	0.25	0.21	0.22	0.51	0.12	0.09	0.24	0.73	0.37	0.30	0.47
T_3	5.76	9.86	6.21	7.28	0.22	0.22	0.22	0.22	0.50	0.16	0.01	0.22	0.71	0.38	0.23	0.44
T_4	8.30	8.36	8.61	8.42	0.21	0.19	0.18	0.19	0.75	0.10	0.04	0.30	0.96	0.29	0.22	0.49
T_5	11.12	8.68	10.29	10.03	0.08	0.22	0.15	0.18	0.49	0.09	0.07	0.22	0.57	0.31	0.23	0.41
T_6	16.17	12.51	12.29	13.66	0.25	0.18	0.22	0.22	0.29	0.09	0.04	0.14	0.53	0.27	0.26	0.36
Mean	10.98	8.48	8.38		0.21	0.21	0.19		0.47	0.10	0.06		0.68	0.32	0.24	
CD (0.05)	T: 2.31 S: 1.63 T x S: 4.00				T: NS S: NS T x S: 0.12				T: NS S: 0.11 T x S: 0.28				T: NS S: 0.11 T x S: 0.27			

Table 13. Influence of plant growth promoters (T), growing systems (S) and T x S interaction on diffusive resistance and chlorophyll content in three year old plants at six months after treatment

Treatments	Diffusive resistance (S cm^{-1})				Chlorophyll a (mg g^{-1} leaf wt.)				Chlorophyll b (mg g^{-1} leaf wt.)				Total chlorophyll (mg g^{-1} wt.)			
	S_1	S_2	S_3	Mean	S_1	S_2	S_3	Mean	S_1	S_2	S_3	Mean	S_1	S_2	S_3	Mean
T_1	16.00	17.03	6.65	13.23	0.14	0.29	0.08	0.17	0.18	0.13	0.11	0.14	0.32	0.42	0.19	0.31
T_2	10.72	9.23	8.49	9.48	0.12	0.27	0.10	0.16	0.15	0.12	0.13	0.13	0.27	0.39	0.23	0.30
T_3	21.27	8.10	11.32	13.56	0.09	0.40	0.12	0.20	0.20	0.20	0.09	0.15	0.28	0.60	0.22	0.35
T_4	12.60	22.80	14.90	16.77	0.15	0.29	0.08	0.17	0.17	0.14	0.11	0.14	0.32	0.43	0.19	0.31
T_5	13.55	34.81	7.16	18.51	0.19	0.30	0.09	0.18	0.28	0.14	0.14	0.19	0.47	0.44	0.22	0.37
T_6	6.07	17.83	9.93	11.28	0.11	0.31	0.09	0.17	0.25	0.08	0.10	0.14	0.36	0.39	0.19	0.31
Mean	13.37	18.30	9.74		0.13	0.31	0.09		0.20	0.13	0.11		0.33	0.44	0.20	
CD (0.05)	T: 5.57 S: 3.94 T x S: 9.66				T: NS S: 0.05 T x S: 0.11				T: 0.05 S: 0.03 T x S: 0.09				T: NS S: 0.06 T x S: 0.17			

4.4 Root parameters

Various observations on root growth at different combination of plant growth promoters (treatments) under three growing systems *viz*., two level shade house (S_1), top ventilated poly house (S_2) and fan and pad system (S_3) of plants in two stages of plant growth *viz*., six month old and three year old plants were recorded, analyzed and the results are presented in Tables 14 and 15. The data on root parameters were recorded at the time of flower bud formation.

4.4.1 Number of roots per plant

Analysis of data corresponding to number of roots per plant in six month old and three year old plants is presented in Tables 14 and 15.

In six month old plants, significantly higher number of roots per plant was recorded in T_6 (91.00) which was followed by T_3 (82.70). Lowest number of roots per plant was registered in T_1 (62.83). In three year old plants, highest number of roots per plant was recorded in T_6 (79.72) which was on par with T_3 (76.17), T_2 (73.56) and T_4 (71.25). Lowest number of roots per plant was registered in T_5 (51.02) which was on par with T_1 (59.07).

It is inferred that the combination of NPK + GR + OM + VW + PGPRE + Bone meal (T_6) recorded significantly higher number of roots in both stages of plants.

Growing systems had significant influence on number of roots per plant in six month old plants. Significantly higher number of roots was recorded in S_2 (89.00) (Plate 10) which were followed by S_1 (79.04). The system S_3 recorded lowest number of roots per plant (60.65). In three year old plants, significantly higher number of roots was recorded in S_2 (94.75) which was followed by S_1 (66.98) (Plate 10). Lowest number of roots per plant was recorded in S_3 (43.66).

Two level shade house (S_1)

Two level shade house (S_1)

Top ventilated polyhouse (S_2)

Top ventilated polyhouse (S_2)

Fan and pad system (S_3)

Fan and pad system (S_3)

Plate 10. Influence of growing systems on number of roots per plant

It is concluded that top ventilated polyhouse (S_2) had significant influence on number of roots per plant irrespective of the age of the plants.

T x S interactions was found to be significant. In six month old plants, interaction T_4S_2 recorded significantly higher number of roots per plant (106.83) which was on par with T_6S_2 (101.83) and T_3S_1 (101.10). Combination of T_4S_3 recorded minimum number of roots per plant (48.00). In three year old plants, interaction T_4S_2 recorded significantly higher number of roots per plant (119.00) which was followed by T_3S_2 (106.17), T_6S_2 (101.67). Combination of T_5S_3 recorded minimum number of roots per plant (29.00).

It is concluded that the treatment POP + OM + VW + PGPRE + Bone meal + GR (T_4) and top ventilated polyhouse (S_2) recorded significantly higher number of roots per plants.

4.4.2 Root length

Analysis of data corresponding to root length in six month old and three year old plants is presented in Tables 14 and 15.

Treatments had significant influence on root length in six month old plants. Significantly higher root length was recorded in T_4 (34.01 cm) which was followed by T_2 (27.68 cm) and which was on par with T_3 (27.19 cm) and T_6 (26.16 cm). Lowest root length of 21.97 cm was registered in T_1. In three year old plants, significantly higher root length was recorded in T_3 (47.06 cm) which was followed by T_2 (37.03 cm). The treatment T_2 was on par with T_4 (33.73 cm), T_5 (33.00 cm) and T_1 (31.88 cm). Lowest root length of 23.54 cm was recorded in T_6.

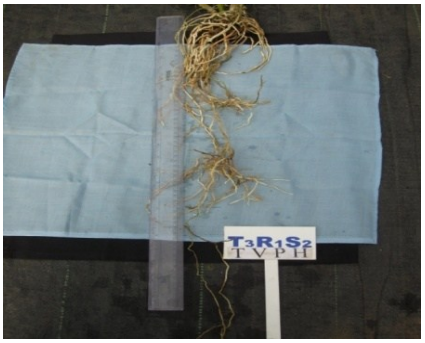
It is concluded that the treatment POP + OM + VW + PGPRE + Bone meal + GR (T_4) in six month old plants and POP + OM + VW + PGPRE + Bone meal (T_3) in three year old plants recorded significantly higher root length.

Growing systems had significant influence on root length in six month old plants. Significantly highest root length of 31.44 cm was recorded in S_2 which was followed by S_1 (26.43 cm) (Plate 11). System S_3 recorded minimum root length of

Two level shade house (S_1)

Two level shade house (S_1)

Top ventilated polyhouse (S_2)



Top ventilated polyhouse (S_2)

Fan and pad system (S_3)

Fan and pad system (S_3)

Plate 11. Influence of growing systems on root length (cm)

23.00 cm. In three year old plants, significantly higher root length was recorded in S_2 (43.33 cm) which was followed by S_1 (32.30 cm). Lowest root length of 27.49 cm was recorded in S_3.

It is concluded that top ventilated polyhouse (S_2) had significant influence on root length irrespective of the age of the plants.

T x S interactions was found to be significant in six month old plants. Significantly higher root length was recorded in T_4S_2 (41.73 cm) which was followed by T_5S_2 (35.90 cm) and was on par with T_4S_3 (32.56 cm), T_2S_1 (32.42 cm), T_2S_2 (31.90 cm) and T_6S_2 (31.83 cm). Minimum root length of 17.10 cm was recorded under T_5S_3. In three year old plants, the interaction T_3S_2 recorded significantly higher root length (67.87 cm) followed by T_4S_2 (48.73 cm). The treatment combination T_4S_2 was on par with T_3S_1 (46.73 cm), T_2S_2 (39.88 cm), T_1S_2 (39.68 cm), T_5S_2 (38.62 cm) and T_2S_3 (38.38 cm). Lowest root length of 17.75 cm was recorded under T_6S_3.

It is inferred that in six month old plants, the combination of POP + OM + VW + PGPRE + Bone meal + GR (T_4) and POP + OM + VW + PGPRE + Bone meal (T_3) in three year old plants recorded significantly higher root length in top ventilated polyhouse (S_2).

4.4.3 Root volume

Analysis of data corresponding to root volume in six month old and three year plants is presented in Tables 14 and 15.

The treatments had significant influence on root volume. In six month old plants, highest root volume was recorded in T_6 (16.34 m^3) which was on par with T_4 (15.40 m^3), T_3 (14.38 m^3) and T_2 (14.14 m^3). Lowest root volume of 11.22 m^3 was recorded in T_1 which was on par with T_5 (13.29 m^3). In three year old plants, highest root volume was recorded in T_6 (14.19 m^3) which was on par with T_2 (13.89 m^3) and T_3 (13.58 m^3). Lowest root volume of 7.08 m^3 was recorded in T_1.

It is concluded that the treatment NPK + GR + OM + VW + PGPRE + Bone meal (T_6) recorded highest root volume in both stages of plants.

Two level shade house (S_1)

Two level shade house (S_1)

Toventilated polyhouse (S_2)

Top ventilated polyhouse (S_2)

Fan and pad system (S_3)

Fan and pad system (S_3)

Plate 12. Influence of growing systems on root volume (m^3)

Growing systems had significant influence on root volume. In six month old plants, significantly higher root volume of 17.14 m^3 was recorded in S_2 which was followed by S_1 (14.29 m^3). System S_3 recorded lowest root volume of 10.94 m^3. In three year old plants, significantly higher root volume of 19.16 m^3 was recorded in S_2 which was followed by S_1 (9.51 m^3). Lowest root volume of 7.39 m^3 was recorded in S_3. It is concluded that top ventilated polyhouse (S_2) had significant influence on root volume irrespective of the age of the plants.

T x S interactions was found to be significant. In six month old plants, significantly higher root volume of 26.67 m^3 was recorded in the combination T_4S_2 which was followed by T_6S_1 (21.00 m^3). The interaction T_6S_1 was on par with T_6S_3 (20.67 m^3), T_3S_2 (20.50 m^3), T_2S_2 (19.83 m^3) and T_5S_2 (17.33 m^3). Lowest root volume of 6.67 m^3 was recorded in T_4S_3. In three year old plants, T_3S_2 recorded significantly higher root volume (25.07 m^3) which was followed by T_2S_2 (21.67 m^3) and T_4S_2 (21.50 m^3). Lowest root volume of 4.67 m^3 was recorded under T_1S_3.

It is inferred that in six month old plants, the combination of POP + OM + VW + PGPRE + Bone meal + GR (T_4) and POP + OM + VW + PGPRE + Bone meal (T_3) in three year old plants recorded significantly higher root volume in top ventilated polyhouse (S_2).

4.4.4 Root colonization of *Piriformospora indica*

Analysis of data pertaining to root colonization of *P. indica* in six month old and three year plants is presented in Tables 14 and 15.

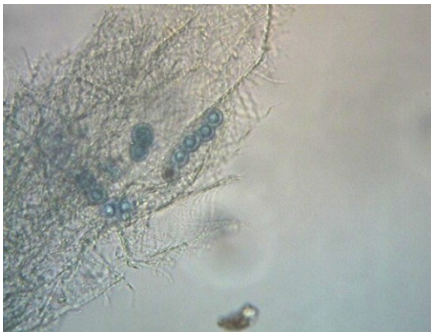
Treatments had significant influence on root colonization of *P. indica*. In six month old plants, the treatment T_4 recorded significantly higher value of 66.63 per cent which was on par with T_6 (61.48 per cent) (Plate 13). Lowest value for root colonization of *P. indica* was recorded in T_2 (34.07 per cent) which was on par with T_3 (41.48 per cent). In three year old plants, highest root colonization of 49.38 per cent was recorded in T_6 which was on par with T_4 (47.90 per cent). Lowest value for root colonization (21.98 per cent) was recorded in T_2.

Table 14. Influence of plant growth promoters (T), growing systems (S) and T x S interaction on root parameters in six month old plants of *Dendrobium* cv. Earsakul at the time of flower bud formation

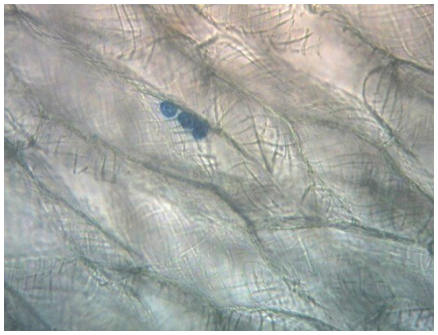
Treatments	Number of roots per plant				Root length (cm)				Root volume (m^3)				Root colonization (%)			
	S_1	S_2	S_3	Mean	S_1	S_2	S_3	Mean	S_1	S_2	S_3	Mean	S_1	S_2	S_3	Mean
T_1	62.67	68.17	57.66	62.83	21.50	17.68	26.73	21.97	13.50	11.17	9.00	11.22	0.00	0.00	0.00	0.00
T_2	85.17	79.33	52.56	72.35	32.42	31.90	18.73	27.68	12.58	19.83	10.00	14.14	31.10	48.90	22.22	34.07
T_3	101.10	85.17	61.83	82.70	30.47	29.57	21.53	27.19	13.97	20.50	8.67	14.38	51.10	57.77	15.55	41.48
T_4	68.50	106.83	48.00	74.44	27.76	41.73	32.56	34.01	12.83	26.67	6.67	15.40	79.91	84.44	35.55	66.63
T_5	73.17	92.67	56.33	74.05	21.20	35.90	17.10	24.73	11.88	17.33	10.67	13.29	0.00	0.00	0.00	0.00
T_6	83.67	101.83	87.50	91.00	25.25	31.83	21.40	26.16	21.00	7.37	20.67	16.34	71.10	62.23	51.17	61.48
Mean	79.04	89.00	60.65		26.43	31.44	23.00		14.29	17.14	10.94		58.30	63.34	31.11	
CD (0.05)	T: 6.71 S: 4.75 T x S: 11.63				T: 2.68 S: 1.89 T x S: 4.64				T: 2.79 S: 1.97 T x S: 4.83				T: 8.26 S: 7.16 T x S: 14.32			

Table 15. Influence of plant growth promoters (T), growing systems (S) and T x S interaction on root parameters in three year old plants at the time of flower bud formation

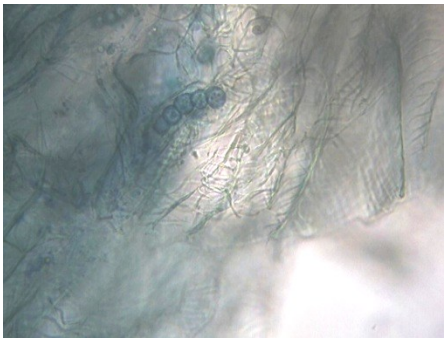
Treatments	Number of roots per plant				Root length (cm)				Root volume (m^3)				Root colonization (%)			
	S_1	S_2	S_3	Mean	S_1	S_2	S_3	Mean	S_1	S_2	S_3	Mean	S_1	S_2	S_3	Mean
T_1	56.00	67.50	53.71	59.07	27.33	39.68	28.62	31.88	7.17	9.40	4.67	7.08	0.00	0.00	0.00	0.00
T_2	95.67	87.67	37.33	73.56	32.83	39.88	38.38	37.03	13.33	21.67	6.67	13.89	24.45	30.37	11.11	21.98
T_3	88.00	106.17	34.33	76.17	46.73	67.87	26.58	47.06	8.33	25.07	7.33	13.58	30.36	28.15	22.22	26.91
T_4	56.83	119.00	37.93	71.25	27.73	48.73	24.72	33.73	6.83	21.50	6.33	11.56	55.55	50.37	37.77	47.90
T_5	37.57	86.50	29.00	51.02	31.50	38.62	28.88	33.00	7.00	20.83	7.67	11.83	0.00	0.00	0.00	0.00
T_6	67.83	101.67	69.67	79.72	27.70	25.17	17.75	23.54	14.40	16.50	11.67	14.19	49.62	56.30	42.22	49.38
Mean	66.98	94.75	43.66		32.30	43.33	27.49		9.51	19.16	7.39		39.99	41.30	28.33	
CD (0.05)	T: 11.30 S: 7.99 T x S: 19.57				T: 6.04 S: 4.27 T x S: 10.47				T: 2.21 S: 1.56 T x S: 3.83				T: 4.85 S: 4.20 T x S: 8.40			



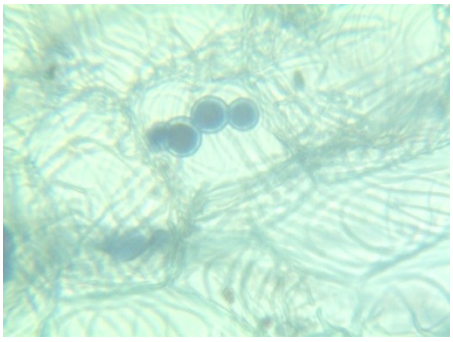
POP+OM+VW+PGPRE+Bone meal+GR (T_4) Bone meal (66.63 per cent)



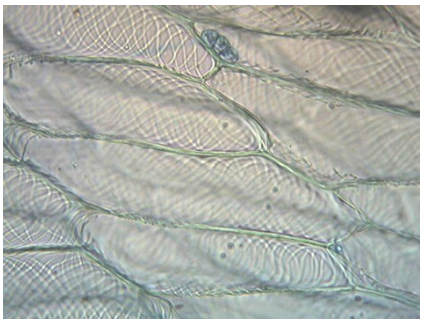
NPK+GR+OM+VW+PGPRE+ (T_6) (49.38 per cent)



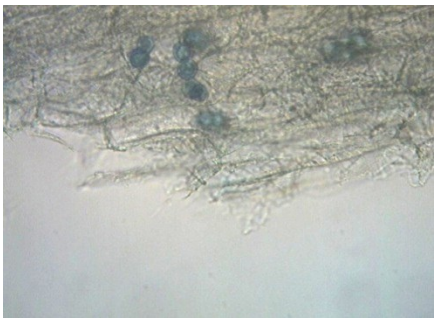
NPK+GR+OM+VW+PGPRE+ Bone meal (T_6) meal+GR (61.48 per cent)



POP+OM+VW+PGPRE+Bone (T_4) (47.90 per cent)



POP+PGPRE+Bone meal (T_2) (34.07 per cent)



POP+PGPRE+Bone meal (T_2) (21.98 per cent)

Plate 13. Influence of treatments on root colonization of *Piriformospora indica*

It is concluded that the treatment POP + OM + VW + PGPRE + Bone meal + GR (T_4) in six month old plants and NPK + GR + OM + VW + PGPRE + Bone meal (T_6) in three year old plants recorded highest root colonization of *P. indica.*

Growing systems had significant influence on root colonization of *P. indica*. In six month old plants, highest value of 63.34 per cent was recorded in S_2 which was on par with S_1 (58.30 per cent). System S_3 recorded minimum root colonization of 31.11 per cent. In three year old plants, highest root colonization of *P. indica* was recorded in S_2 (41.30 per cent) which was on par with S_1 (39.99 per cent). Lowest root colonization of 28.33 per cent was recorded in S_3.

It is concluded that top ventilated polyhouse (S_2) had significant influence on root colonization of *P. indica* irrespective of the age of the plants.

T x S interaction was found to be significant. In six month old plants, highest root colonization of *P. indica* was recorded in T_4S_2 (84.44 per cent) which was on par with T_4S_1 (79.91 per cent) and T_6S_1 (71.10 per cent). Lowest value for root colonization (15.55 per cent) was recorded in T_3S_3. In three year old plants, the combination of T_6S_2 recorded significantly higher value for root colonization (56.30 per cent) which was on par with T_4S_1 (55.55 per cent), T_4S_2 (50.37 per cent) and T_6S_1 (49.62 per cent). Lowest value for root colonization (11.11 per cent) was recorded in T_2S_3.

It is concluded that the treatment POP + OM + VW + PGPRE + Bone meal + GR (T_4) and NPK + GR + OM + VW + PGPRE + Bone meal (T_6) had more influence on root colonization of *P. indica* in top ventilated poly house (S_2) irrespective of age of the plants.

4.5 Nutrient content

Various observations on nutrient content at different combination of plant growth promoters (treatments) under three growing systems *viz*., two level shade house (S_1), top ventilated poly house (S_2) and fan and pad system (S_3) of plants in two stages of plant growth *viz*., six month old and three year old plants were recorded, analyzed

and the results are presented in Tables 16 and 17. The data on nutrient content were recorded at the time of flower bud formation.

4.5.1 Nitrogen

Analysis of data corresponding to N content in six month old plants and three year old is presented in Tables 16 and 17.

Treatments had significant influence on N content of the plants. In six month old plants, the treatment T_4 recorded significantly higher N content (1.90 per cent) which was on par with T_5 (1.81 per cent). Lowest N content of 1.29 per cent was recorded in T_1 which was followed by T_2 (1.53 per cent). In three year old plants, treatment T_3 recorded significantly higher N content (1.94 per cent) which was on par with T_4 (1.80 per cent), T_6 (1.71 per cent) and T_2 (1.39 per cent). Lowest N content of 0.87 per cent was recorded in T_1 which was on par with T_5 (1.30 per cent) and T_2 (1.39 per cent).

It is concluded that the treatment POP + OM + VW + PGPRE + Bone meal + GR (T_4) in six month old plants and POP + OM + VW + PGPRE + Bone meal (T_3) in three year old plants recorded significantly higher N content.

Growing systems had significant influence on N content of the plants in six month old plants. Significantly higher N content was recorded in S_2 (1.82 per cent). Lowest N content of 1.57 per cent was recorded in S_1 (1.57 per cent) which was on par with S_3 (1.60 per cent). Growing systems had no significant influence on N content of the plants in three year old plants.

It is concluded that top ventilated polyhouse recorded significantly higher N content in six month old plants.

T x S interactions was found to be significant. In six month old plants, highest N content of 2.21 per cent was recorded in combination of T_4S_2 which was on par with T_4S_1 (2.15 per cent) and T_2S_2 (2.05 per cent). Lowest N content of 1.00 per cent was recorded in treatment combination T_1S_1. In three year old plants, highest N content of 2.38 per cent was recorded in combination of T_3S_1 which was on par with T_6S_2 (2.09

per cent), T_4S_3 (2.03 per cent), T_3S_2 (1.85 per cent), T_4S_1 (1.80 per cent), T_6S_1 (1.75 per cent), T_5S_2 (1.68 per cent), T_3S_3 (1.60 per cent), T_2S_1 (1.59 per cent) and T_4S_2 (1.56 per cent). Lowest N content of 0.57 per cent was recorded in T_1S_3.

It is concluded that the treatment POP + OM + VW + PGPRE + Bone meal + GR (T_4) and top ventilated polyhouse (S_2) in six month old plants and POP + OM + VW + PGPRE + Bone meal (T_3) and two level shade house (S_1) recorded highest N content in three year old plants.

4.5.2 Phosphorus

Analysis of data corresponding to P content in six month old and three year old plants is presented in Tables 16 and 17.

The treatments had significant influence on P content of the plants. In six month old plants, treatment T_4 recorded significantly higher P content of 0.25 per cent which was on par with T_6 (0.23 per cent). Lowest P content of 0.11 per cent was recorded in T_1 which was on par with T_2 (0.13 per cent) and T_3 (0.15 per cent). In three year old plants, treatment T_3 recorded significantly higher P content (0.21 per cent) which was on par with T_4 (0.19 per cent), T_6 (0.17 per cent), T_2 (0.14 per cent) and T_5 (0.12 per cent). Lowest P content of 0.10 per cent was recorded in T_1 which was on par with all other treatments except T_3.

It is concluded that the treatment POP + OM + VW + PGPRE + Bone meal + GR (T_4) in six month old plants and POP + OM + VW + PGPRE + Bone meal (T_3) in three year old plants recorded significantly higher P content.

Growing systems had significant influence on P content of the plants. In six month old plants, significantly higher P content of 0.22 per cent was recorded in S_2. Lowest P content of 0.15 per cent was recorded in S_3 which was on par with S_1 (0.16 per cent). In three year old plants, highest P content of 0.20 per cent was recorded in S_2 which was on par with S_1 (0.15 per cent). Lowest P content of 0.12 per cent was recorded in S_3 which was on par with S_1 (0.15 per cent).

It is concluded that top ventilated polyhouse (S_2) recorded significantly higher P content in both stages of plants.

T x S interactions on P content was found to be significant. In six month old plants, highest P content of 0.33 per cent was recorded in combination T_4S_2 which was followed by T_6S_2 (0.31 per cent), T_6S_3 (0.27 per cent), T_4S_1 (0.25 per cent) and T_5S_2 (0.24 per cent). The interaction T_1S_1 recorded lowest P content of 0.10 per cent. T x S interaction had no significant influence on P content of the plants in three year old plants.

It is concluded that the treatment POP + OM + VW + PGPRE + Bone meal + GR (T_4) and top ventilated polyhouse (S_2) recorded highest P content in six month old plants.

4.5.3 Potassium

Analysis of the data corresponding to K content in six month old and three year plants is presented in Tables 16 and 17.

Treatments had significant influence on K content of the plants. In six month old plants, treatment T_4 recorded significantly higher K content (1.47 per cent) which was on par with T_6 (1.46 per cent), T_3 (1.28 per cent) and T_5 (1.13 per cent). Lowest K content of 0.88 per cent was recorded in T_1 which was on par with T_2 (1.05 per cent), T_5 (1.13 per cent) and T_3 (1.28 per cent). In three year old plants, treatment T_4 recorded significantly higher K content (1.25 per cent) which was on par with T_6 (1.17 per cent), T_3 (1.16 per cent) and T_1 (1.12 per cent). The treatment T_5 recorded lowest K content (0.90 per cent) which was on par with T_2 (0.97 per cent).

It is concluded that the treatment POP + OM + VW + PGPRE + Bone meal + GR (T_4) recorded significantly higher K content irrespective of age of the plants.

Growing systems had no significant influence on K content of the plants in six month old plants. In three year old plants, growing systems had significant influence on K content. Highest K content of 1.22 per cent was recorded under S_2 which was on par

Table 16. Influence of plant growth promoters (T), growing systems (S) and T x S interaction on nutrient content in six month old plants of *Dendrobium* cv. Earsakul at the time of flower bud formation

Treatments	Nitrogen (%)				Phosphorus (%)				Potassium (%)			
	S_1	S_2	S_3	Mean	S_1	S_2	S_3	Mean	S_1	S_2	S_3	Mean
T_1	1.00	1.20	1.68	1.29	0.10	0.13	0.10	0.11	0.76	0.87	1.00	0.88
T_2	1.26	2.05	1.27	1.53	0.15	0.12	0.12	0.13	0.86	1.00	1.28	1.05
T_3	1.96	1.69	1.57	1.74	0.18	0.16	0.12	0.15	1.23	1.33	1.28	1.28
T_4	2.15	2.21	1.34	1.90	0.25	0.33	0.17	0.25	1.63	1.63	1.15	1.47
T_5	1.82	1.79	1.81	1.81	0.15	0.24	0.15	0.18	1.46	1.23	0.70	1.13
T_6	1.21	1.98	1.97	1.72	0.11	0.31	0.27	0.23	1.36	1.51	1.52	1.46
Mean	1.57	1.82	1.60		0.16	0.22	0.15		1.21	1.26	1.15	
CD (0.05)	T: 0.10 S: 0.03 T x S: 0.17				T: 0.05 S: 0.04 T x S: 0.09				T: 0.40 S: NS T x S: 0.70			

Table 17. Influence of plant growth promoters (T), growing systems (S) and T x S interaction on nutrient content in three year old plants of *Dendrobium* cv. Earsakul at the time of flower bud formation

Treatments	Nitrogen (%)				Phosphorus (%)				Potassium (%)			
	S_1	S_2	S_3	Mean	S_1	S_2	S_3	Mean	S_1	S_2	S_3	Mean
T_1	0.78	1.25	0.57	0.87	0.10	0.10	0.10	0.10	1.07	1.11	1.19	1.12
T_2	1.59	1.34	1.23	1.39	0.10	0.22	0.10	0.14	0.79	1.08	1.04	0.97
T_3	2.38	1.85	1.60	1.94	0.27	0.24	0.13	0.21	1.26	1.18	1.05	1.16
T_4	1.80	1.56	2.03	1.80	0.15	0.27	0.15	0.19	1.14	1.40	1.21	1.25
T_5	1.18	1.68	1.04	1.30	0.10	0.16	0.10	0.12	0.65	1.04	1.01	0.90
T_6	1.75	2.09	1.28	1.71	0.17	0.18	0.17	0.17	1.16	1.49	0.87	1.17
Mean	1.58	1.63	1.29		0.15	0.20	0.12		1.01	1.22	1.06	
CD (0.05)	T: 0.56 S: NS T x S: 0.97				T: 0.09 S: 0.07 T x S: NS				T: 0.25 S: 0.18 T x S: 0.43			

S_1- Two level shade house, S_2- Top ventilated poly house, S_3- Fan and pad system

with S_3 (1.06 per cent). Growing system S_1 recorded lowest K content (1.01 per cent) which was on par with S_3 (1.06 per cent).

It is concluded that top ventilated polyhouse (S_2) recorded highest K content in three year old plants.

T x S interactions had significant influence on K content. In six month old plants, highest K content of 1.63 per cent was recorded under combination of T_4S_2 which was on par with all other interactions except T_1S_2 (0.87 per cent), T_2S_1 (0.86 per cent), T_1S_1 (0.76 per cent) and T_5S_3 (0.70 per cent). The interaction T_5S_3 recorded lowest K content of 0.70 per cent. In three year old plants, T_6S_2 recorded significantly higher K content (1.49 per cent) which was on par with T_4S_2 (1.40 per cent), T_3S_1 (1.26 per cent), T_4S_3 (1.21 per cent), T_1S_3 (1.19 per cent), T_3S_2 (1.18 per cent), T_6S_1 (1.16 per cent), T_4S_1 (1.14 per cent), T_1S_2 (1.11 per cent), T_2S_2 (1.08 per cent) and T_1S_1 (1.07 per cent). The interaction T_5S_1 recorded lowest K content of 0.65 per cent.

It is concluded that the treatment POP + OM + VW + PGPRE + Bone meal + GR (T_4) in six month old plants and NPK + GR + OM + VW + PGPRE + Bone meal (T_6) in three year old plants recorded significantly higher K content in top ventilated polyhouse (S_2).

4.6. Study on symbiotic interactions between *Dendrobium* cv. Earsakul and PGPRE (*Piriformospora indica)*

4.6.1. Radio isotope labelling (^{32}P) to study the functional linkage between the host and *Piriformospora indica*

The fungus was radio labeled with ^{32}P and the radio assay was conducted for the presence of ^{32}P in the plant. The brief information on the details and result of autoradiography is furnished in the table 18.

Autoradiography showed that the orchid roots absorbed ^{32}P from the source i.e. when labelled $N:P_2O_5:K_2O$ (1:2:2) nutrient solution applied to the media inoculated with non labelled fungus (T_3). The image of the root (Plate 14 and 15) indicated that,

^{32}P had moved through root from the source of application and translocated into the root tissues. Plants treated with treatment T_1 and T_2 did not give any image (Table 18).

Radio assay

Distribution pattern of ^{32}P assimilate partitioning in various plant parts of *Dendrobium* cv. Earsakul are summarized in Table 18.

Results of the radio assay from the table showed variation in radioactive counts of ^{32}P in different parts of the plant. The radioactivity was higher in pseudo bulb portion than in roots and leaves of the *Dendrobium* cv. Earsakul.

Highest radioactivity (240.27 cpm g^{-1}) was recorded in the leaves of the plants where labelled $KH_2{}^{32}PO_4$ applied to the media inoculated with non-labelled fungus (T_1). Lowest radioactivity (209.39 cpm g^{-1}) was recorded in T_2. However, plants which are treated with labeled $N:P_2O_5:K_2O$ (1:2:2) nutrient solution applied to the media inoculated with non labeled fungus (T_3) showed radioactivity of 235.18 cpm g^{-1}. This would suggest that the fungus acted as the extension of the root system enhancing the nutrient absorption.

The radio assay study in case of the plants which are inoculated with labeled fungus indicated from the table that, among plant parts, radioactivity was higher (362.21 cpm g^{-1} and 1638.93 cpm g^{-1}) in pseudobulb portion in treatments T_4 and T_6, respectively. While, highest radioactivity of 530.11 cpm g^{-1} was recorded in roots of the treatment T_5 compared to leaves and pseudo bulb. The treatments T_4 and T_6 recorded lower radioactivity of 253.07 cpm g^{-1} and 245.36 cpm g^{-1}, respectively in roots (Table 18).

4.6.2. Anatomical studies in roots for structural linkage between host (*Dendrobium* cv. Earsakul) and PGPRE (*Piriformospora indica*)

After inoculation, in *Dendrobium* cv. Earsakul roots, hyphae of the *Piriformospora indica* entered into the tissue of the root through the root tip (Plate 16a). Hyphae, first touching the root surface (Plate 16b) entered through velamen tissue (Plate 16c). In the inoculated plants, the hyphal growth of the fungus was detected on

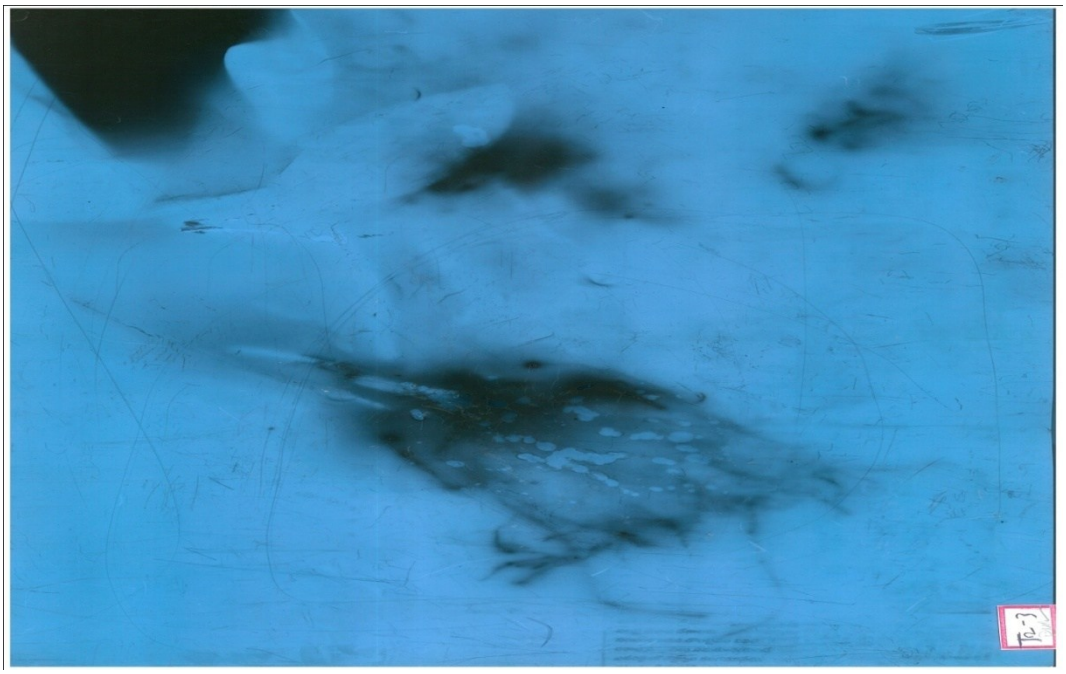


Plate 14. Autoradiography showing ^{32}P labelled fungus in orchid roots (T_2).

Plate 15. Autoradiography showing ^{32}P labelled fungus in orchid roots (T_3)

Table 18. Distribution pattern of ^{32}P assimilate partitioning in *Dendrobium* cv. Earsakul

Treatments	Details of the treatment	Autoradiography	Radioassay	
			Plant parts digested	Radioactive counts (cpm g^{-1})
T_1	Labelled $KH_2{}^{32}PO_4$ applied to the roots inoculated with non labeled fungus (1.7 µ Ci)	No image in X ray film	Leaves	240.27
T_2	Labelled $KH_2{}^{32}PO_4$ applied to the roots without fungus (1.7 µ Ci)	No image in X ray film	Leaves	209.39
T_3	Labelled $N:P_2O_5:K_2O$ (1:2:2) nutrient solution applied to the roots inoculated with non labelled fungus (2.4 µ Ci)	Image in X ray film was observed	Leaves	235.18
T_4	Inoculated with labelled fungus (1.29 µ Ci)	-	Roots	253.07
			Pseudobulb	362.21
			Leaves	287.21
T_5	Inoculated with labelled fungus (1.94 µ Ci)	-	Roots	530.11
			Pseudobulb	325.95
			Leaves	364.35
T_6	Inoculated with labelled fungus (2.58 µ Ci)	-	Roots	245.36
			Pseudobulb	1638.93
			Leaves	575.91

Plate 16. Anatomical studies in roots for structural linkage between *Dendrobium* cv. Earsakul and *Piriformospora indica* (a PGPRE)

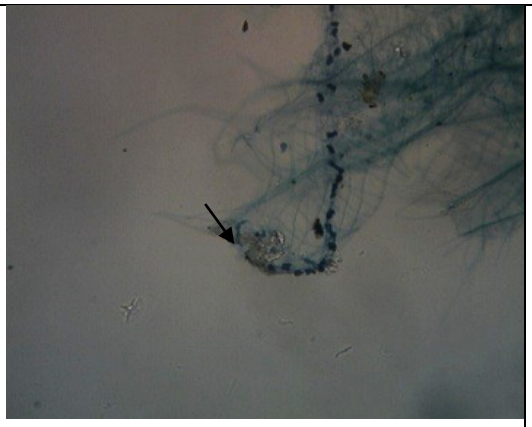


Plate 16 a. Fungus entry through root tip (60x)

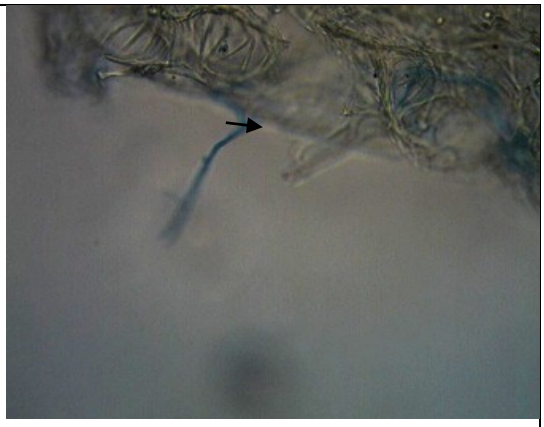


Plate 16 b. Hyphae touching the root surface (60x)

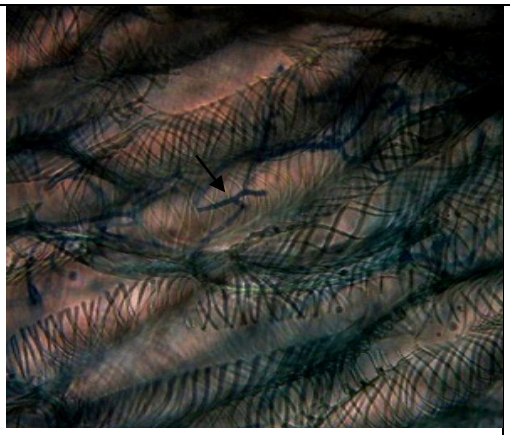


Plate 16 c. Fungus entry through velamen of the root tissue (60x)

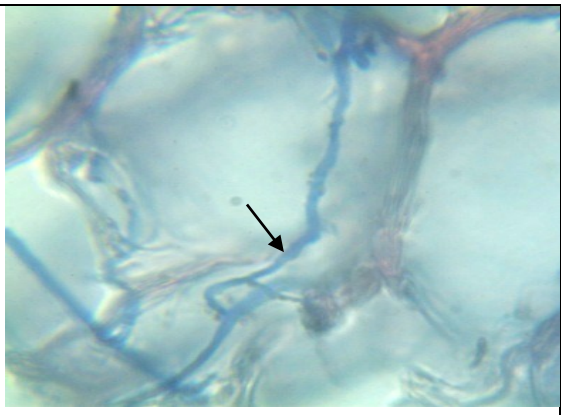


Plate 16 d. Hyphae of the fungus was detected in cortical cells (100x)

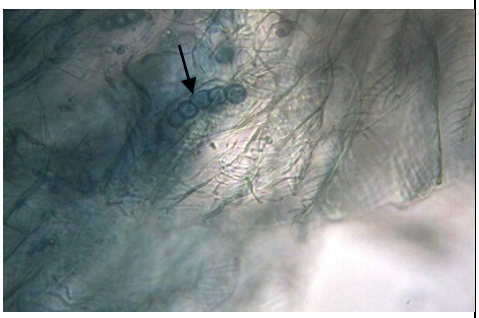


Plate 16 e.The fungus produced chlamydospores at the apex of undifferentiated hyphae (60x)

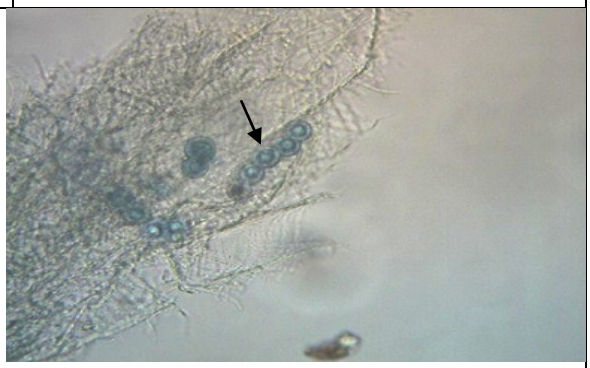


Plate 16 f. Pear-shaped chlamydospores in root tissue (60x)

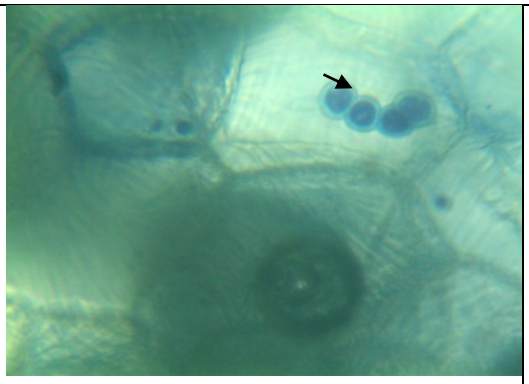


Plate 16 g. Cortical cells showing round bodies (60x)

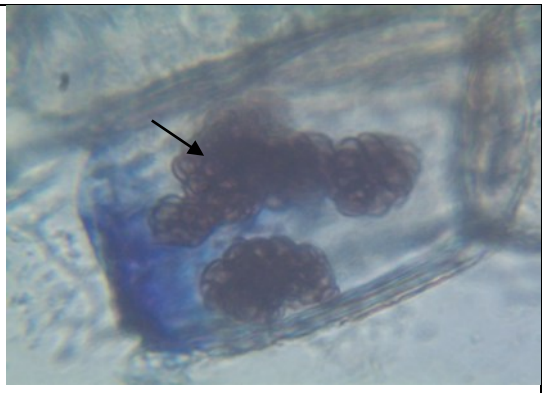


Plate 16 h. Cortical cells with highly coiled intracellular structures (60x)

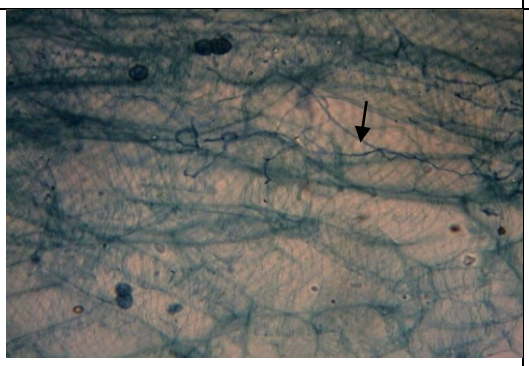


Plate 16 i. Fungus hyphae in cortical cells (40x)

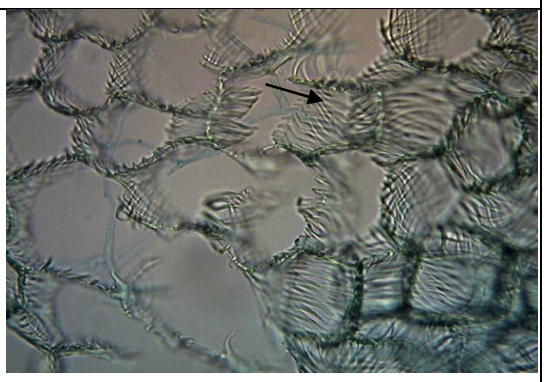


Plate 16 j. Fungus hyphae in cortical cells (60x)

the root surface between the outer cell layers of the cortex and within the cortical cells (Plate 16d). The fungus produced chlamydospores at the apex of undifferentiated hyphae (Plate 16e) and within the cortical cells of the root tissue (Plate 16f). The fungal hyphae invade the cortical cells and form tightly interwoven coils called 'pelotons' characteristic of orchid mycorrhizae. In the cortical cells of the roots, development of intracellular hyphal coils and round bodies could be observed (Plate 16g, 16h). Hyphae multiplied within the cortical tissues of the *Dendrobium* orchid and never traversed through endodermis (Plate 16i, 16j).

4.7. Correlation

Canonical correlation studies in six month old plants (Table 19) revealed that there was a significant correlation between growth and flower characters in all stages of growth under two level shade house (S_1) except in 6 MAP. It was observed that during all periods, there was significant correlation between growth and flower characters under top ventilated poly house (S_2). Correlation between growth and flower characters was not significant under fan and pad system (S_3). In three year old plants, correlation studies indicated no significant correlation under S_1 in all stages of growth (Table 19). When viewed independently, it was noted that at 18 MAT and 24 MAP, significant correlation existed under S_2 and S_3 (Table 19).

With regard to growth and root characters, in six month old plants, in all periods, significant correlation was observed between growth and root parameters under S_1 and S_2 (except 12 MAP) (Table 20). Under S_3, correlation was significant during the later stage of the crop growth (18, 24 MAP). In three year old plants, between growth and root parameters, during 12 MAP and 24 MAP, significant correlation was observed in S_1 and S_2, respectively (Table 20). In early stage of growth only (6 MAP), correlation was significant in S_3.

With regard to N,P and K, except during 6 MAP, 12 MAP in S_1 and 12 MAP in S_3, (Table 21) correlation between growth characters and N,P,K content was significant in S_1, S_2 and S_3. In three year old plants, except during 18 MAP under S_2, correlation was non significant under three growing systems (Table 21).

Table 19. Canonical correlation of growth characters (plant height, no. of leaves, no. of shoots, girth of shoot and internodal length) with flower characters (days to flowering, length of the spike, number of flowers, size of the flower and number of spikes per plant) in six month and three year old plants.

Month	Six month old plants			Three year old plants		
	S_1	S_2	S_3	S_1	S_2	S_3
6 MAP	0.85957	0.91007*	0.83067	0.75597	0.89150	0.84858
	0.57454	0.11634	0.65791	0.88184	0.34350	0.38155
12 MAP	0.92592*	0.97277*	0.83526	0.84551	0.74468	0.81120
	0.14167	0.00534	0.80100	0.21637	0.89408	0.68148
18 MAP	0.95391*	0.93924*	0.86112	0.84801	0.93068*	0.92594*
	0.04319	0.01797	0.21224	0.39794	0.08189	0.18144
24 MAP	0.94540*	0.94684*	0.88691	0.94341	0.92511*	0.95268*
	0.04239	0.02321	0.42157	0.16734	0.02091	0.03819

* Significant at 0.2 level

Table 20. Canonical correlation of growth characters with root parameters (number of roots, root length, root volume and root colonization) in six month and three year old plants.

Month	Six month old plants			Three year old plants		
	S_1	S_2	S_3	S_1	S_2	S_3
6 MAP	0.91296*	0.85951*	0.63537	0.76025	0.76605	0.82989*
	0.02690	0.04008	0.92123	0.77732	0.41200	0.13583
12 MAP	0.87691*	0.81935	0.69310	0.89621*	0.89704*	0.78095
	0.18822	0.26423	0.93251	0.00974	0.12348	0.50595
18 MAP	0.95276*	0.85346*	0.80483*	0.79602	0.72980	0.73433
	0.00230	0.01689	0.16034	0.33073	0.58675	0.72881
24 MAP	0.89768*	0.93220*	0.87020*	0.93585*	0.87788*	0.87492
	0.18883	0.00139	0.02144	0.00705	0.08208	0.28044

Table 21. Canonical correlation of growth characters with nutrient content (N,P,K) in six month and three year old plants

Month	Six month old plants			Three year old plants		
	S_1	S_2	S_3	S_1	S_2	S_3
6 MAP	0.78563	0.82892*	0.80337*	0.76199	0.65420	0.72882
	0.61573	0.10731	0.18655	0.38706	0.50637	0.52849
12 MAP	0.75273	0.76217*	0.69292	0.75128	0.77339	0.56608
	0.20486	0.16743	0.67731	0.30221	0.44546	0.81368
18 MAP	0.81823*	0.84812*	0.87483*	0.51096	0.76708*	0.64942
	0.10002	0.08110	0.12334	0.98973	0.10942	0.79280
24 MAP	0.84678*	0.83132*	0.77550*	0.79011	0.78163	0.65757
	0.06213	0.08121	0.08774	0.45274	0.42607	0.52579

S_1-Two level shade house, S_2- Top ventilated polyhouse, S_3- Fan and pad system

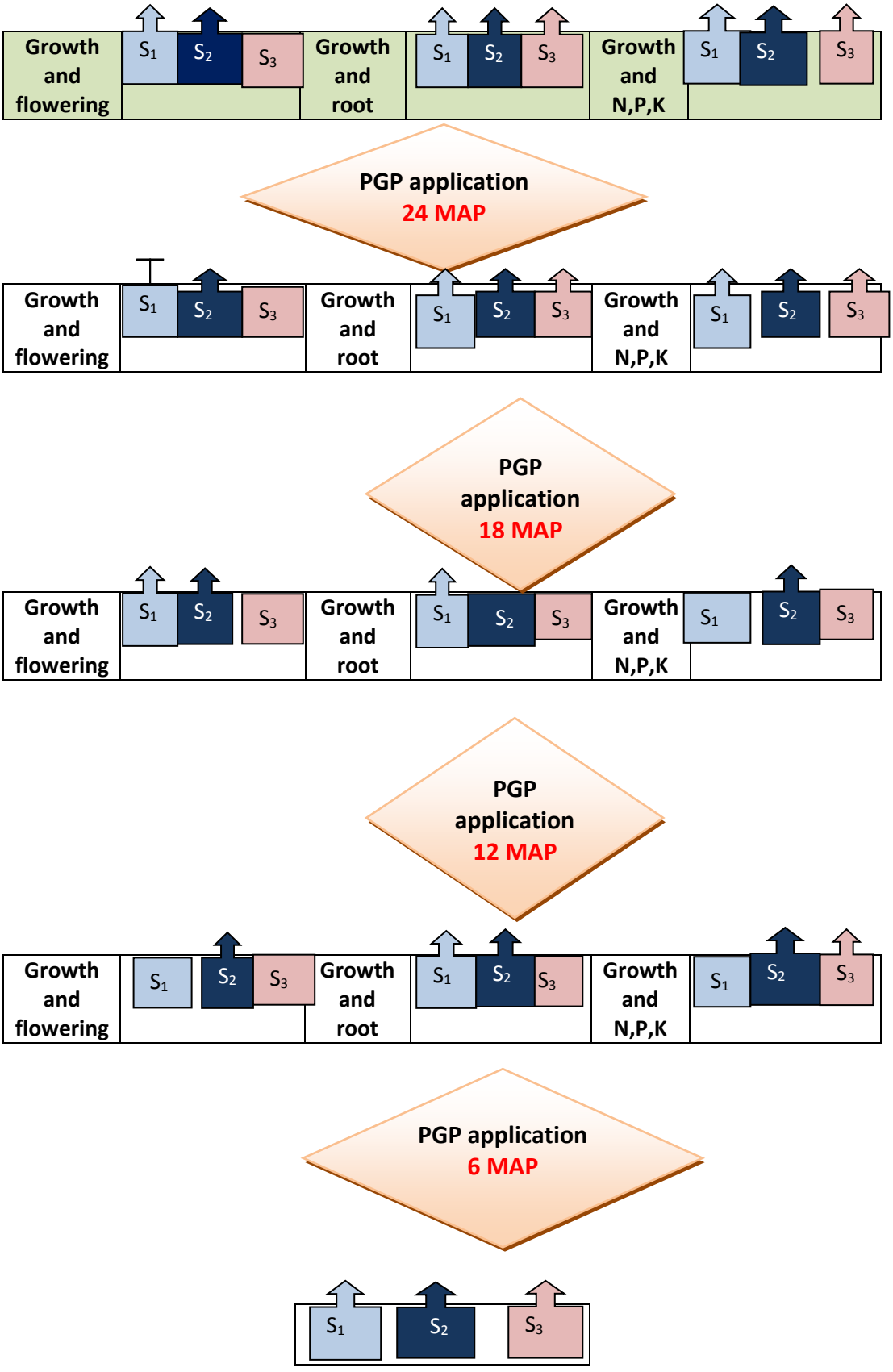


Plate 17. Correlation in six month old plants

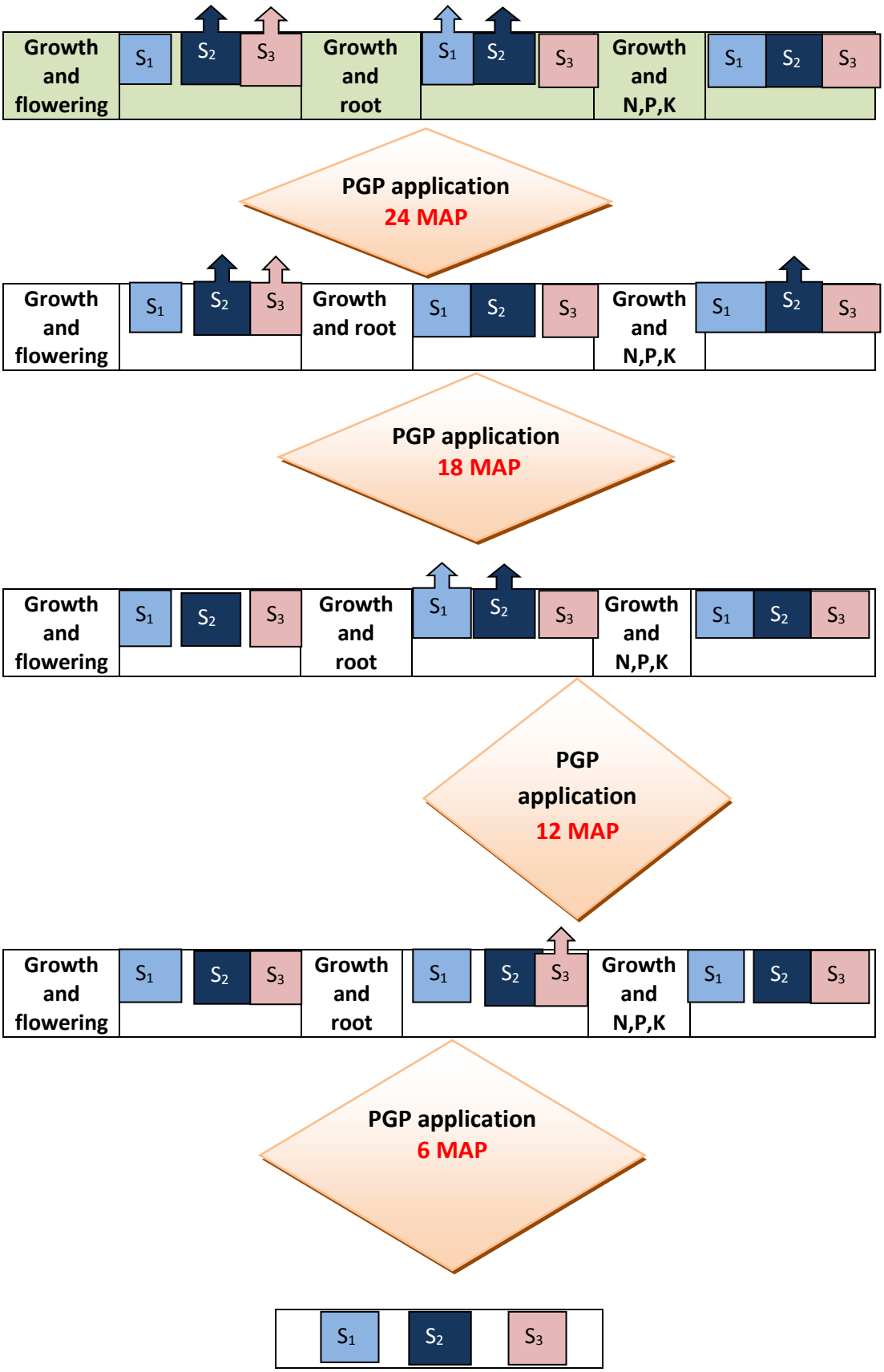


Plate 18. Correlation in three year old plants

Discussion

5. DISCUSSION

The results of the study pertaining to the influence of plant growth promoters on plants under three systems of growing are discussed under seven captions namely growth characters, flower characters, physiological parameters, content of nutrients, root parameters, study on symbiotic interactions and pest and disease incidence.

5.1 Growth characters

5.1.1 Plant height

Among various plant growth promoters used, the combination POP + OM + VW + PGPRE + Bone meal recorded the maximum plant height irrespective of the age of the plants (Tables 3a and 3b and Fig. 1, 3). As reported by Dhinesh (2009), the positive influence of combination of organic manures, inorganic nutrients and *P. indica* might have influenced plant height. Similar observations were made by Swapna (2000) and Kabir *et al*. (2012) in *Dendrobium.*

Out of the three systems of growing, the top ventilated polyhouse had the maximum influence on plant height irrespective of the age of the plants (Fig. 2 and 5). This could be attributed to the favourable environmental conditions like high temperature, high light intensity, low relative humidity (Appendix V) and proper air circulation inside the growing system. Proper shade (35-50 per cent) might also be possible reason for highest plant height. Working with *Dendrobium*, Samasya (2000), Fernandez (2001), Roychowdhary *et al*. (2004) and Leonhardt (2000) put forward similar results.

5.1.2 Number of leaves per plant

The study revealed that, the combination of POP + OM + VW + PGPRE + Bone meal + GR had maximum number of leaves per plant irrespective of the age of the plants (Tables 4a, 4b and Fig. 7, 11) The growth regulator cytokinin might have influenced the production of number of leaves per plant irrespective of the

Fig. 1. Influence of plant growth promoters (treatments) on plant height (cm) in six month old plants of *Dendrobium* cv. Earsakul

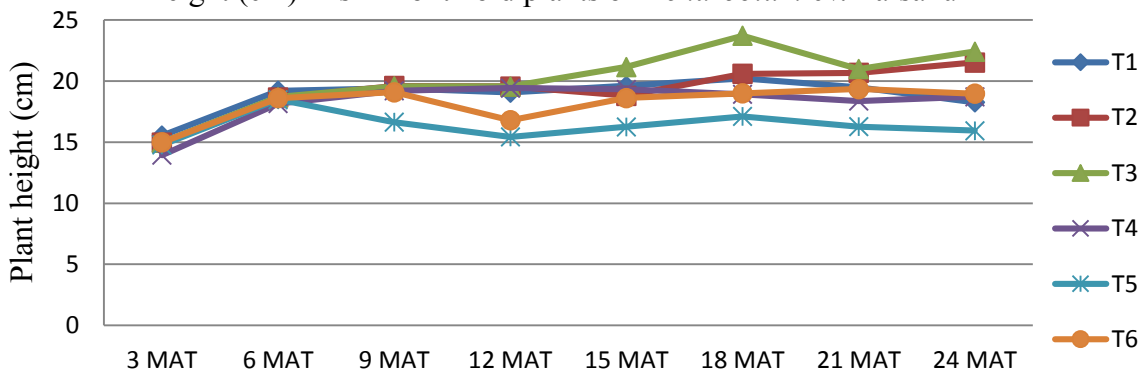


Fig. 2. Influence of growing systems on plant height (cm) in six month old plants of *Dendrobium* cv. Earsakul

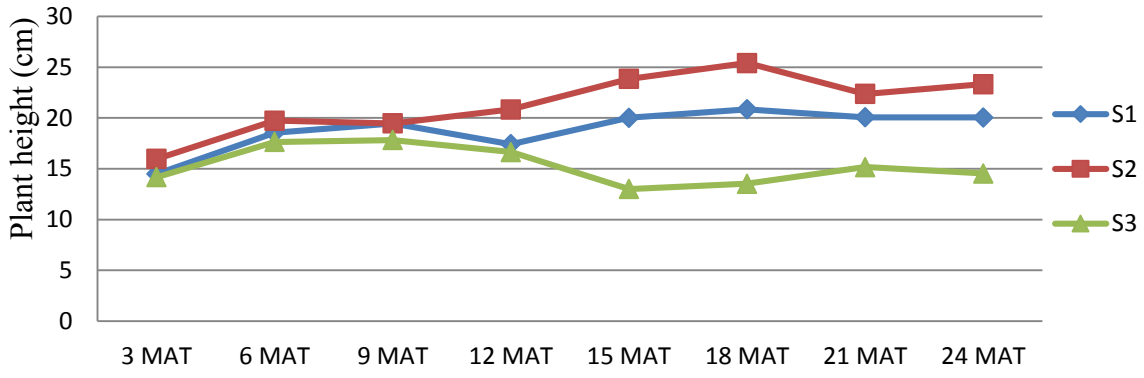


Fig. 3. Influence of treatment interactions on plant height (cm) in six month old plants of *Dendrobium* cv. Earsakul

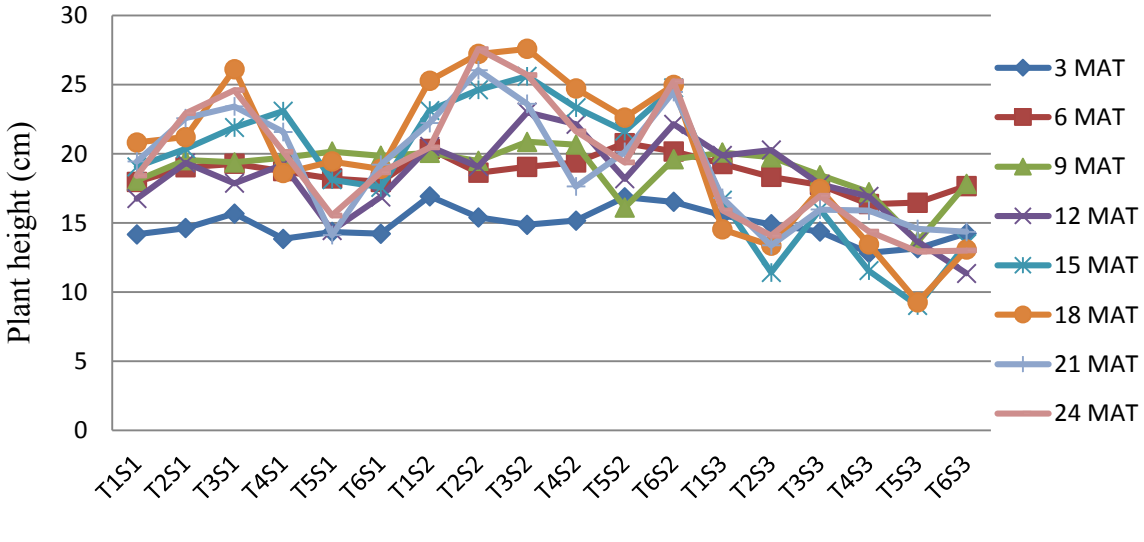


Fig. 4. Influence of plant growth promoters (treatments) on plant height (cm) in three year old plants of *Dendrobium* cv. Earsakul

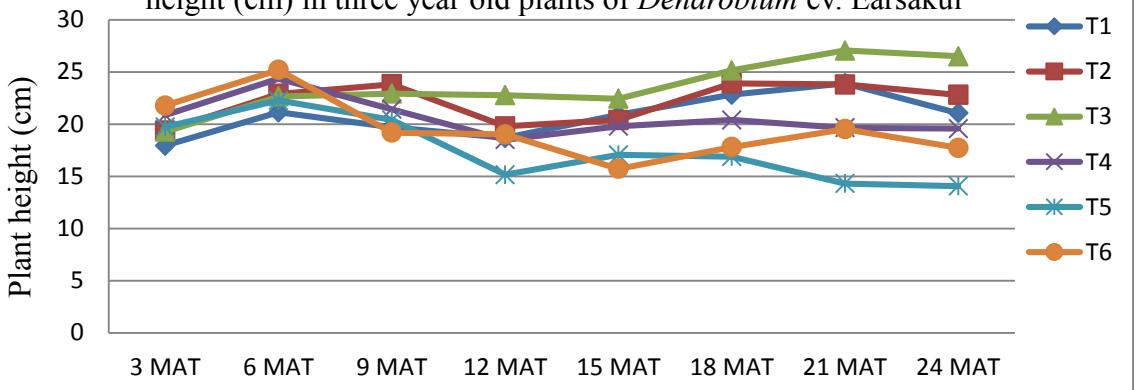


Fig. 5. Influence of growing systems on plant height (cm) in three year old plants of *Dendrobium* cv. Earsakul

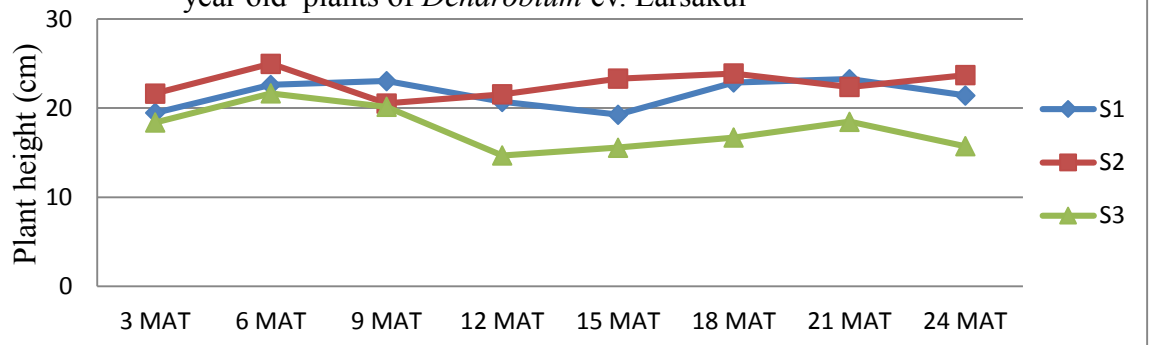


Fig. 6. Influence of treatment interactions on plant height (cm) in three year old plants of *Dendrobium* cv. Earsakul

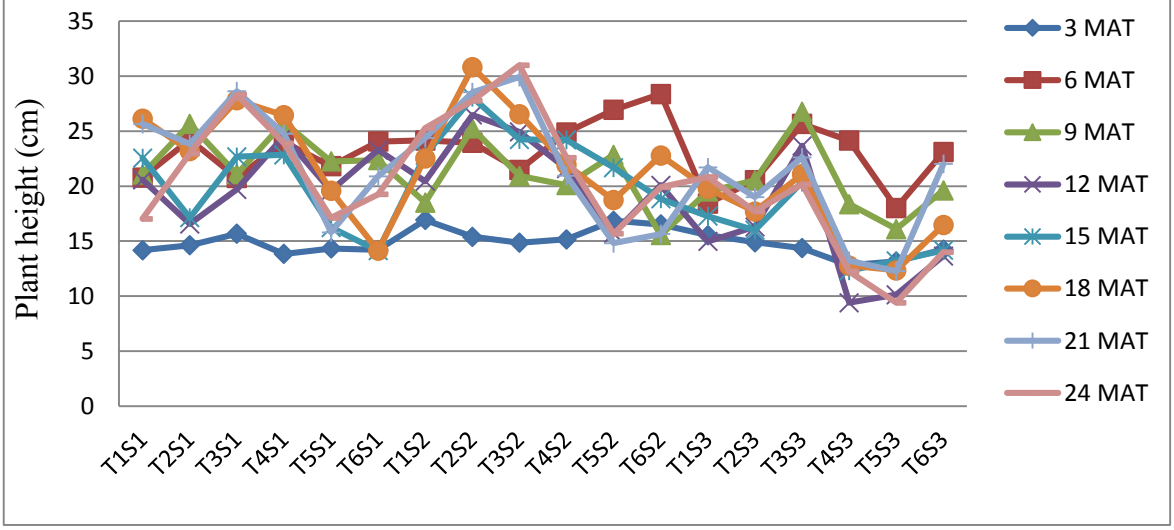


Fig. 7. Influence of plant growth promoters (treatments) on number of leaves in six month old plants of *Dendrobium* cv. Earsakul

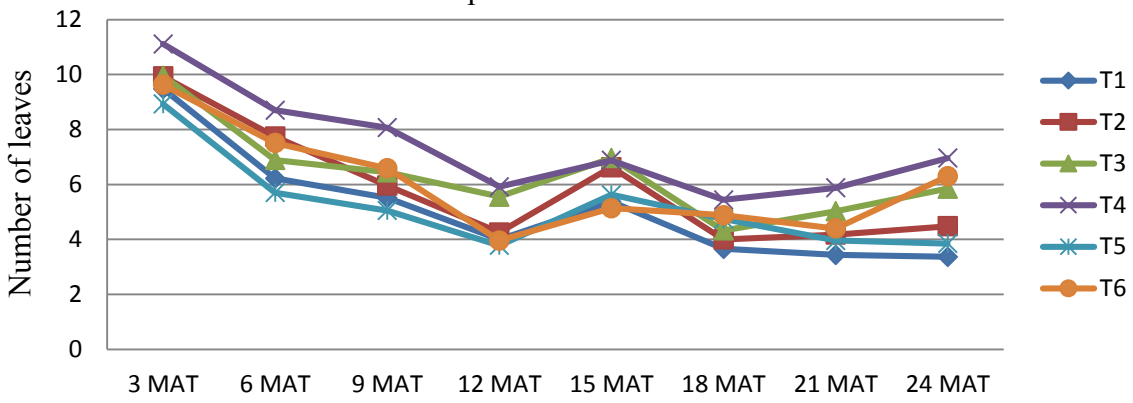


Fig. 8. Influence of growing systems on number of leaves in six month old plants of *Dendrobium* cv. Earsakul

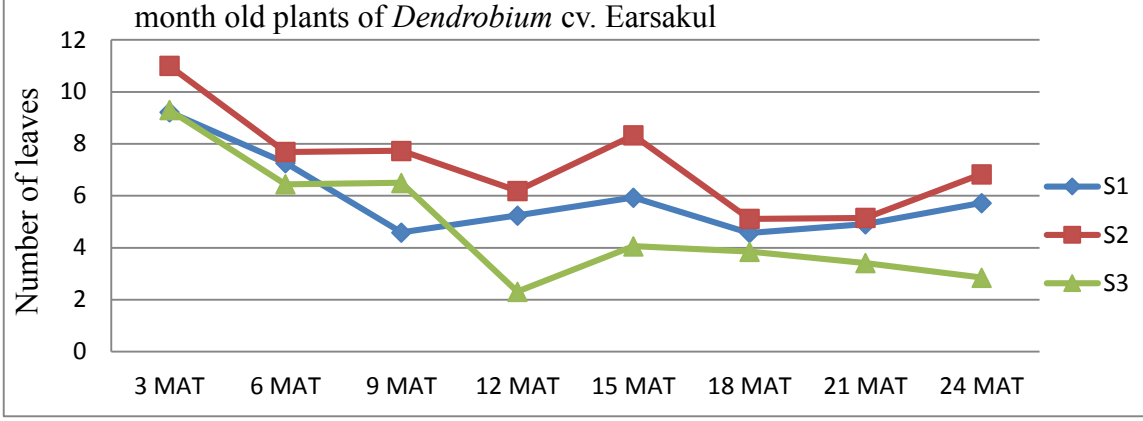


Fig. 9. Influence of treatment interactions on number of leaves in six month old plants of *Dendrobium* cv. Earsakul

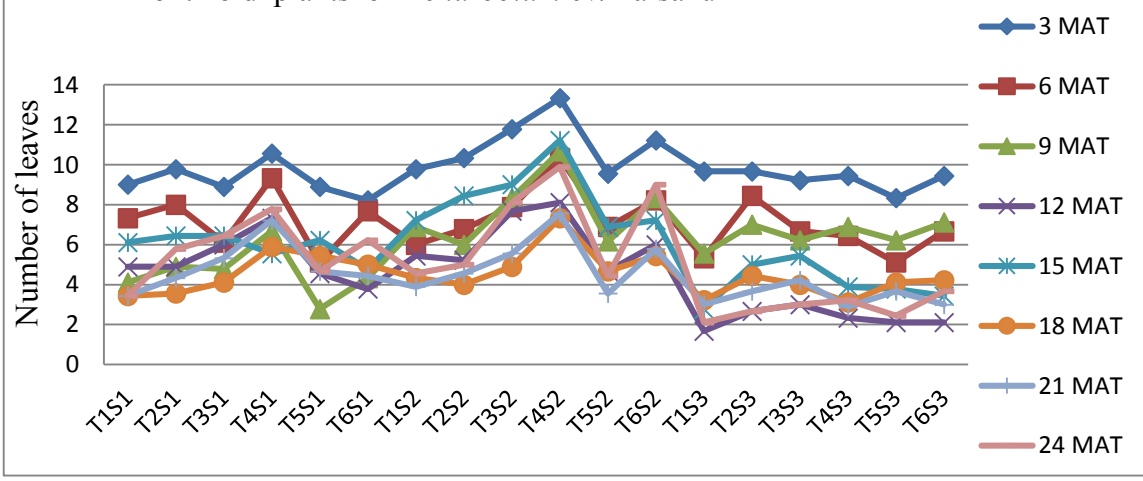


Fig. 10. Influence of plant growth promoters (treatments) on number of leaves in three year old plants of *Dendrobium* cv. Earsakul

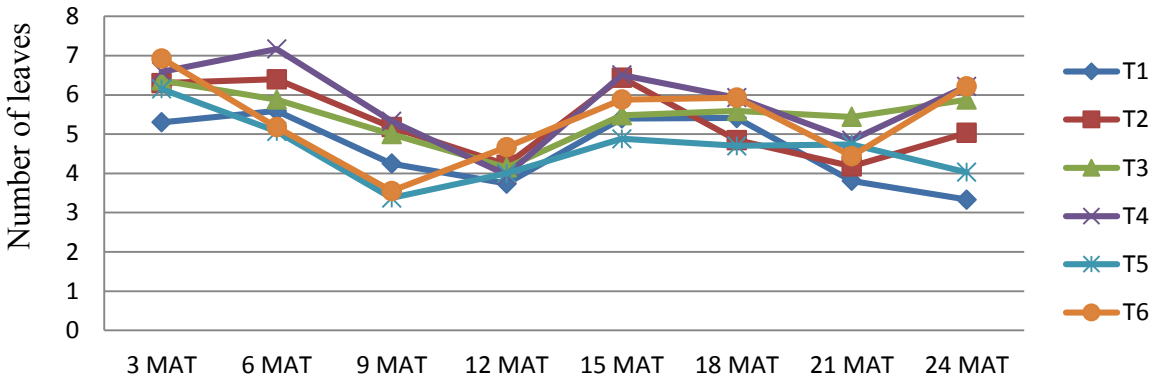


Fig. 11. Influence of growing systems on number of leaves in three year old plants of *Dendrobium* cv. Earsakul

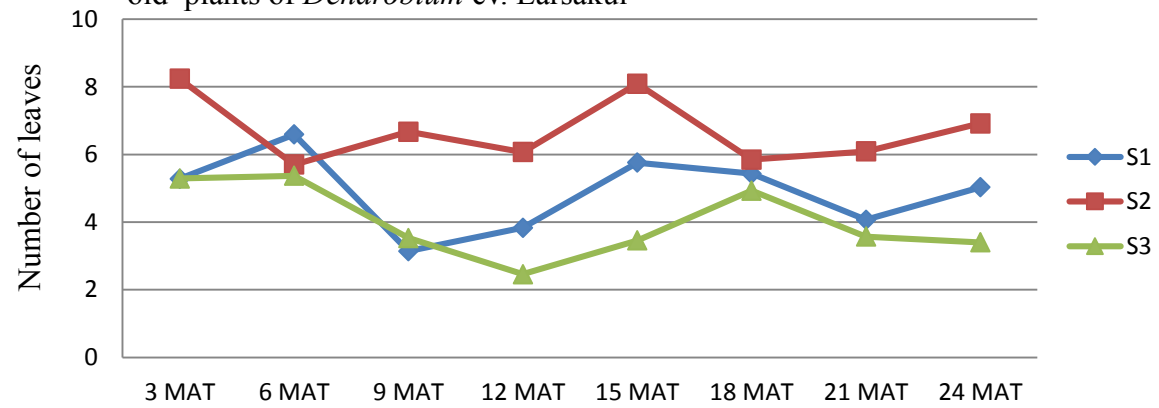
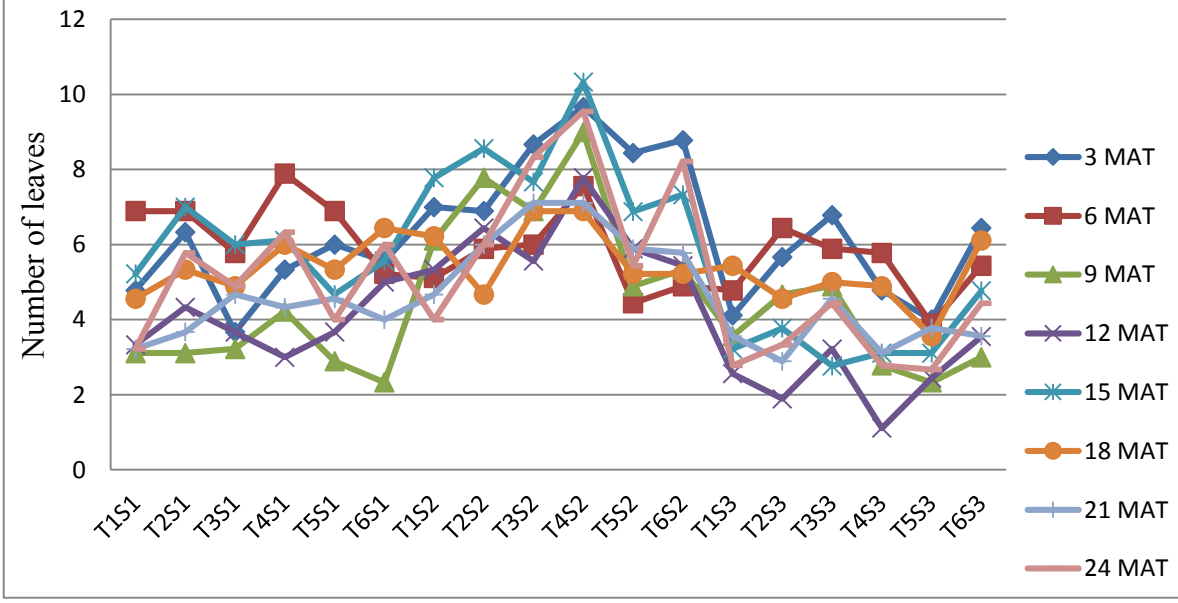


Fig. 12. Influence of treatment interactions on number of leaves in three year old plants of *Dendrobium* cv. Earsakul



age of plants as reported by Sobhana (2000), Swapna (2000), Binisha (2003) and Nair and Sujatha (2010) in *Dendrobium*.

Top ventilated polyhouse had significant influence on production of leaves per plant irrespective of the age of the plants as in the case of plant height (Fig. 8 and 11).

The combination of POP + OM + VW + PGPRE + Bone meal + GR under top ventilated polyhouse had maximum number of leaves per plant irrespective of age of the plant (Fig. 9, 12). This interaction effect result reinforces the effects of inorganic and organic manures + vermiwash has a positive influence under the congenial system of growing under top ventilated polyhouse with high temperature, light intensity and low relative humidity (Appendix V).

5.1.3 Number of shoots per plant

The combination of POP + OM + VW + PGPRE + Bone meal showed maximum number of shoots per plant in six month old plants (Table 5a and Fig. 13), whereas in three year old plants, the combination of POP + PGPRE + Bone meal recorded maximum number of shoots per plant (Table 5b and Fig.16). Application of *P. indica* induces growth of the root system and proportionately the shoot production also. In three year old plants also, the treatment POP + PGPRE + Bone meal application might have induced root system and the P from the bone meal also had synergetic effect in enhancing the shoot production. This is supported by Dhinesh (2009) in *Dendrobium*.

Among systems of growing, top ventilated polyhouse had significant influence on production of number of shoots per plant irrespective of the age of the plants (Fig. 14 and 17). Possible reason might be due to high light intensity (Appendix V) stimulating the growth and tillering of the plants. This is in accordance with the findings of Deinum *et al*. (1996) and Xia *et al*. (1999).

The interaction effect proved that the combination of POP + OM + VW + PGPRE + Bone meal and top ventilated polyhouse in six months old plants

(Fig. 15, 18). The reason for the result of production of higher number of shoots

Fig. 13. Influence of plant growth promoters (treatments) on number of shoots in six month old plants of *Dendrobium* cv. Earsakul

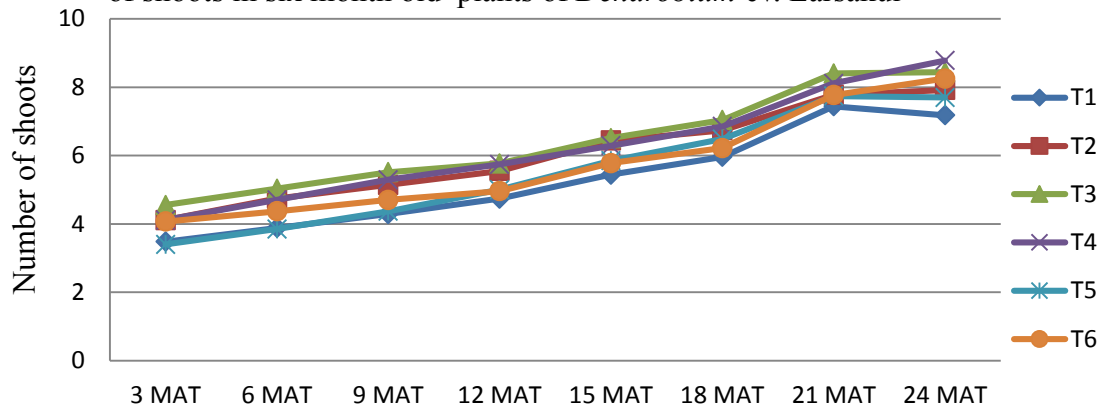


Fig. 14. Influence of growing systems on number of shoots in six month old plants of *Dendrobium* cv. Earsakul

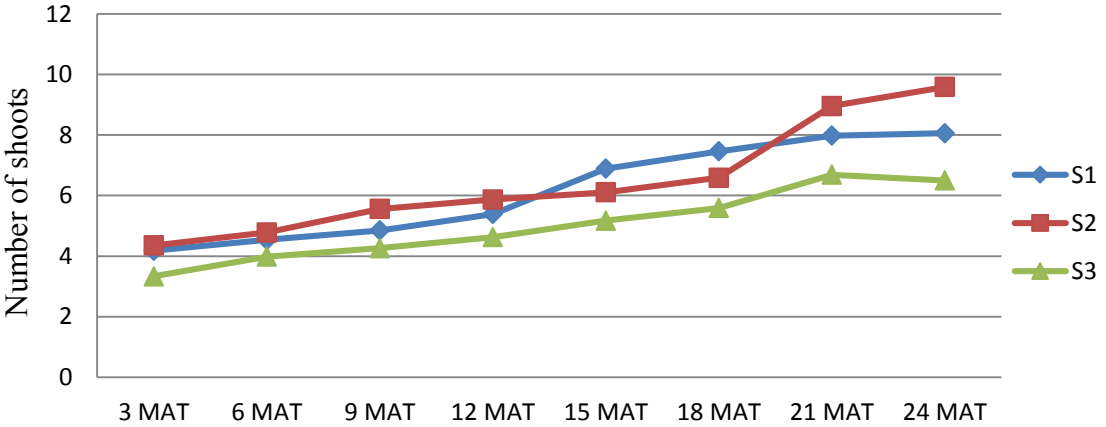


Fig. 15. Influence of treatment interactions on number of shoots in six month old plants of *Dendrobium* cv. Earsakul

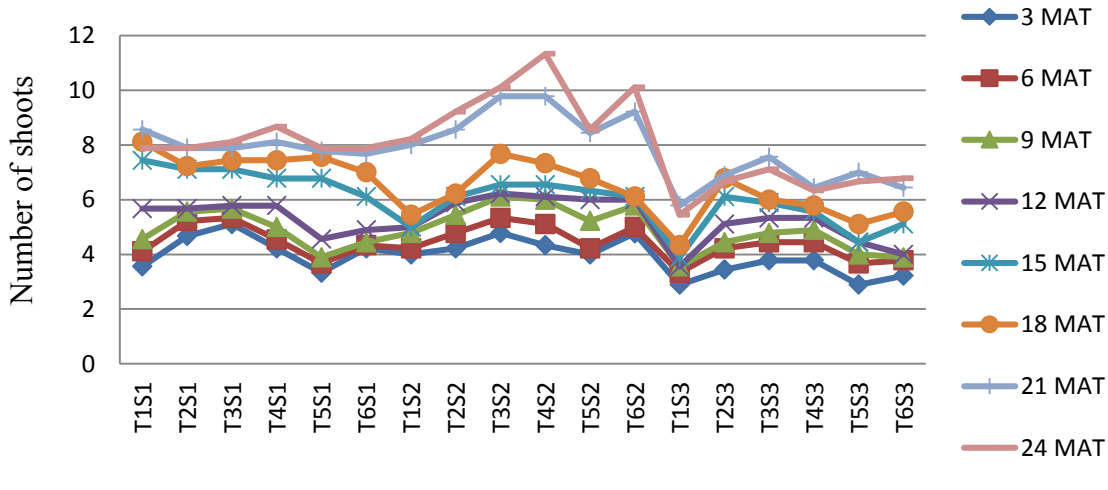


Fig. 16. Influence of plant growth promoters (treatments) on number of shoots in three year old plants of *Dendrobium* cv. Earsakul

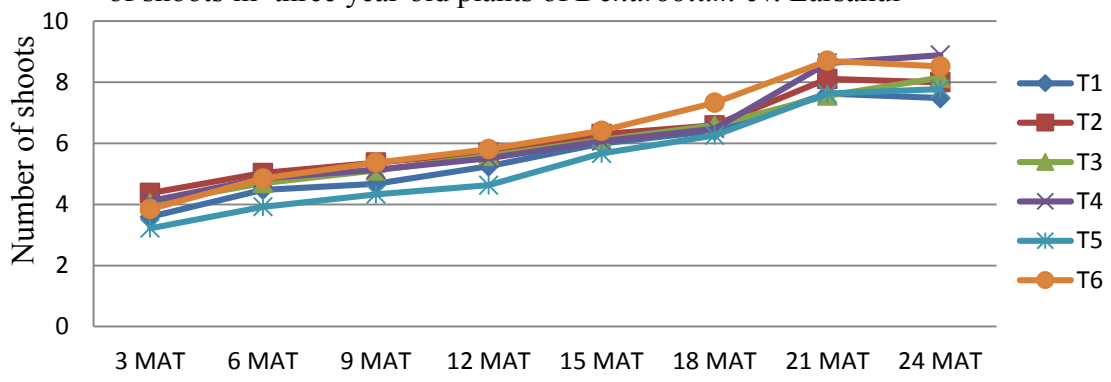


Fig. 17. Influence of growing systems on number of shoots in three year old plants of *Dendrobium* cv. Earsakul

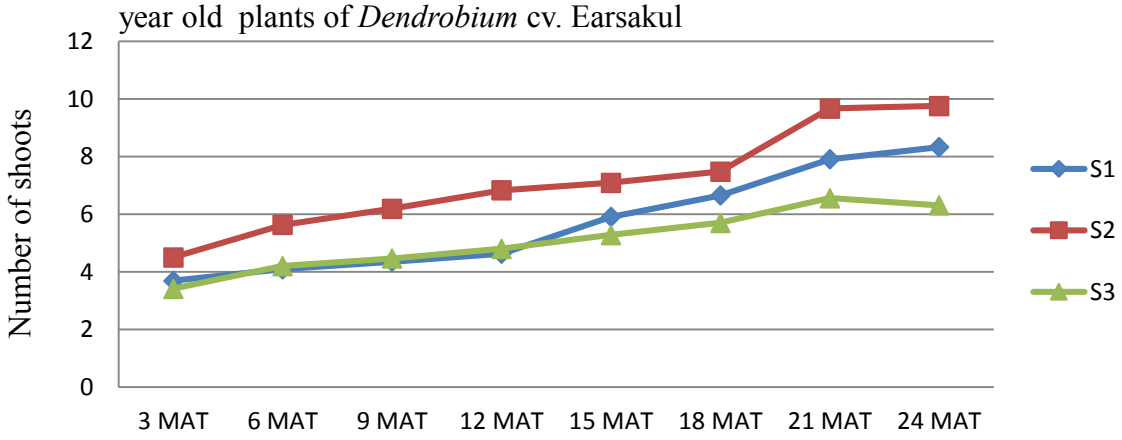
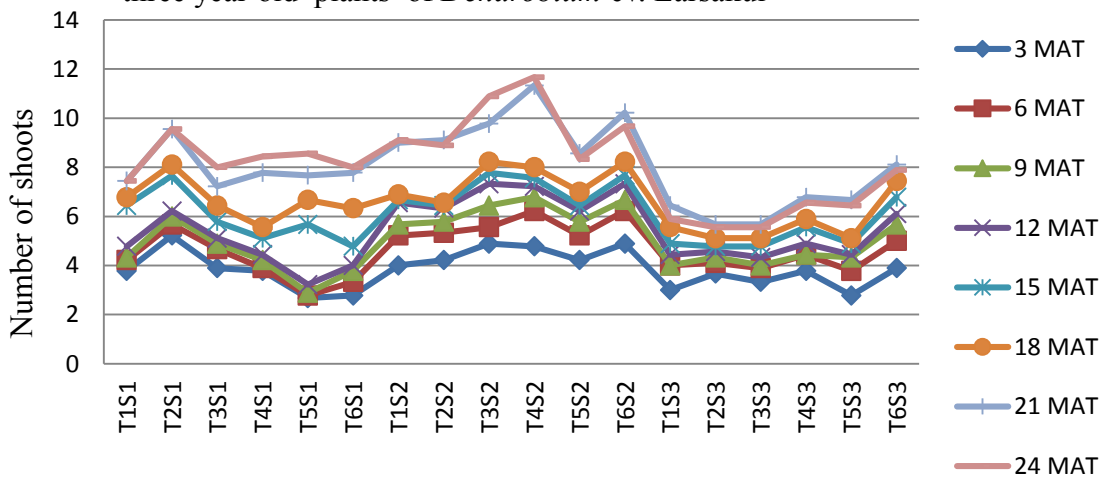


Fig. 18. Influence of treatment interactions on number of shoots in three year old plants of *Dendrobium* cv. Earsakul



recorded maximum number of shoots per plant, whereas in three year old plants, the combination of POP + OM + VW + PGPRE + Bone meal + GR and top ventilated polyhouse recorded significantly higher number of shoots per plant per plant might be the influence of BA which promoted shoot production. This is in accordance with the report of Xia *et al*. (1999) in *Dendrobium nobile.*

5.1.4 Girth of shoot

The treatment POP + OM + VW + PGPRE + Bone meal recorded maximum girth of the shoot in both stages of plants (Tables 6a, 6b and Fig. 19, 22). Application of inorganic nutrients and organic manures along with *P. indica* showed positive influence on girth of shoot as reported by Dhinesh (2009) and Kabir *et al*. (2012) in *Dendrobium*. Further, this may be due to the reason that microbial association of the plants in turn help in absorption of nutrients thereby increasing storage of nutrients in pseudobulb resulting in more shoot girth.

Among the systems of growing, top ventilated polyhouse in six month old plants and two level shade house in three year old plants had maximum influence on girth of shoot (Fig. 20, 23). This might be due to vigorous growth of the plant due to congenial environmental conditions prevailing inside the systems which in turn would develop the highest girth of the shoot.

5.1.5 Internodal length

Among various plant growth promoters used in six month old plants, the internodal length did not vary significantly among different treatments, whereas in three year old plants, combination of POP + OM + VW + PGPRE + Bone meal recorded maximum internodal length (Tables 7a, 7b and Fig. 25, 28). The height of the plant was significantly increased under treatment POP + OM + VW + PGPRE + Bone meal, hence the same treatment effect is acting on the internodal length proportionately. Similar observations were made by Dhinesh (2009) and Thekkayam (1996) in *Dendrobium*.

Fig. 19. Influence of plant growth promoters (treatments) on girth of shoot (cm) in six month old plants of *Dendrobium* cv. Earsakul

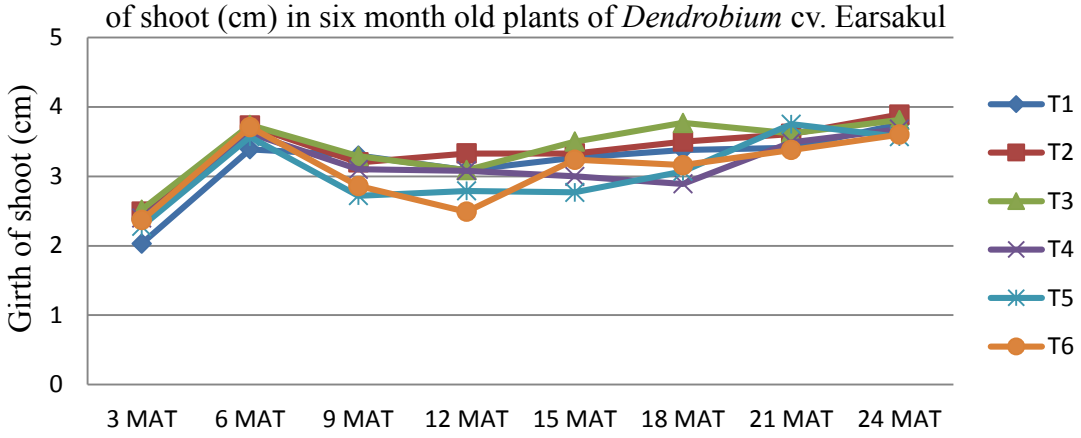


Fig. 20. Influence of growing systems on girth of shoot (cm) in six month old plants of *Dendrobium* cv. Earsakul

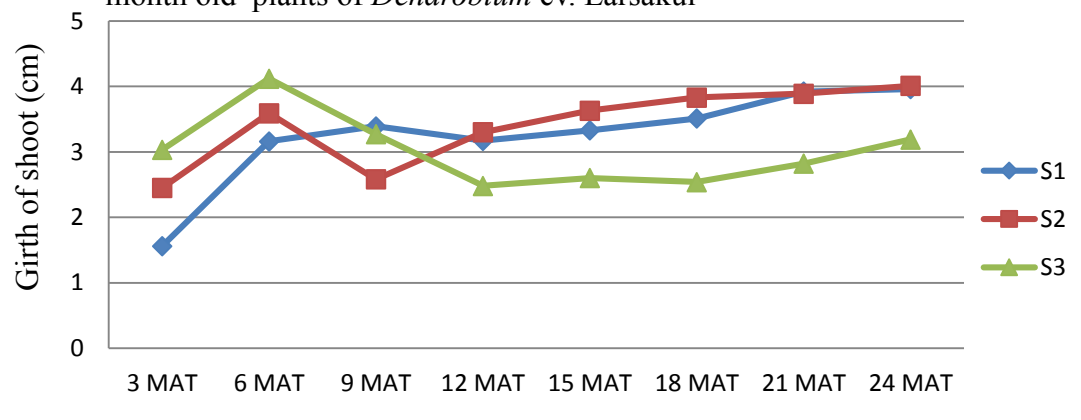


Fig. 21. Influence of treatment interactions on girth of shoot (cm) in six month old plants of *Dendrobium* cv. Earsakul

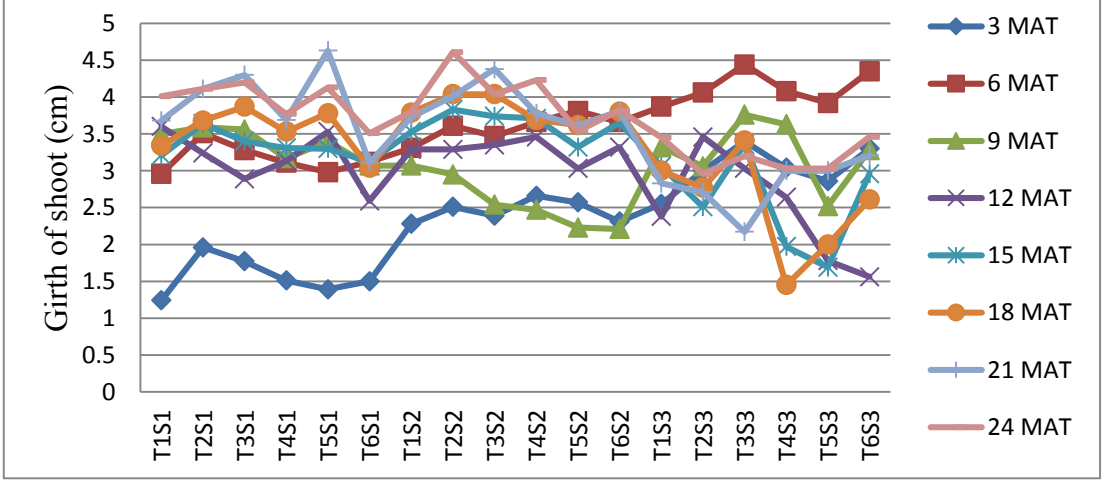


Fig. 22. Influence of plant growth promoters (treatments) on girth of shoot (cm) in three year old plants of *Dendrobium* cv. Earsakul

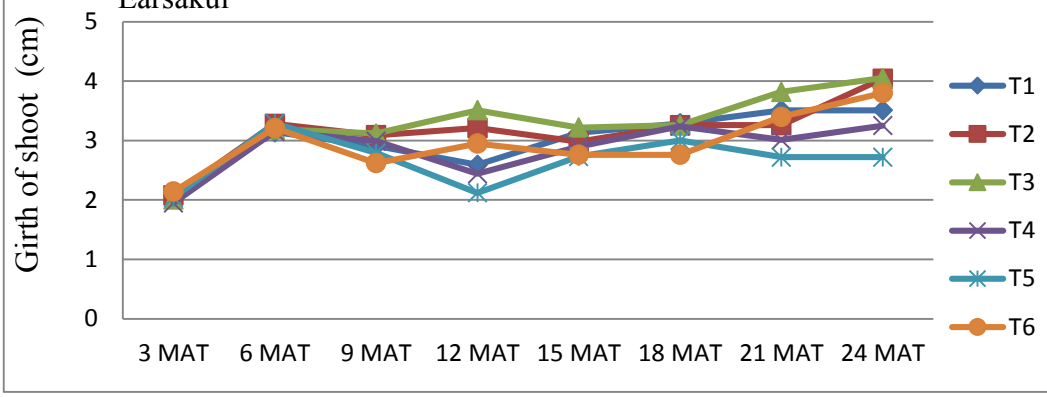


Fig. 23. Influence of growing systems on girth of shoot (cm) in three year old plants of *Dendrobium* cv. Earsakul

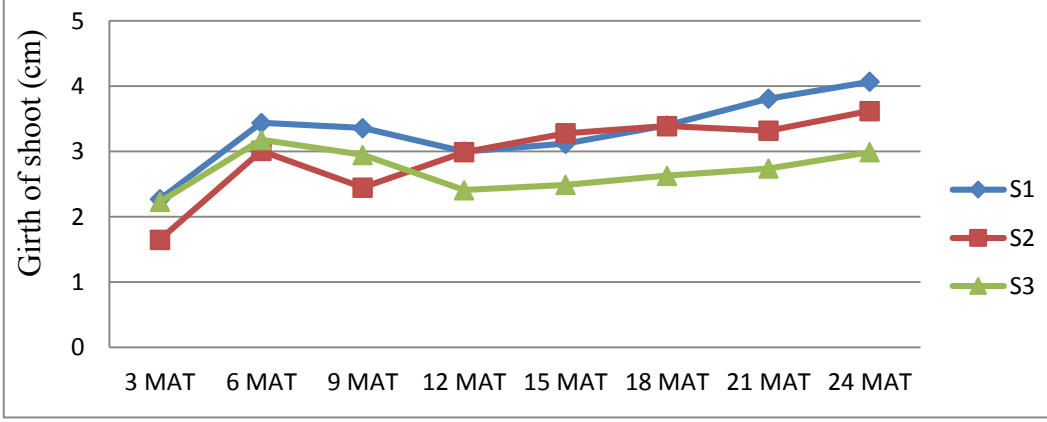


Fig. 24. Influence of treatment interactions on girth of shoot (cm) in three year old plants of *Dendrobium* cv. Earsakul

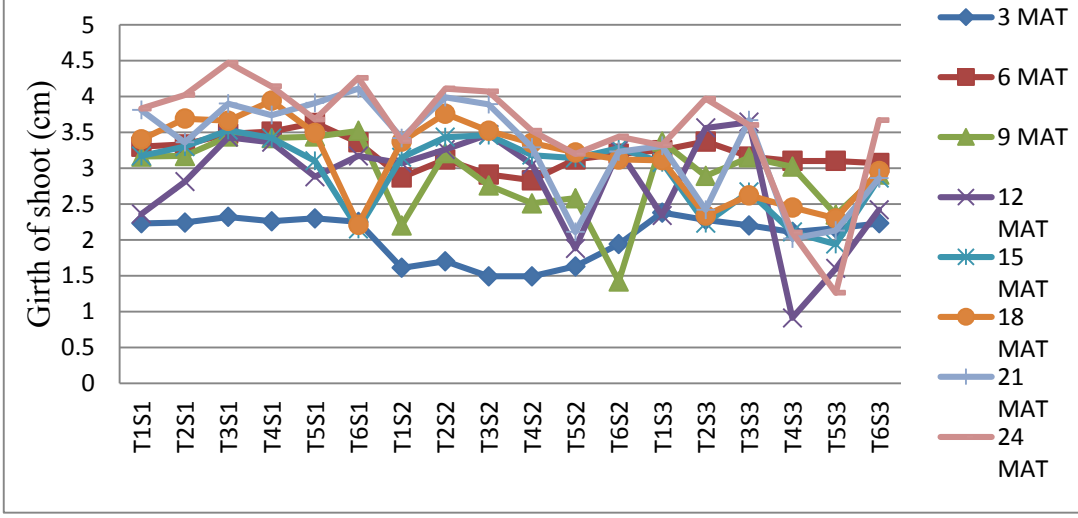


Fig. 25. Influence of plant growth promoters (treatments) on internodal length (cm) in six month old plants of *Dendrobium* cv. Earsakul

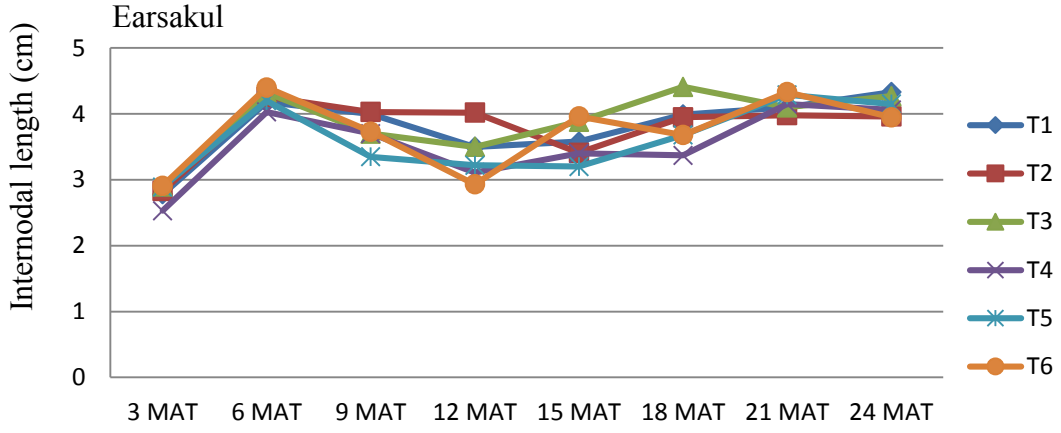


Fig. 26. Influence of growing systems on internodal length (cm) in six month old plants of *Dendrobium* cv. Earsakul

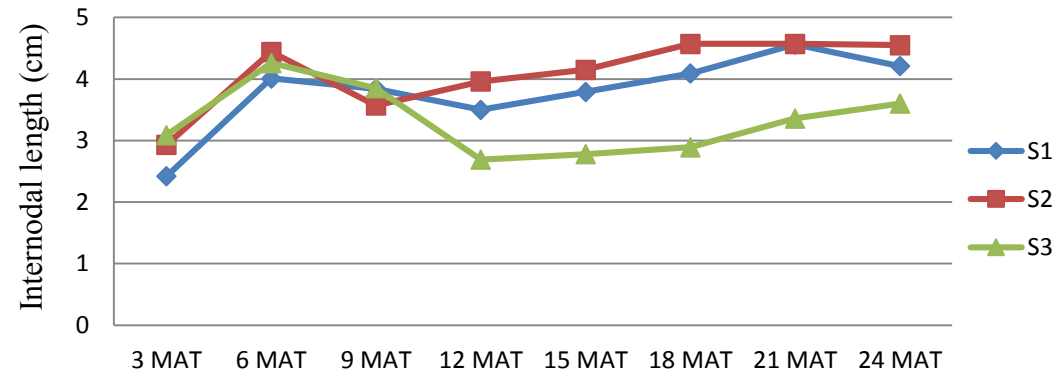


Fig. 27. Influence of treatment interactions on internodal length (cm) in six month old plants of *Dendrobium* cv. Earsakul

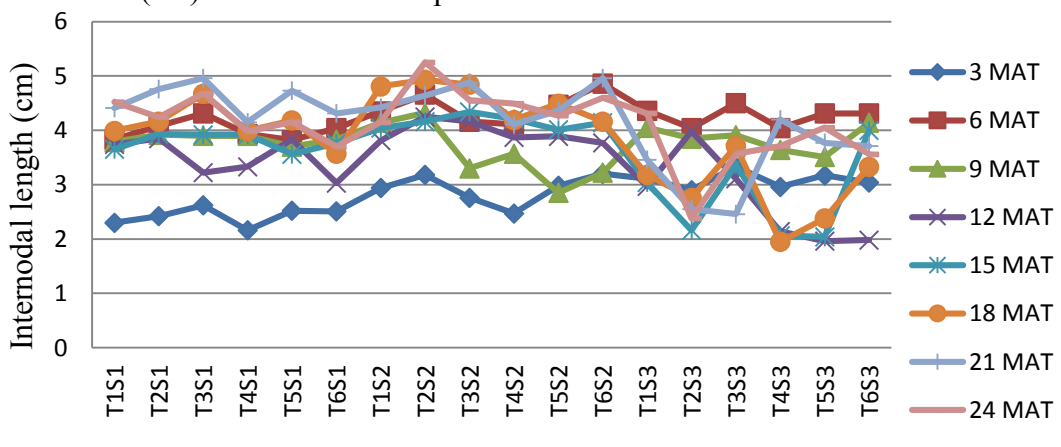


Fig. 28. Influence of plant growth promoters (treatments) on internodal length (cm) in three year old plants of *Dendrobium* cv. Earsakul

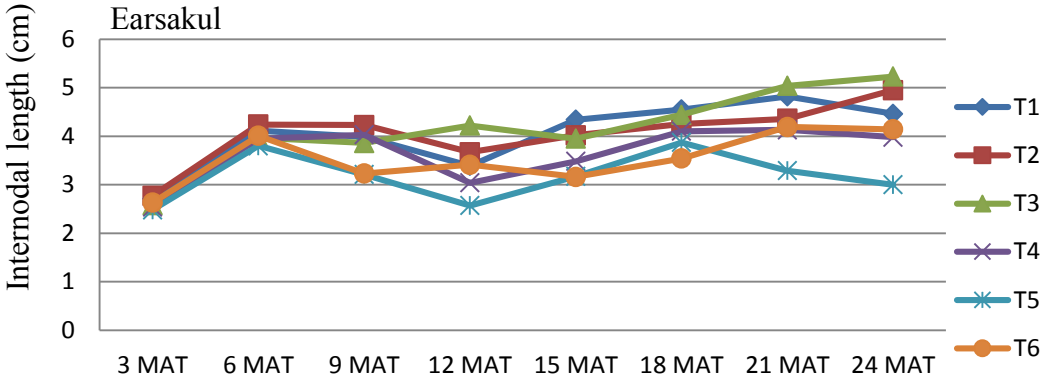


Fig. 29. Influence of growing systems on internodal length (cm) in three year old plants of *Dendrobium* cv. Earsakul

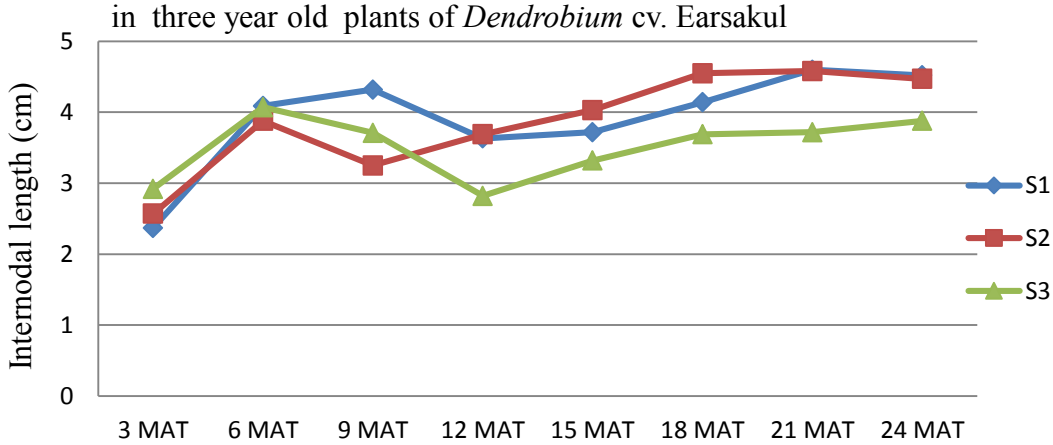
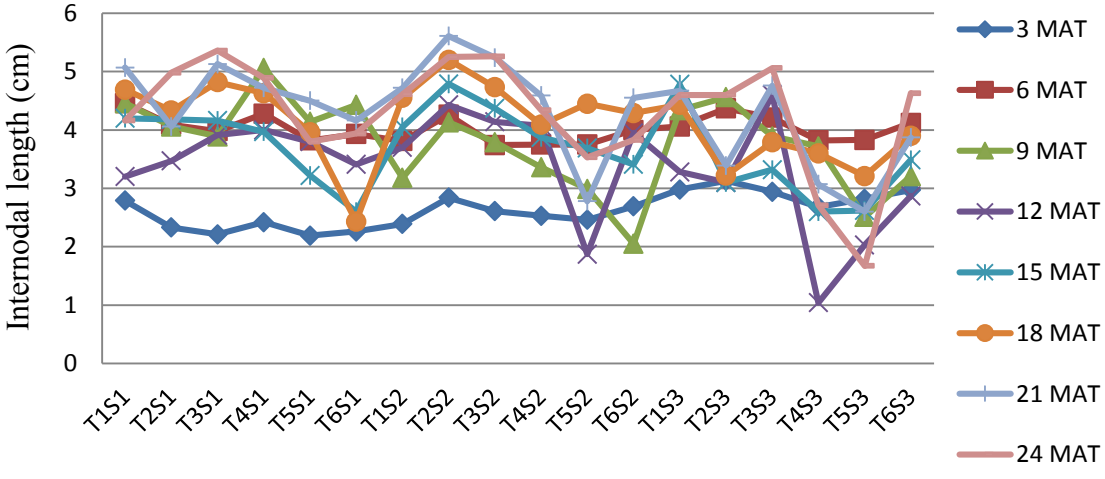


Fig. 30. Influence of treatment interactions on internodal length (cm) in three year old plants of *Dendrobium* cv. Earsakul



Out of three systems of growing, the top ventilated polyhouse had maximum internodal length irrespective of the age of the plants (Fig. 26 and 29). The findings could be explained in the same corollary as in the case of plant height in top ventilated polyhouse.

In the interaction of plant growth promoters and systems of growing, the treatment NPK + GR + OM + VW + PGPRE + Bone meal under top ventilated polyhouse recorded maximum internodal length in six month old plants. But in three year old plants, interaction was not explicit in all stages of growth (Fig. 27, 30).

5.2 Flower characters

5.2.1 Days to flowering

In six month old plants, the days to flowering did not vary significantly among various plant growth promoters, whereas the treatment combination POP + OM + VW + PGPRE + Bone meal + GR recorded early days to flowering in three year old plants (Tables 8, 9 and Fig. 31). This result could be explained by the phenomenon that the *Dendrobium* plants normally bloom one year after planting. Since the age of the plant is below one year (vegetative phase), the treatment had no effect on blooming, whereas in three year old plants, significant effect was observed in treatment POP + OM + VW + PGPRE + Bone meal + GR due to the reason that the growth regulators *viz.,* BA and GA_3 would have accelerated the flowering (in 3 year old plants *i.e* flowering phase). A similar trend was observed in *Dendrobium* by Swapna (2000) and Dhinesh (2009).

Among three systems of growing, top ventilated polyhouse had significant influence on days to flowering irrespective of the age of the plants (Fig. 32). The reason for this finding could be attributed that temperature is the most important factor coupled with light which controls the performance of the plant both in terms of growth and development in top ventilated polyhouse. These reasons may be attributed to early flowering in six month old plants.

Fig. 31. Influence of plant growth promoters (treatments) on days to flowering in six month old and three year old plants of *Dendrobium* cv. Earsakul

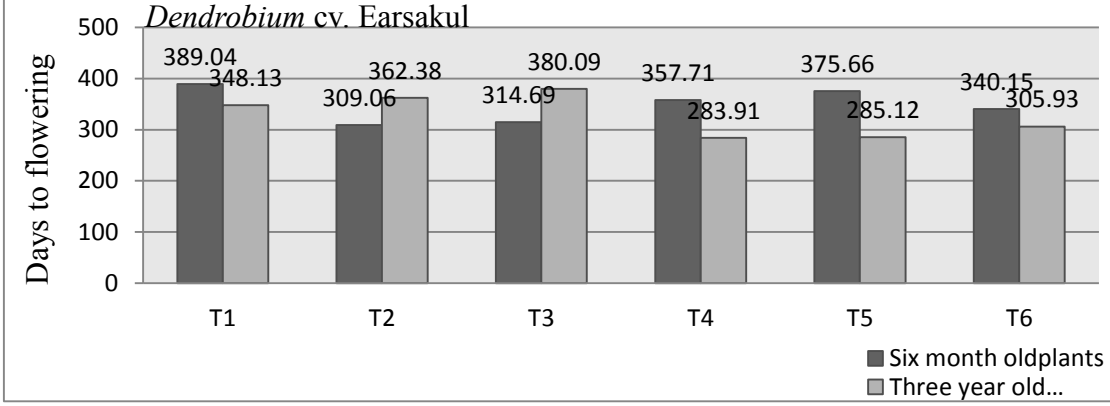


Fig. 32. Influence of growing systems on days to flowering in six month old and three year old plants of *Dendrobium* cv. Earsakul

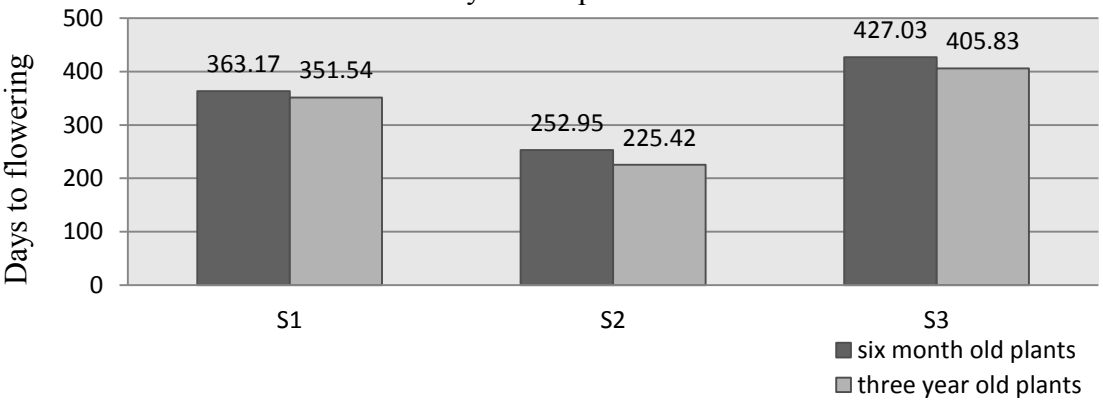
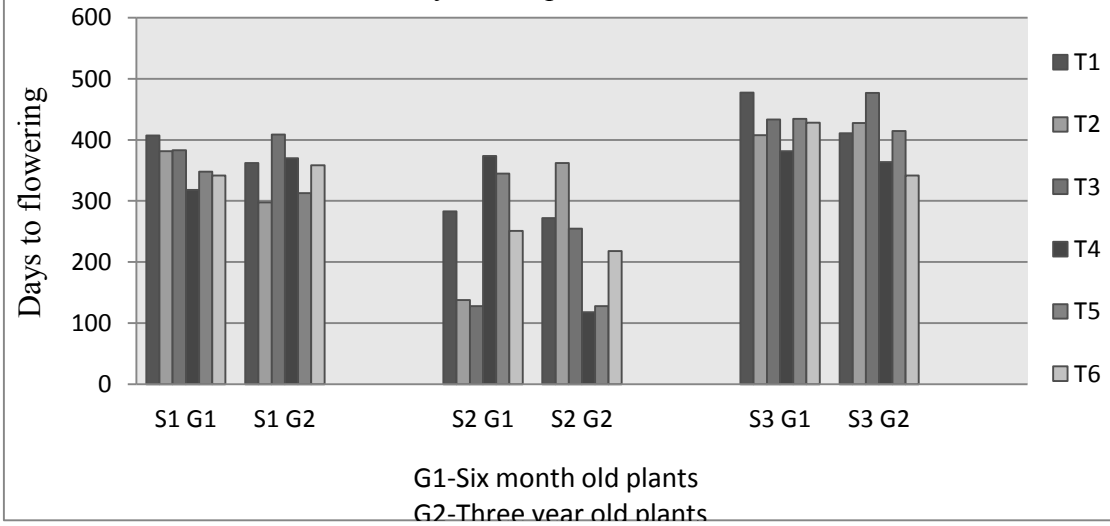


Fig. 33. Influence of treatment interactions on days to flowering in six month old and three year old plants of *Dendrobium* cv. Earsakul



In six month old plants, the combination of POP + OM + VW + PGPRE + Bone meal and top ventilated polyhouse recorded minimum time for days to flowering. However in three year old plants, POP + OM + VW + PGPRE + Bone meal + GR took minimum days for flowering in top ventilated polyhouse (Fig. 33). The possible reason that could be attributed to this phenomenon is that the days to flowering in six month old and three year old plants was purely influenced by the systems of growing.

5.2.2 Days to first flower opening

The influence of plant growth promoters showed that the combination of NPK + GR + OM + VW + PGPRE + Bone meal took minimum days for first flower opening in six month old plants (Table 8 and Fig. 34). The reason might be due to positive influence of nutrients along with *P. indica* which may be favourable for best growth and ultimately for earliest time for the plants to come to show first flower opening. This is in confirmation with the findings of Binisha (2003), Dhinesh (2009), Sugapriya *et al*. (2012) and Nambiar *et al*. (2012) in *Dendrobium*.

Among systems of growing, days to first flower opening was not significantly influenced by growing systems irrespective of the age of the plants (Fig. 35). This may be due to the reason that systems of growing had no effect on days to first flower opening in both stages of plants.

The combination of NPK + GR + OM + VW + PGPRE + Bone meal and two level shade house took minimum days for first flower opening in six month old plants (Fig. 36).

5.2.3 Days to last flower opening

The combination of POP + OM + VW + PGPRE + Bone meal + GR took minimum days for last flower opening in three year old plants (Table 9 and Fig. 37). This may be due to the positive influence of nutrients and *P. indica* help the

Fig. 34. Influence of plant growth promoters (treatments) on days to first flowering in six month old and three year old plants of *Dendrobium* cv. Earsakul

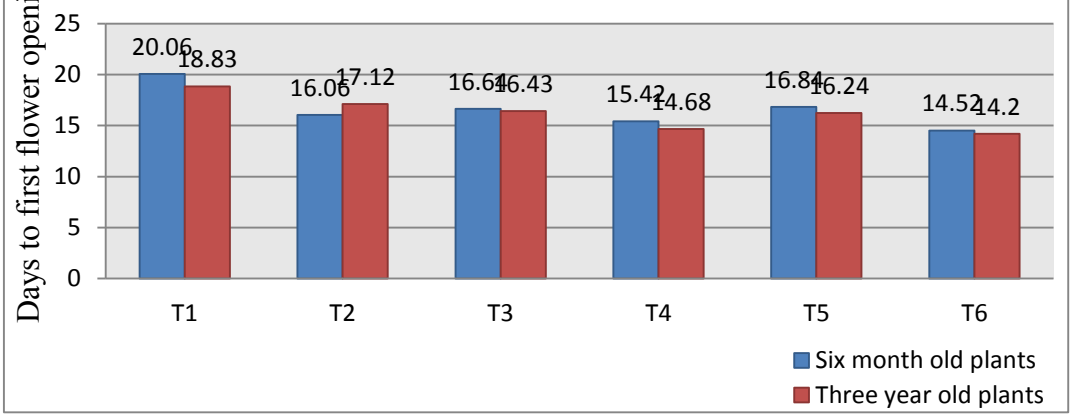


Fig. 35. Influence of growing systems on days to first flower opening in six month old and three year old plants of *Dendrobium* cv. Earsakul

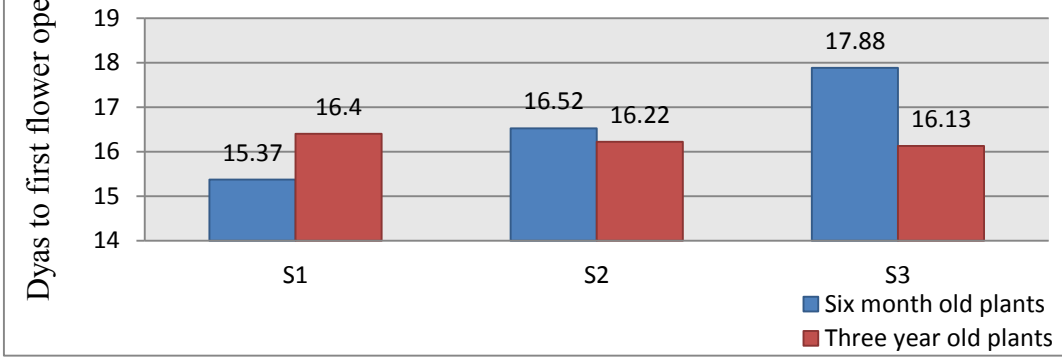


Fig. 36. Influence of treatment interactions on days to first flower opening in six month old and three year old plants of *Dendrobium* cv. Earsakul

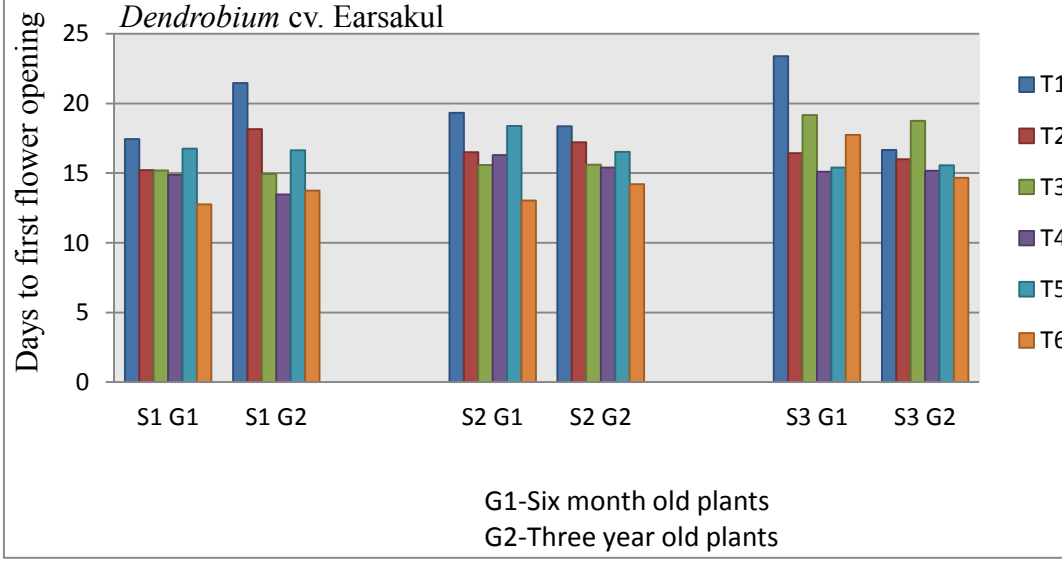


Fig. 37. Influence of plant growth promoters (treatments) on days to last flowering in six month old and three year old plants of *Dendrobium* cv. Earsakul

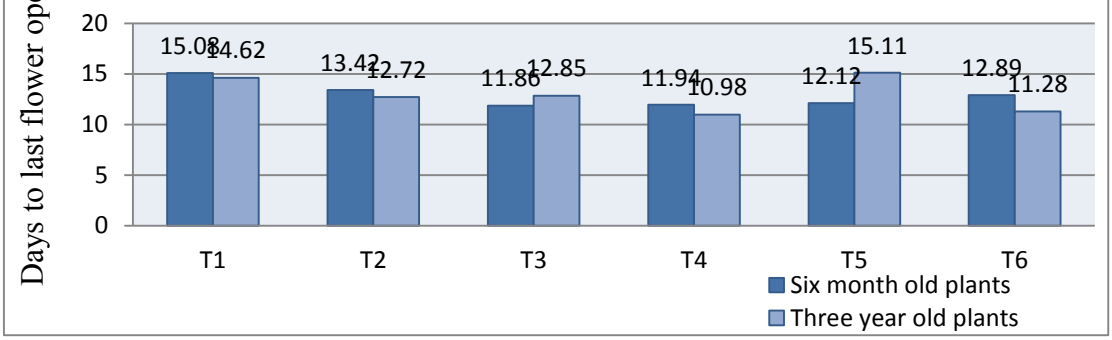


Fig. 38. Influence of growing systems on days to last flower opening in six month old and three year old plants of *Dendrobium* cv. Earsakul

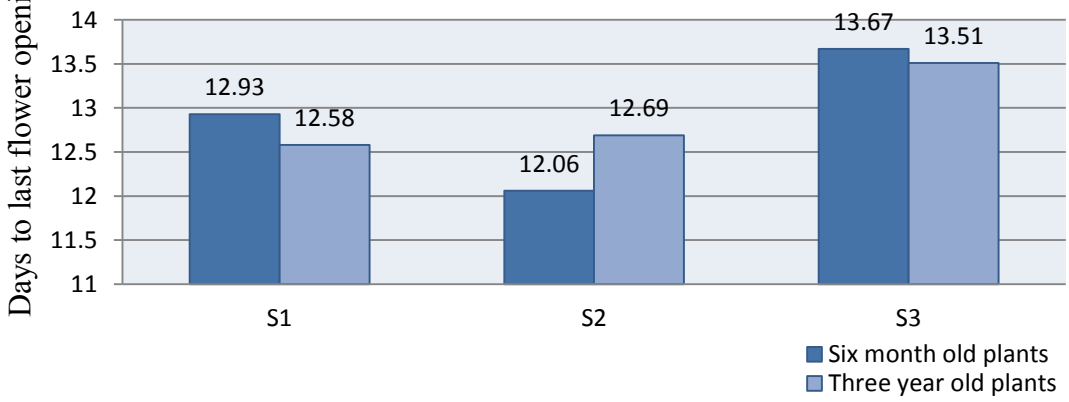
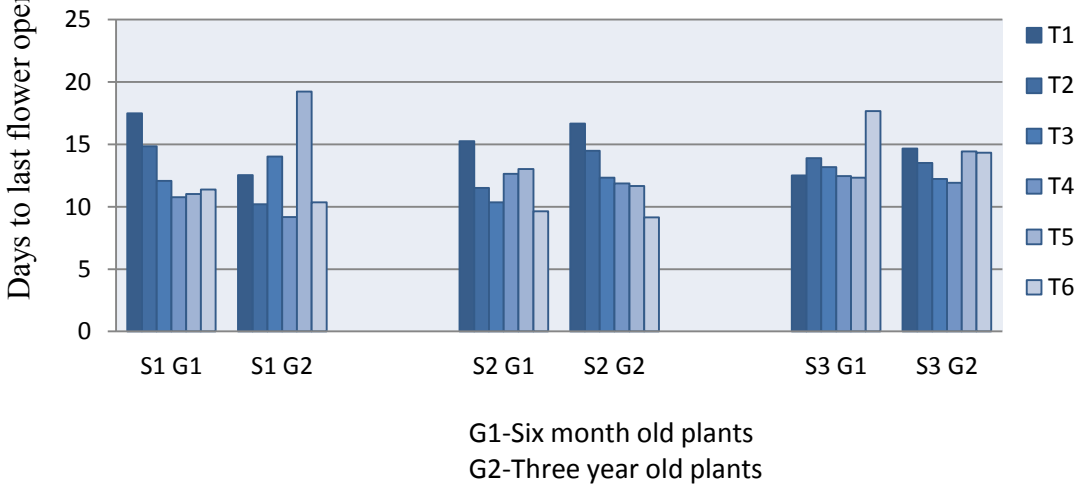


Fig. 39. Influence of treatment interactions on days to last flower opening in six month old and three year old plants of *Dendrobium* cv. Earsakul



plants for taking shorter period for last flower opening on the spike. This is in agreement with the findings of Dhinesh (2009) in *Dendrobium*.

Among different systems of growing, plants grown in two level shade house recorded minimum days for last flower opening in three year old plants (Fig. 38).

The combination of NPK + GR + OM + VW + PGPRE + Bone meal and top ventilated polyhouse took minimum days for last flower opening in both stages of plants (Fig. 39). This might be due to positive influence of nutrients and congenial environmental conditions may be the reason for taking minimum period for last flower opening in plants grown under top ventilated polyhouse.

5.2.4 Length of the spike

The treatment POP + OM + VW + PGPRE + Bone meal + GR in six month old plants and NPK + GR + OM + VW + PGPRE + Bone meal in three year old plants recorded significantly longer spikes (Tables 8, 9 and Fig. 40). This result could be explained by the fact that the length of the spike was directly influenced by the growth characters of the plant which was determined by nutrients, growth regulators and *P. indica*. Whereas in three year old plants also the combination includes growth regulators and *P. indica* that could be influencing the length of spike. A similar trend was reported by Swapna (2000), Ramachandrudu (2008), Meghana (2008), Nair and Sujatha (2010) in *Dendrobium*.

Among three systems of growing, top ventilated polyhouse had significant influence on length of the spike irrespective of the age of the plants (Fig. 41). This may be due to the influence of high temperature, high light intensity and low relative humidity prevailing in top ventilated polyhouse (Appendix V). This was in accordance with the findings of Arumugam and Jawaharlal (2004) in *Dendrobium*.

Fig. 40. Influence of plant growth promoters (treatments) on length of the spike (cm) in six month old and three year old plants of *Dendrobium* cv. Earsakul

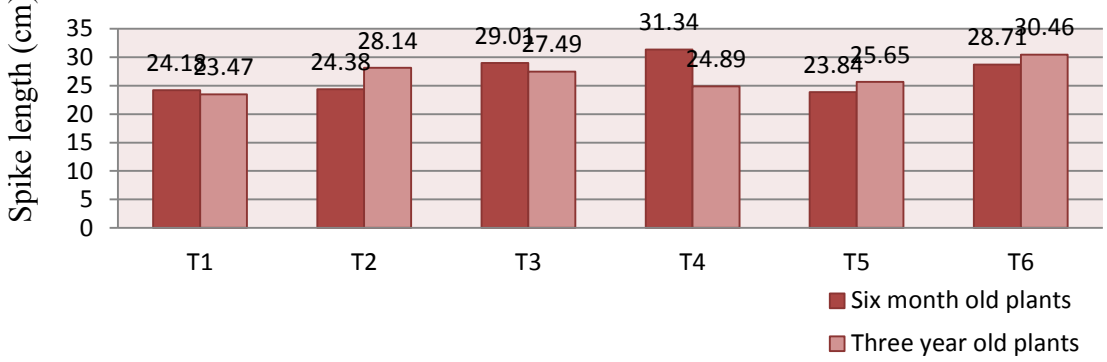


Fig. 41. Influence of growing systems on spike length (cm) in six month old and three year old plants of *Dendrobium* cv. Earsakul

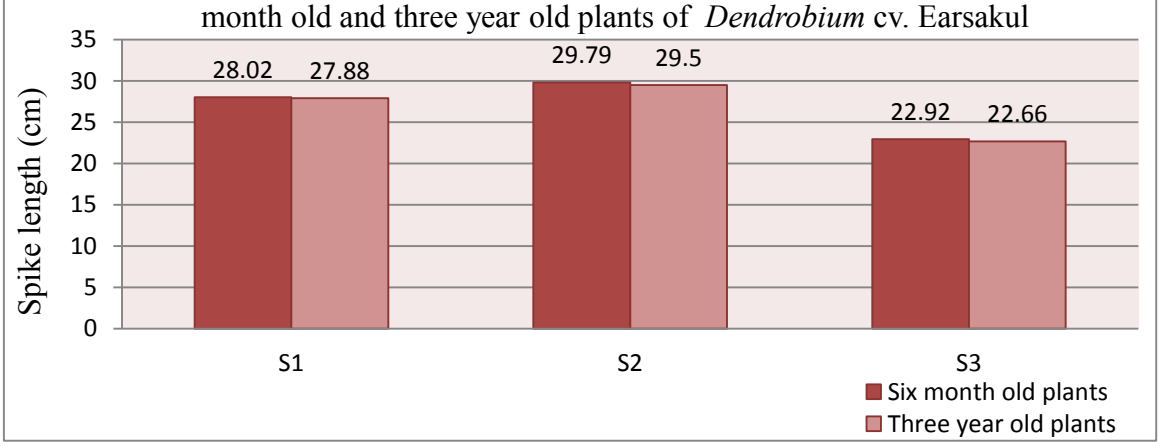
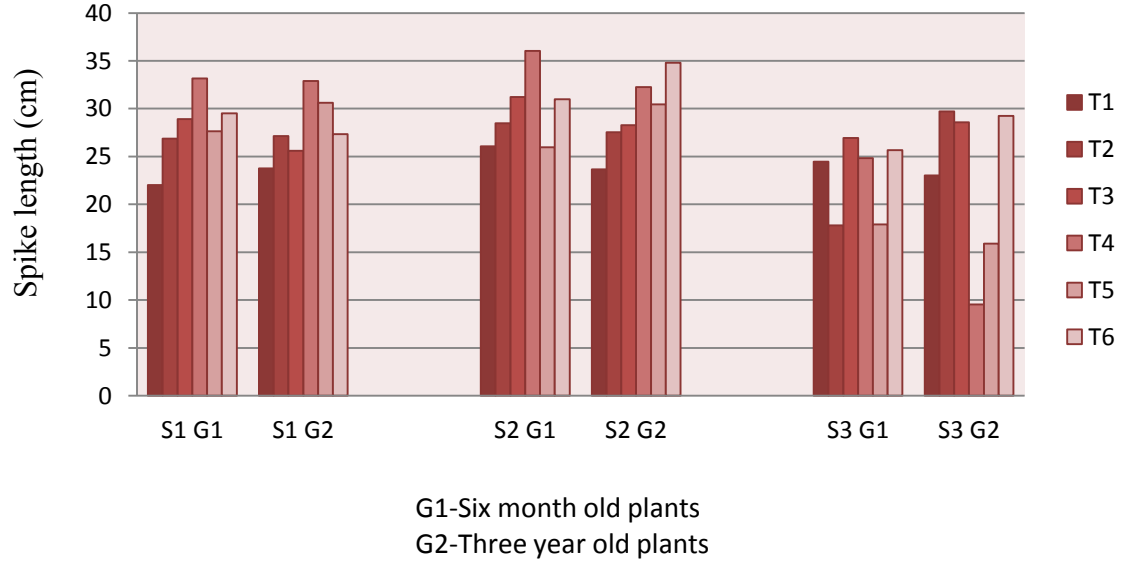


Fig. 42. Influence of treatment interactions on spike length (cm) in six month old and three year old plants of *Dendrobium* cv. Earsakul



The combination of POP + OM + VW + PGPRE + Bone meal + GR and top ventilated polyhouse in six month old plants, NPK + GR + OM + VW + PGPRE + Bone meal and top ventilated polyhouse in three year old plants recorded significantly higher spike length (Fig. 42).

5.2.5 Number of flowers per spike

The combination of POP + OM + VW + PGPRE + Bone meal + GR in six month old plants and NPK + GR + OM + VW + PGPRE + Bone meal in three year old plants recorded significantly higher number of flowers per spike (Tables 8, 9 and Fig. 43). This may be perhaps due to number of flowers per spike was directly proportionate to the length of spike which would have resulted in more number of flowers per spike. This is in conformation with Bichsel and Starman (2008) and Kumar *et al*. (2009). The plant growth promoter contains growth regulators which enhanced the production of flowers per spike in both stages of plants.

Among systems of growing, top ventilated polyhouse had significant influence on number of flowers per spike irrespective of the age of the plants (Fig. 44). The reason may be due to the effect of high temperature, high light intensity and low relative humidity prevailing inside the top ventilated polyhouse (Appendix V). Similar findings were reported by Fernandez (2001) in *Dendrobium* and Hew and Yong (2004) in *Phalaenopsis.*

The interaction of plant growth promoters and systems of growing, the combination of POP + OM + VW + PGPRE + Bone meal and top ventilated polyhouse recorded maximum number of flowers in six month old plants. In three year old plants, the combination of NPK + GR + OM + VW + PGPRE + Bone meal and top ventilated polyhouse recorded significantly higher number of flowers (Fig. 45). This may perhaps due to the influence of nutrients, *P. indica* and congenial environmental conditions prevailing inside top ventilated polyhouse would have influenced for more number of flowers per spike.

Fig. 43. Influence of plant growth promoters (treatments) on number of flowers per spike in six month old and three year old plants of *Dendrobium* cv. Earsakul

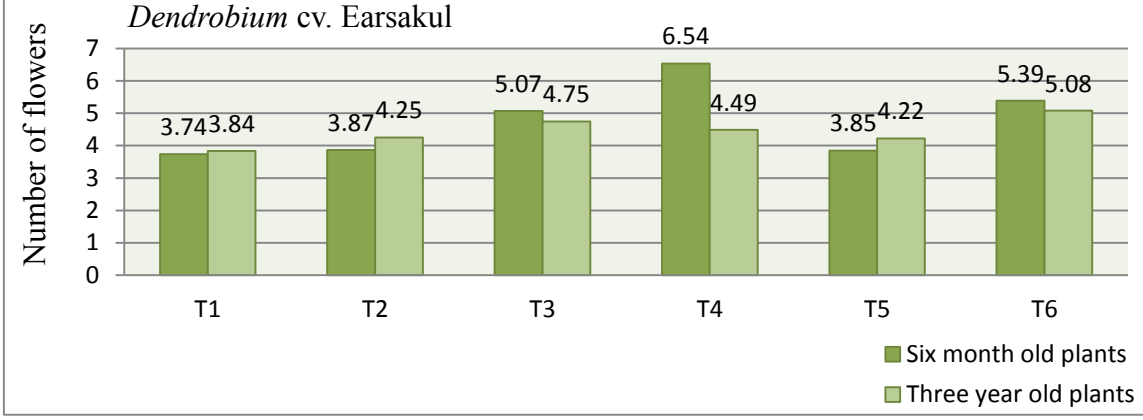


Fig. 44. Influence of growing systems on number of flowers per spike in six month old and three year old plants of *Dendrobium* cv. Earsakul

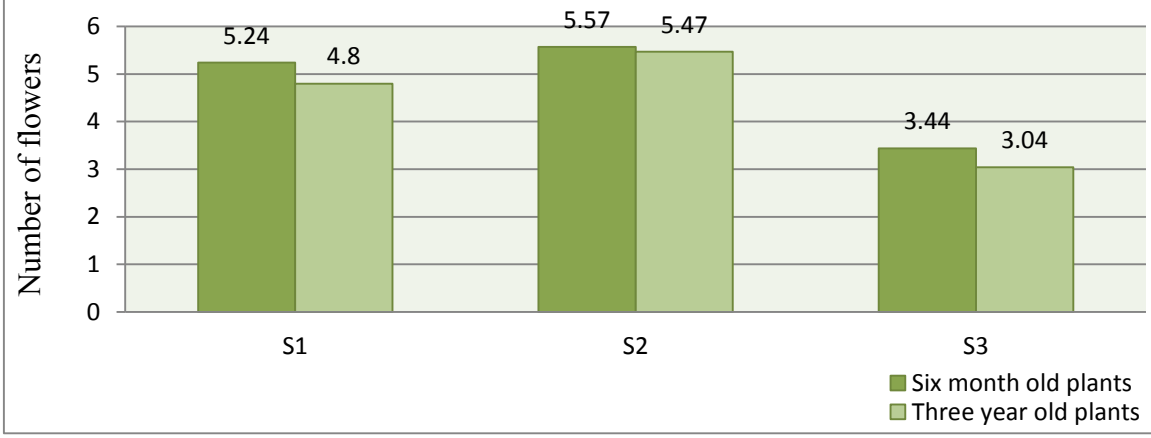
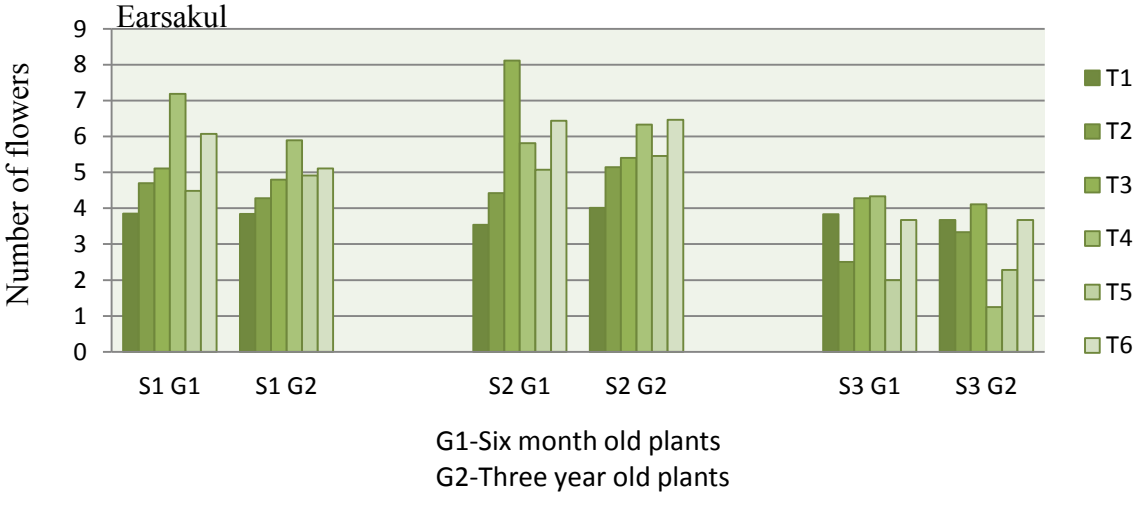


Fig. 45. Influence of treatment interactions on number of flowers per spike in six month old and three year old plants of *Dendrobium* cv. Earsakul



5.2.6 Size of the flower

Size of the flower did not vary significantly among different treatments, growing systems and interactions in both six month old and three year old plants (Tables 8 and 9). This may be due to the genetic factors limiting the size of the flowers in *Dendrobium*.

5.2.7 Number of spikes per plant

The treatment NPK + GR + OM + VW + PGPRE + Bone meal in six month old plants and POP + OM + VW + PGPRE + Bone meal + GR in three year old plants recorded significantly higher number of spikes per plant (Tables 8, 9 and Fig. 46). This may be attributed to the role of *P. indica* in both treatments which would have influenced the root system and absorption of nutrients which further enhances the number of shoots per plant because of which more spikes were produced.

Among systems of growing, top ventilated polyhouse recorded significantly higher number of spike per plant irrespective of the age of the plants (Fig. 47). The reason may be due to the high light intensity and temperature which would have influenced the number of shoots per plant which in turn favoured more number of spikes per plant. Similar finding was reported by Leonhardt (2000) in *Dendrobium*.

The combination of POP + OM + VW + PGPRE + Bone meal + GR had more influence on number of spikes per plant in top ventilated polyhouse in six month old plants and in two level shade house in three year old plants (Fig. 48). This result further reinforced the findings of independent effects of plant growth promoters and systems of growing.

5.2.8 Vase life

The combination of POP + OM + VW + PGPRE + Bone meal + GR recorded significantly higher vase life in both stages of plants (Tables 8, 9 and Fig. 49). This may be due to the reason that the influence of *P. indica* and growth

Fig. 46. Influence of plant growth promoters (treatments) on number of pikes per plant in six month old and three year old plants of *Dendrobium* cv. Earsakul

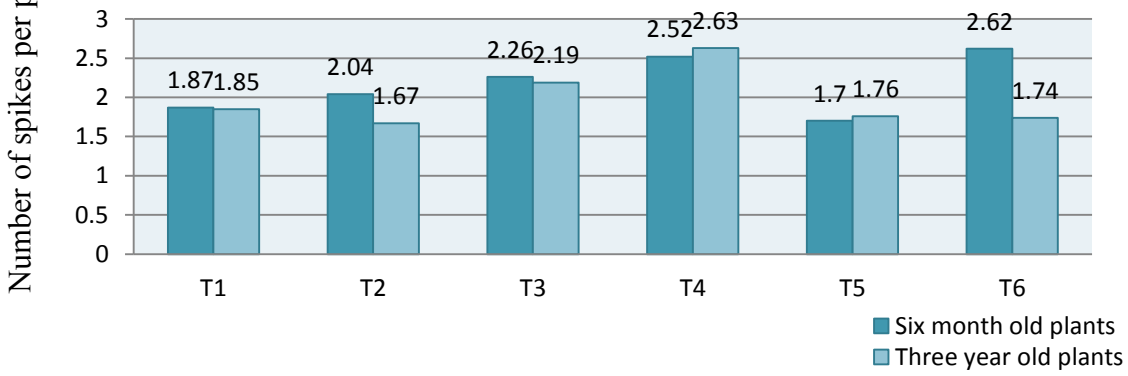


Fig. 47. Influence of growing systems on number of spikes per plant in six month old and three year old plants of *Dendrobium* cv. Earsakul

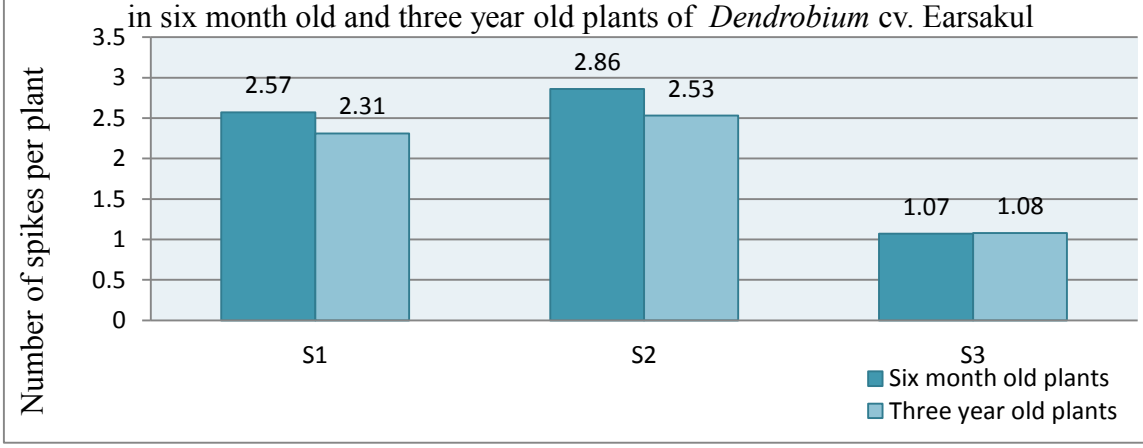


Fig. 48. Influence of treatment interactions on number of spikes per plant in six month old and three year old plants of *Dendrobium* cv. Earsakul

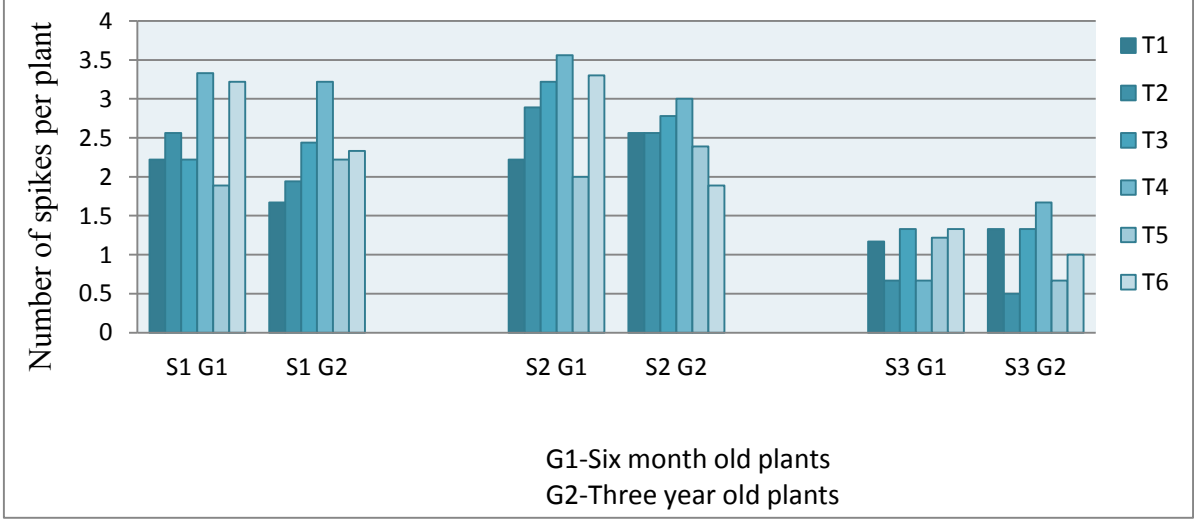


Fig. 49. Influence of plant growth promoters (treatments) on vase life in six month old and three year old plants of *Dendrobium* cv. Earsakul

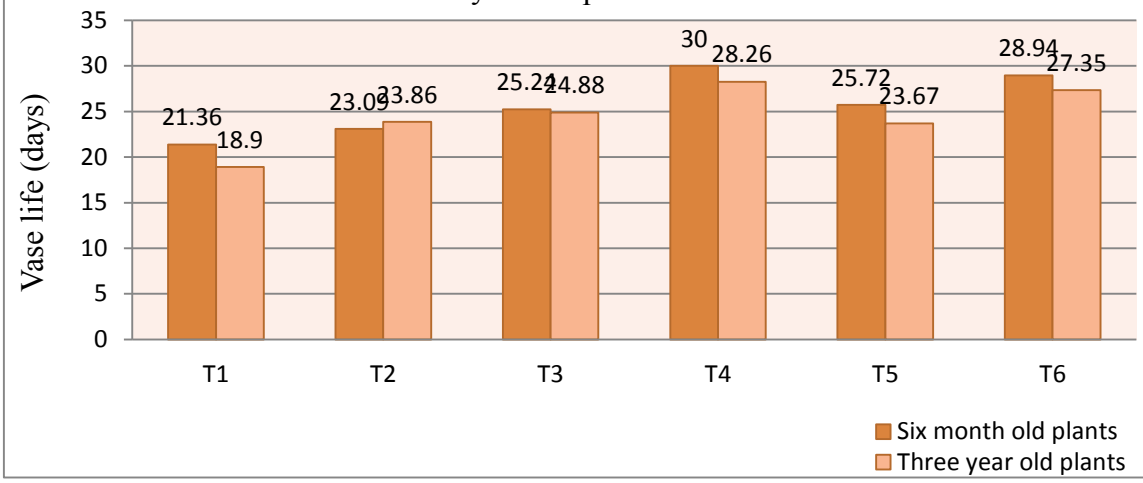


Fig. 51. Influence of treatment interactions on vase life in six month old and three year old plants of *Dendrobium* cv. Earsakul

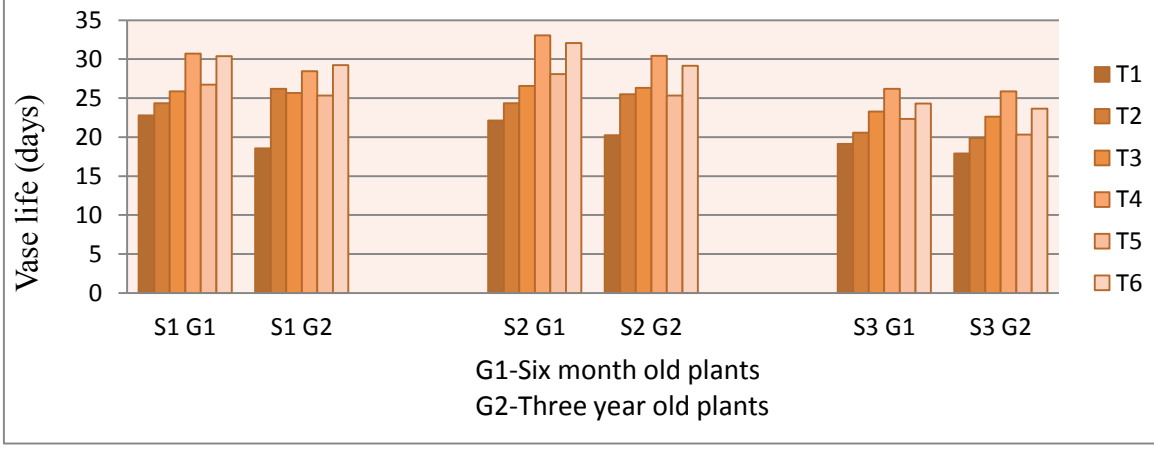
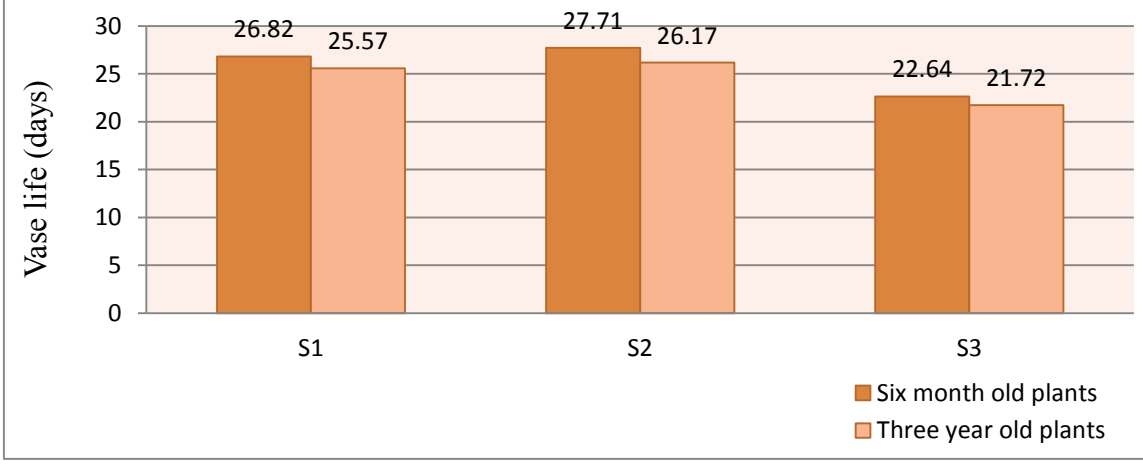


Fig. 50. Influence of growing systems on vase life in six month old and three year old plants of *Dendrobium* cv. Earsakul



regulators in the nutrient combination increased the vase life. Similar finding was reported by Dhinesh (2009) in *Dendrobium*.

Among systems of growing, top ventilated polyhouse recorded significantly higher vase life irrespective of the age of the plants (Fig. 50). Favourable temperature, lower relative humidity and higher light intensity were observed under top ventilated polyhouse. This may be reason for maximum vase life of the flowers recorded in top ventilated polyhouse. The findings are in conformity with the observations of Fernandez (2001) in *Dendrobium*.

The combination of POP + OM + VW + PGPRE + Bone meal + GR and top ventilated polyhouse recorded significantly higher vase life in both stages of plants (Fig. 51). The attributes explained for plant growth promoters and systems of growing for vase life might be the reason for the result.

5.3 Physiological parameters

5.3.1 Leaf area

The combination of POP + OM + VW + PGPRE + Bone meal + GR recorded significantly higher leaf area irrespective of the age of the plants (Tables 10, 11 and Fig. 52). This could be well explained that the leaf area was determined by a number of leaves per plant. The number of leaves was higher in the treatment POP + OM + VW + PGPRE + Bone meal + growth regulators (Tables 4a, 4b) and hence the leaf area.

Among system of growing, top ventilated polyhouse had maximum influence on leaf area in six month old plants (Fig. 53). The increase in leaf number results in increase in leaf area (or) increase in leaf area can be attributed to increase in leaf number.

The combination of POP + OM + VW + PGPRE + Bone meal and top ventilated polyhouse in six month old plants, POP + OM + VW + PGPRE + Bone meal + GR and two level shade house in three year old plants recorded significantly higher leaf area (Fig. 54). In six month old plants, the *P. indica*

Fig. 52. Influence of plant growth promoters (treatments) on leaf area in (cm^2) in six month old and three year old plants of *Dendrobium* cv. Earsakul

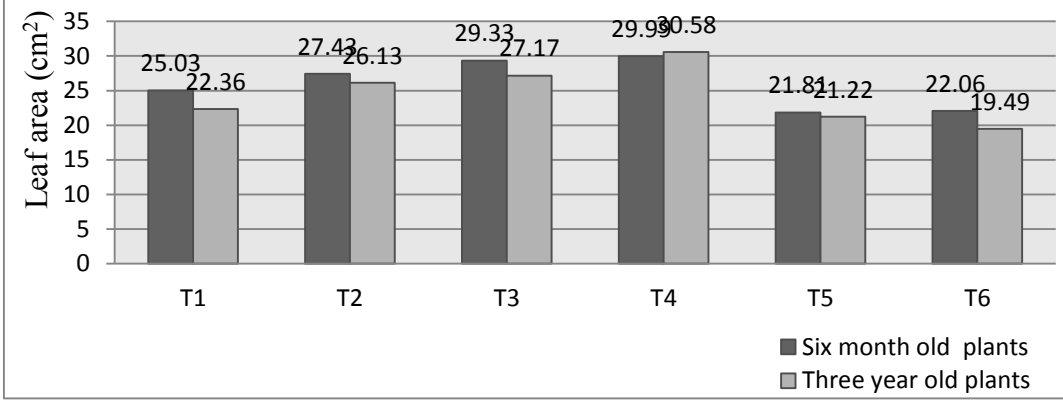


Fig. 53. Influence of growing systems on leaf area (cm^2) of in six month old and three year old plants of *Dendrobium* cv. Earsakul

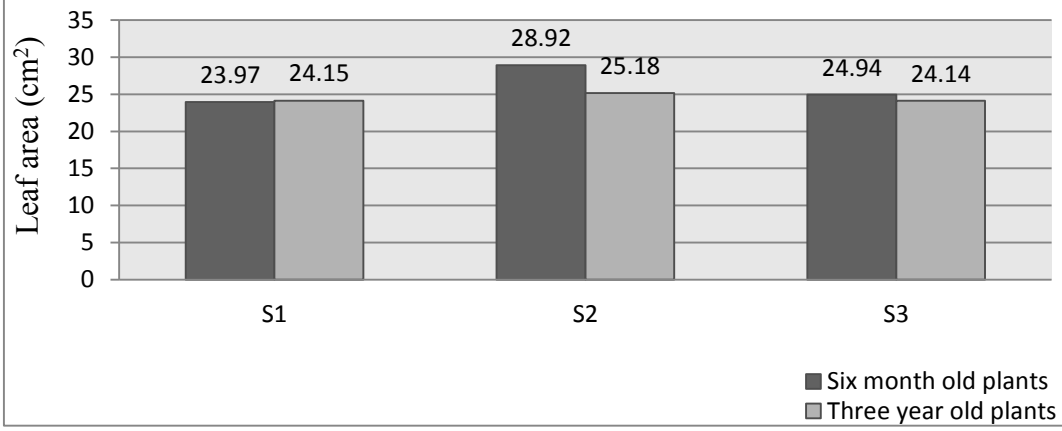
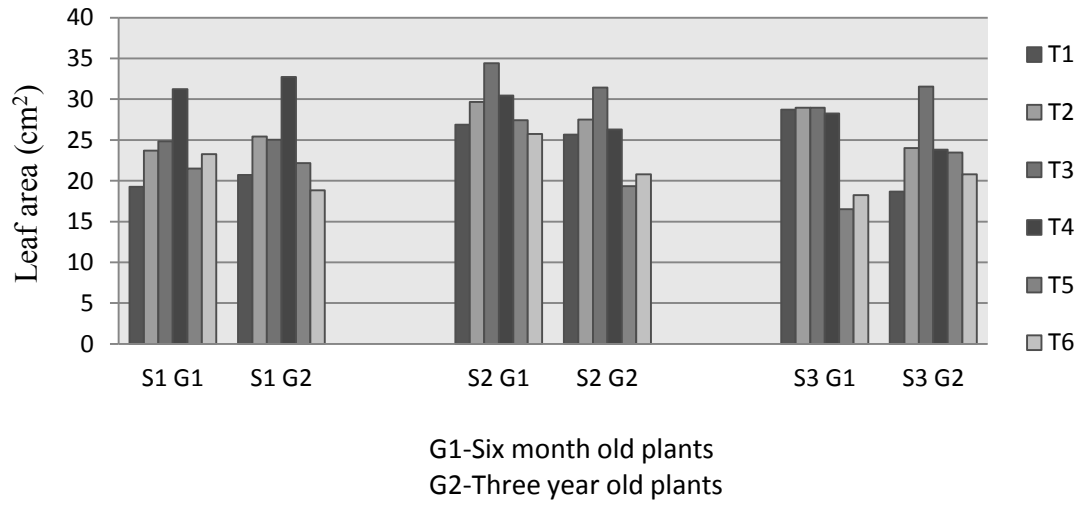


Fig. 54. Influence of treatment interactions on leaf area (cm^2) in six month old and three year old plants of *Dendrobium* cv. Earsakul



would influence the production of more number of leaves per plant which in turn enhance the leaf area in top ventilated polyhouse with the condition of high temperature, high light intensity and low relative humidity (Appendix V). Foliar feeding of organic manures may also the reason for highest leaf area. Whereas in three year old plants, the effect of *P. indica* and growth regulators would influence the production of more number of leaves which ultimately resulted in more leaf area.

5.3.2 Dry matter production

The combination of POP + OM + VW + PGPRE + Bone meal in six month old plants, POP + OM + VW + PGPRE + Bone meal + GR in three year old plant recorded significantly higher DMP (Tables 10, 11 and Fig. 55). The plant height and number of shoots per plant were more in the treatment POP + OM + VW + PGPRE + Bone meal for six month old plants whereas, the number of leaves per plant, leaf area was more in the treatment POP + OM + VW + PGPRE + Bone meal + GR. This may be the reason for more DMP observed in those treatments in six month old and three year old plants, respectively.

Among systems of growing, top ventilated polyhouse had maximum influence on DMP irrespective of age of the plants (Fig. 56). The plant height, number of leaves, number of shoots and leaf area were maximum in top ventilated polyhouse which might have resulted in increased DMP in plants grown under top ventilated polyhouse.

The combination of POP + OM + VW + PGPRE + Bone meal and top ventilated polyhouse in six month old plants and POP + OM + VW + PGPRE + Bone meal + GR and top ventilated polyhouse in three year old plants recorded higher DMP (Fig. 57). These results are in conformity with earlier results of plant growth promoters and systems of growing on DMP.

Fig. 55. Influence of plant growth promoters (treatments) on dry matter production in six month old and three year old plants of *Dendrobium* cv. Earsakul

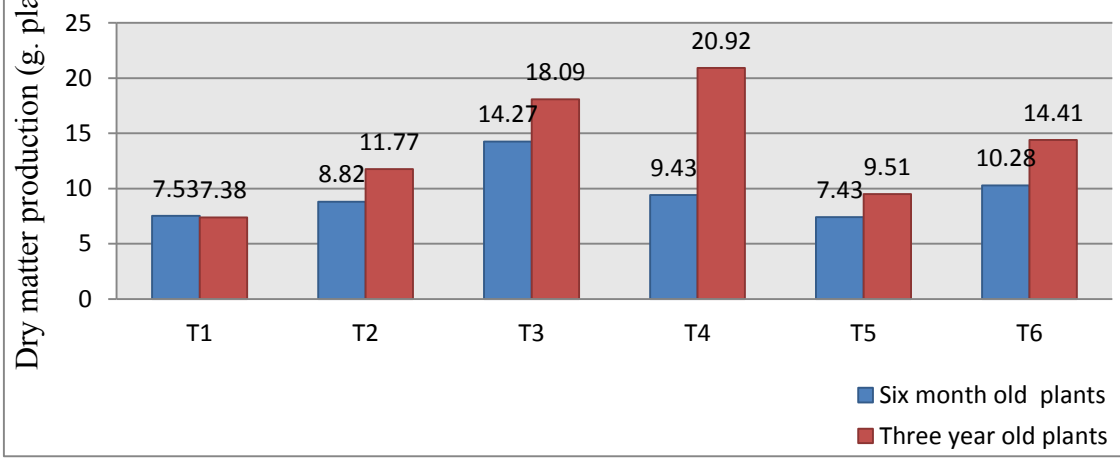


Fig. 56. Influence of growing systems ondry matter production in six month old and three year old plants of *Dendrobium* cv. Earsakul

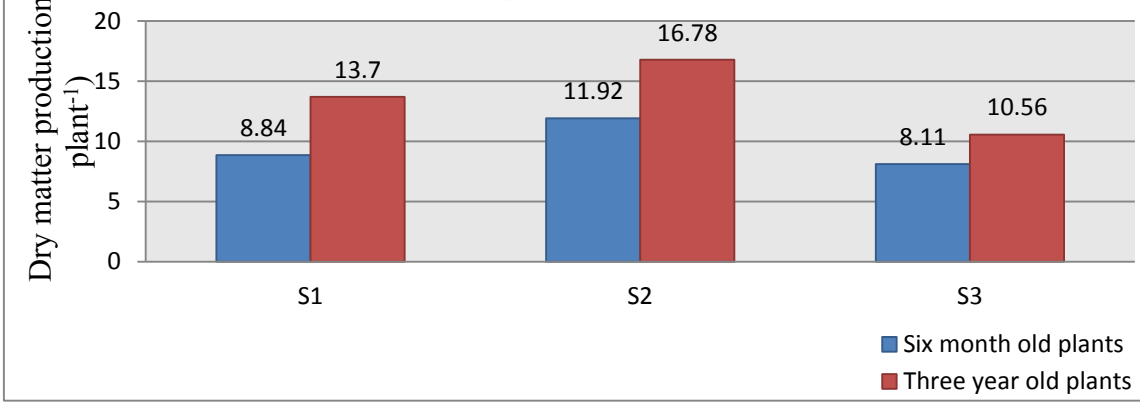
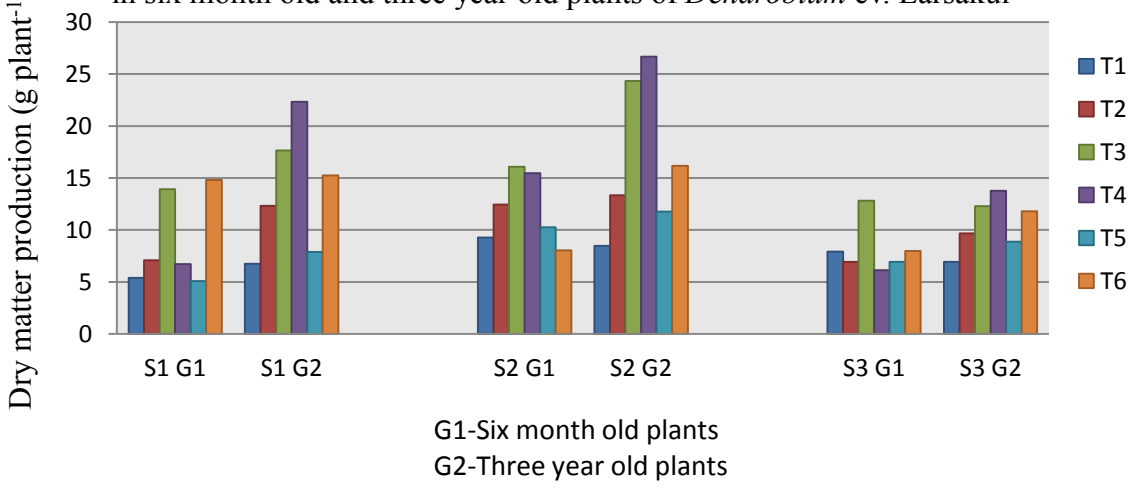


Fig. 57. Influence of treatment interactions on dry matter production in six month old and three year old plants of *Dendrobium* cv. Earsakul



5.3.3 Crop growth rate

The combination of POP + OM + VW + PGPRE + Bone meal in six month old plants, POP + OM + VW + PGPRE + Bone meal + GR in three year old plants recorded significantly higher CGR (Tables 10, 11 and Fig. 58). The CGR is the proportion of dry matter production and time period of growth. The results of DMP also proved that POP + OM + VW + PGPRE + Bone meal in six month old and POP + OM + VW + PGPRE + Bone meal + GR in three year old plants recorded more DMP. A similar trend was also observed in the case of CGR. Highest CGR was recorded in those plants which received POP + *P. indica*. This was in accordance with the findings of Dhinesh (2009) in *Dendrobium*.

Top ventilated polyhouse in six month old plants and two level shad house in three year old plants recorded maximum CGR (Fig. 59).

The combination of NPK + GR + OM + VW + PGPRE + Bone meal and two level shade house in six month old plants, POP + OM + VW + PGPRE + Bone meal + GR and two level shade house in three year old plants recorded higher CGR (Fig. 60). The treatments NPK + GR + PGPRE + OM + VW + Bone meal and POP + PGPRE + OM + VW + Bone meal + GR under the environmental condition of two level shade house may result in high CGR.

5.3.4 Relative growth rate

The combination of POP + OM + VW + PGPRE + Bone meal + GR recorded significantly higher RGR in six month old plants (Tables 10, 11 and Fig. 61). Since the six month plants were in active growth phase, it was significantly showing the unit increasing DMP. This may lead to increase in RGR. The result in the present study was parallel with the findings of Dhinesh (2009) in *Dendrobium*.

Growing systems had no significant effect on RGR in both stages of plants (Fig. 62).

The combination of POP + OM + VW + PGPRE + Bone meal + GR and fan and pad system in six month old plants, NPK + GR + OM + VW + PGPRE +

Fig. 58. Influence of plant growth promoters (treatments) on crop growth rate in six month old and three year old plants of *Dendrobium* cv. Earsakul

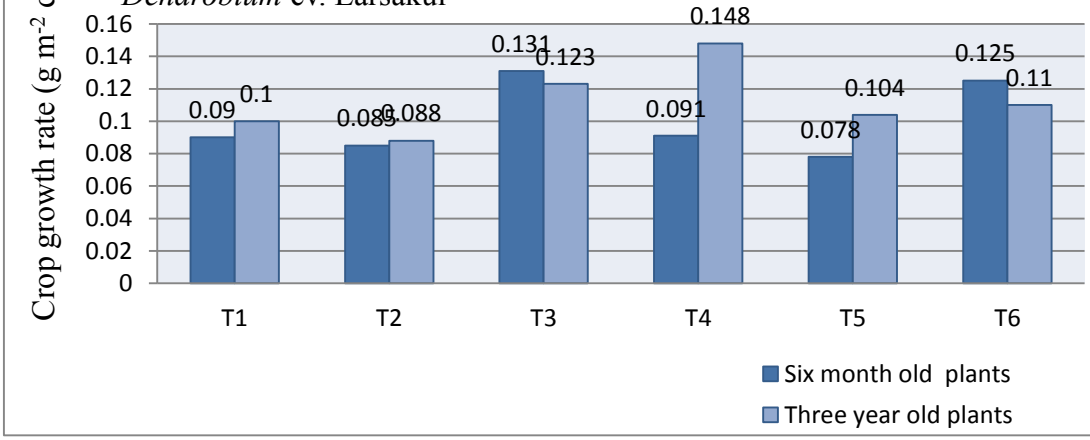


Fig. 59. Influence of growing systems on crop growth rate in six month old and three year old plants of *Dendrobium* cv. Earsakul

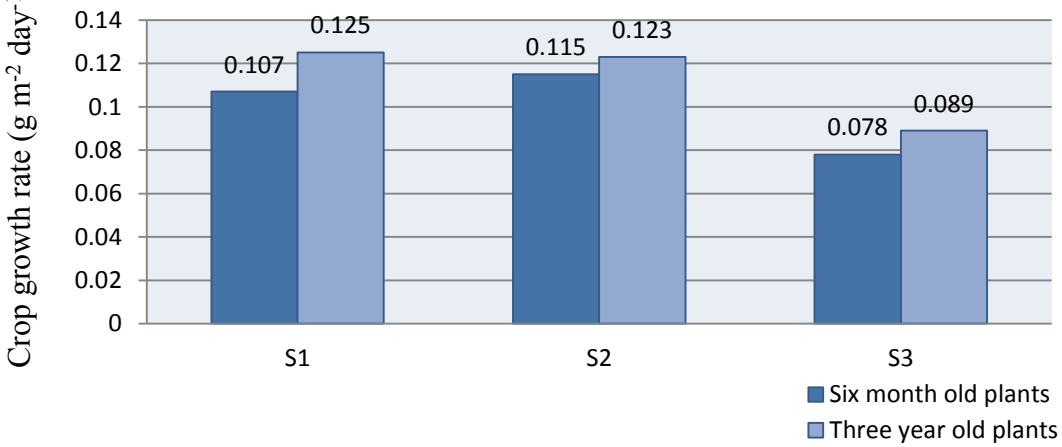


Fig. 60. Influence of treatment interactions on crop growth rate in six month old and three year old plants of *Dendrobium* cv. Earsakul

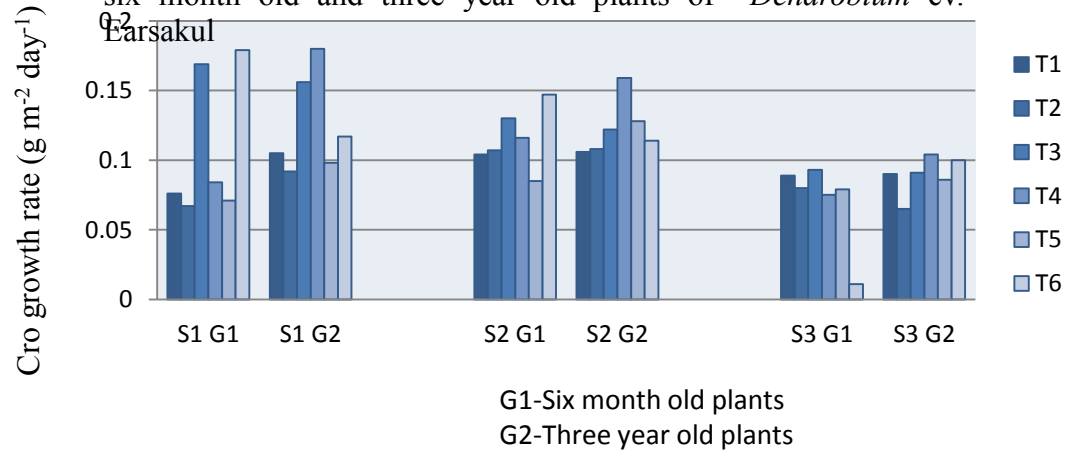


Fig. 61. Influence of plant growth promoters (treatments) on relative growth rate in six month old and three year old plants of *Dendrobium* cv. Earsakul

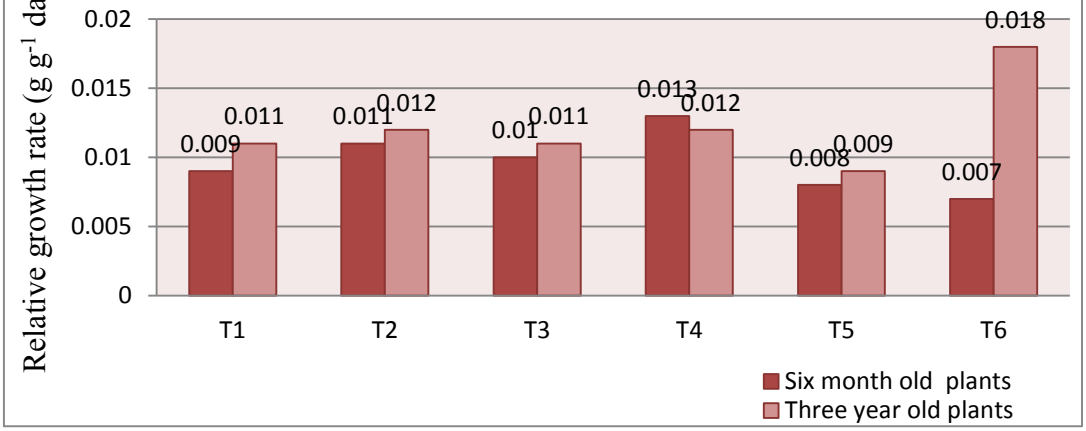


Fig. 62. Influence of growing systems on relative growth rate in six month old and three year old plants of *Dendrobium* cv. Earsakul

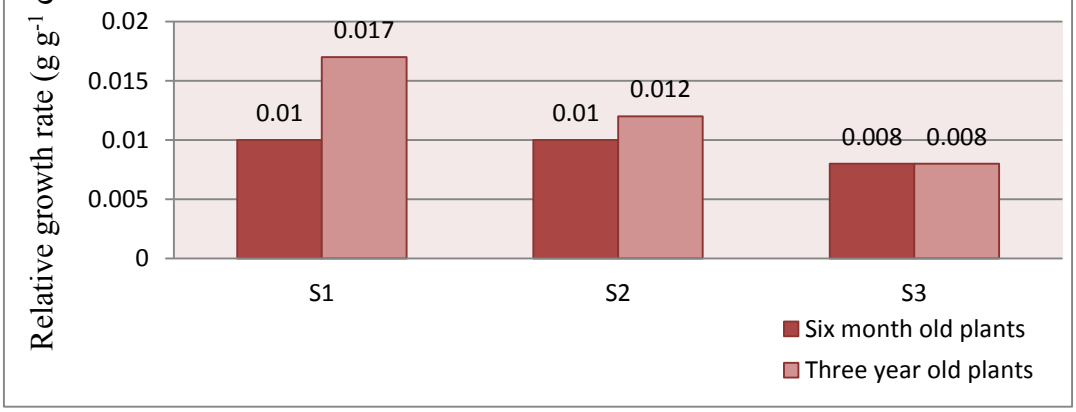
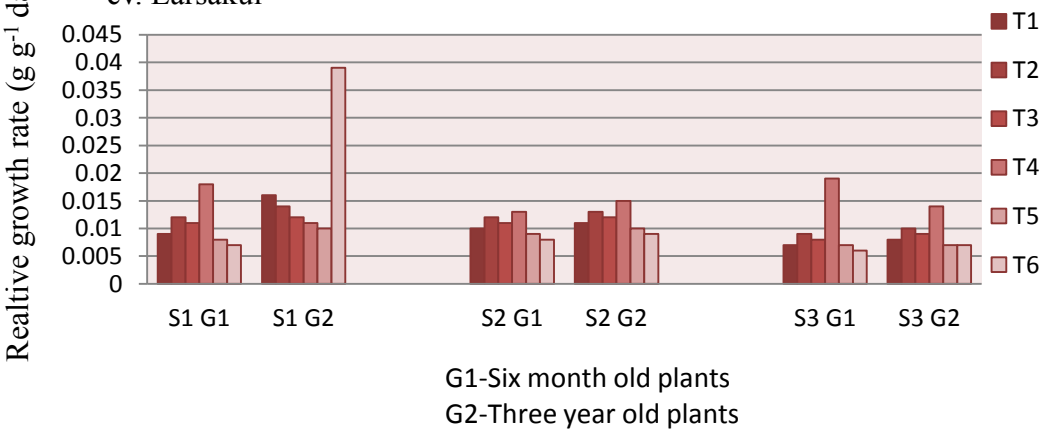


Fig. 63. Influence of treatment interactions on relative growth rate in six month old and three year old plants of *Dendrobium* cv. Earsakul



Bone meal and two level shad house in three year old plants recorded maximum RGR (Fig. 63). Under fan and pad system, a uniform environmental condition with high relative humidity may facilitating the maximum RGR in six month old plants which are in active growth stage, whereas in three year old plants, NPK + GR + OM + VW + PGPRE + Bone meal combination was performing well under two level shade house in increasing RGR.

5.3.5 Net assimilation rate

Treatments had no significant effect on NAR at both stages of plant growth (Tables 10, 11 and Fig. 64).

Among systems of growing, top ventilated polyhouse in six month old plants and two level shade house in three year old plants recorded higher NAR (Fig. 65). The finding is supported by Samasya (2000) in *Dendrobium*.

The combination of NPK + GR + OM + VW + PGPRE + Bone meal had more influence on NAR in top ventilated polyhouse in six month old plants and two level shade house in three year old plants (Fig. 66). The interaction effect was clearly suggesting the results of plant growth promoters and systems of growing in independent cases on NAR.

5.3.6 Number of stomata

The combination of POP + OM + VW + PGPRE + Bone meal + GR in six month old plants and POP + OM + VW + PGPRE + Bone meal in three year old plants recoded higher number of stomata (Tables 10, 11 and Fig. 67). The number of leaves per plant in six month old plants might be high due to influence of growth regulators. Whereas in three year old plants, the individual leaf area were more. This may be the result of more number of stomata due to increasing number of leaves and larger area of the leaves in six month old and three year old plants. A similar trend was recorded in *Dendrobium* by Yukawa *et al*. (1992).

The fan and pad system recorded highest number of stomata in both the stages of plants (Fig. 68). Under fan and pad system, the uniform environmental

Fig. 64. Influence of plant growth promoters (treatments) on net assimilation rate in six month old and three year old plants of *Dendrobium* cv. Earsakul

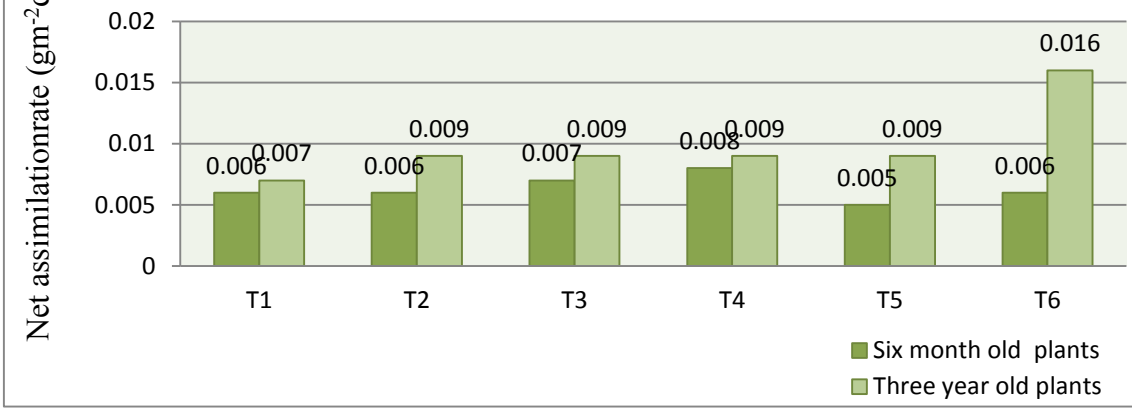


Fig. 65. Influence of growing systems on net assimilation rate in six month old and three year old plants of *Dendrobium* cv. Earsakul

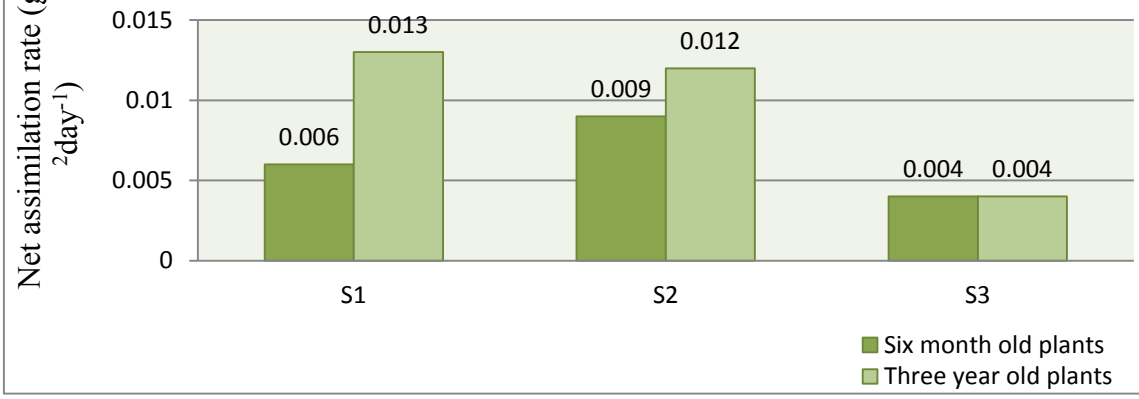


Fig. 66. Influence of treatment interactions on net assimilation rate in six month old and three year old plants of *Dendrobium* cv. Earsakul

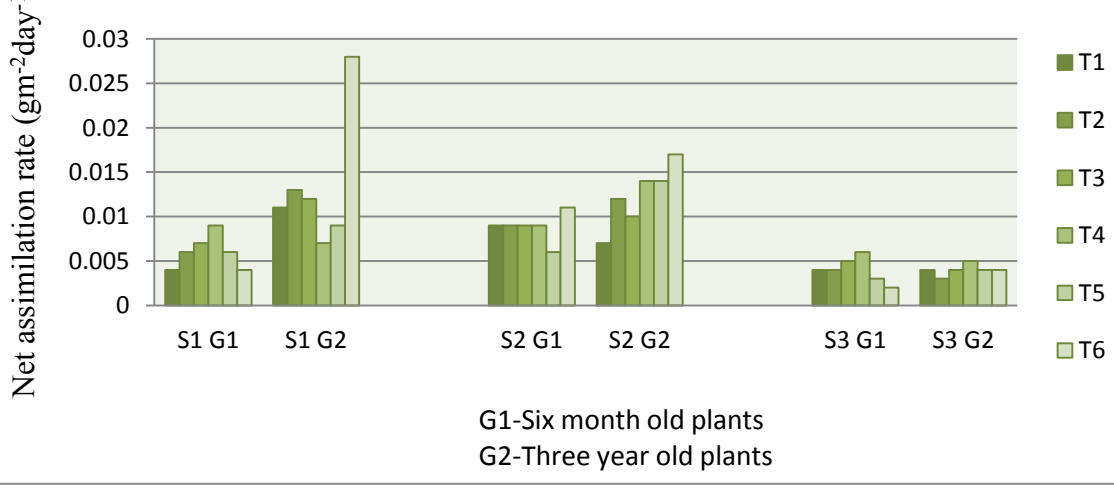


Fig. 67. Influence of plant growth promoters (treatments) on number of stomata in six month old and three year old plants of *Dendrobium* cv. Earsakul

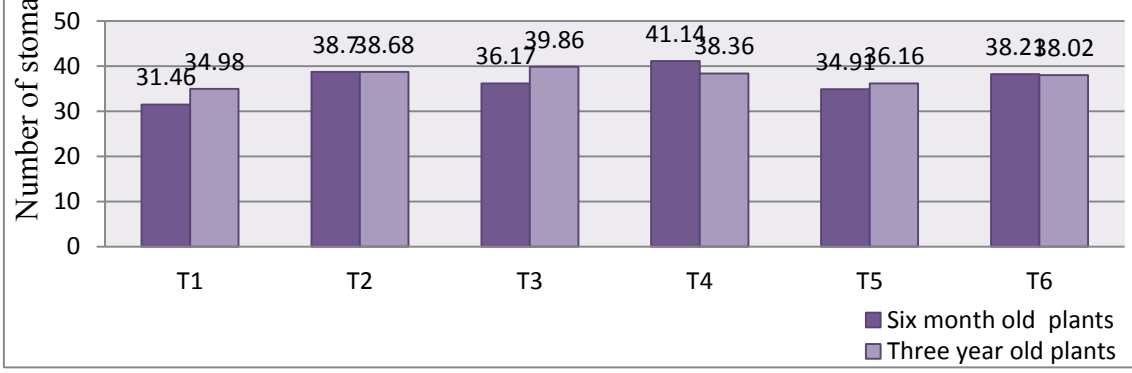
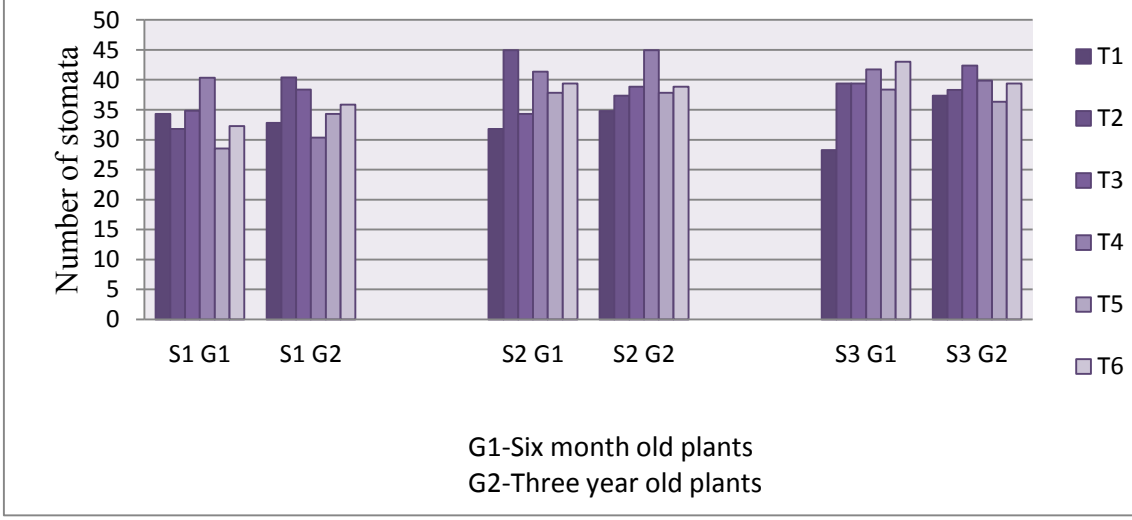


Fig. 68. Influence of growing systems on number of stomata in six month old and three year old plants of *Dendrobium* cv. Earsakul

Fig. 69. Influence of treatment interactions on number of stomata in six month old and three year old plants of *Dendrobium* cv. Earsakul



conditions were maintained throughout the growth phase of the plants. This may be the adaptations for maintaining the physiological processes of the plants.

The combination of POP + PGPRE + Bone meal and top ventilated polyhouse in six month old plants, POP + OM + VW + PGPRE + Bone meal + GR and top ventilated polyhouse in three year old plants had more influence on number of stomata (Fig. 69). This may be due to the fact that in top ventilated polyhouse, the favourable environmental conditions would have influenced the number of stomata in the leaves of both stages of plants.

5.3.7 Rate of photosynthesis

The combination of POP + OM + VW + PGPRE + Bone meal in six month old plants recorded significantly higher rate of photosynthesis (Tables 10, 11 and Fig. 70). The positive effect of POP + OM + VW + PGPRE + Bone meal in increasing DMP and CGR were recorded in earlier results which indicated that higher the rate of photosynthesis would increase the food reserves which subsequently increased DMP and CGR.

Top ventilated polyhouse in six month old plants and fan and pad system in three year old plants recorded highest photosynthetic rate (Fig. 71). This may be explained by the fact that the six month old plants were in active growth stage. Under top ventilated polyhouse system, high temperature and high light intensity result in higher rate of photosynthesis, whereas in three year old plants, uniform environmental conditions of fan and pad system resulted in higher rate of photosynthesis.

The combination of POP + OM + VW + PGPRE + Bone meal and top ventilated polyhouse in six month old plants, POP + OM + VW + PGPRE + Bone meal + GR and fan pad system in three year old plants recorded maximum rate of photosynthesis (Fig. 72). The interaction results in the six month old plants conformed the earlier results in independent observations, whereas in three year old plants, the treatment POP + OM + VW + PGPRE + Bone meal + GR was

Fig. 70. Influence of plant growth promoters (treatments) on rate of photosynthesis in six month old and three year old plants of *Dendrbium* cv. Earsakul

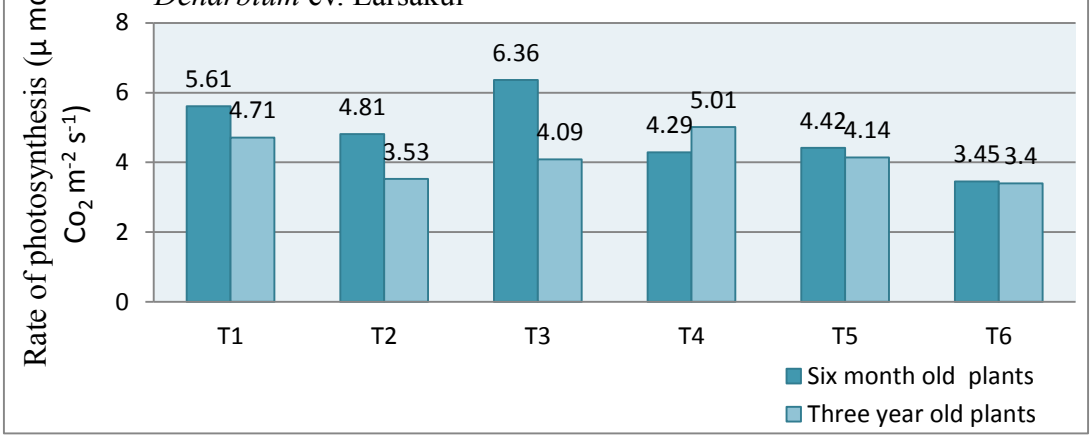


Fig. 71. Influence of growing systems on rate of photosynthesis in six month old and three year old plants of *Dendrobium* cv. Earsakul

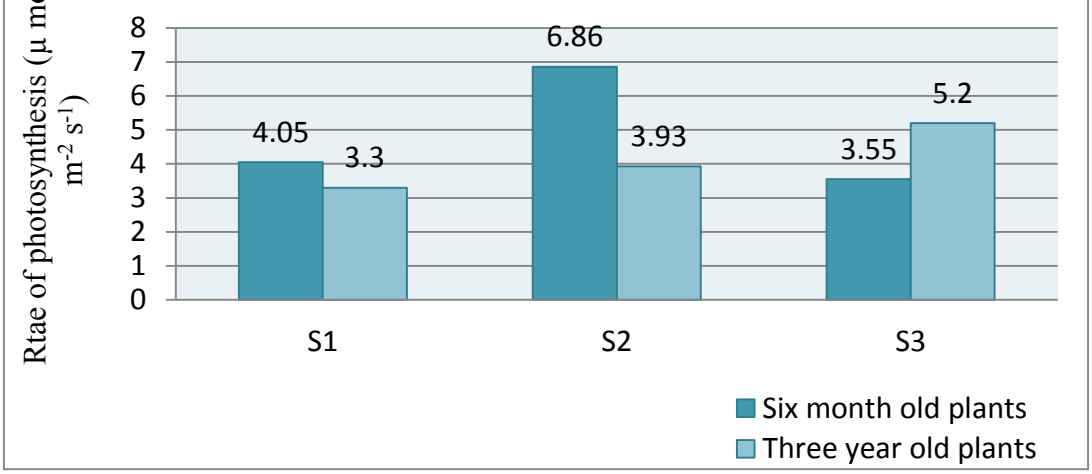


Fig. 72. Influence of treatment interactions on rate of Photosynthesis in six month old and three year old plants of *Dendrobium* cv. Earsakul

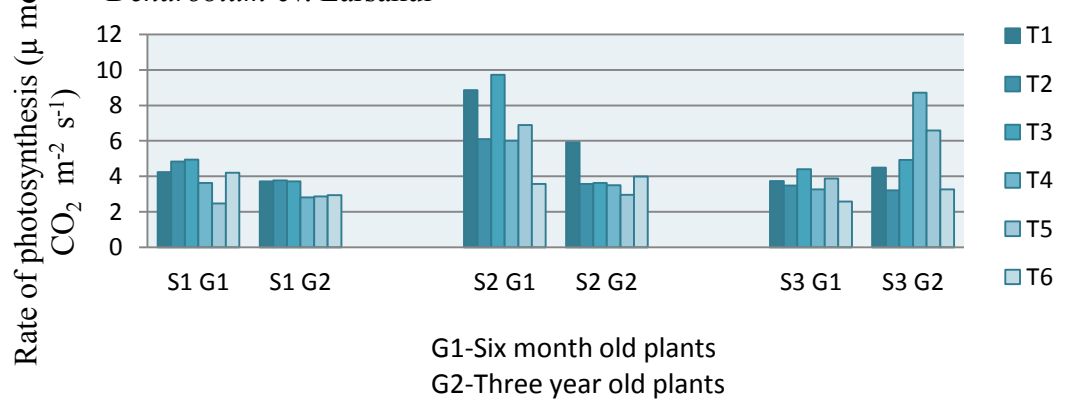


Fig. 73. Influence of plant growth promoters (treatments) on rate of transpiration (at night time) in six month old and three year old plants of *Dendrobium* cv. Earsakul

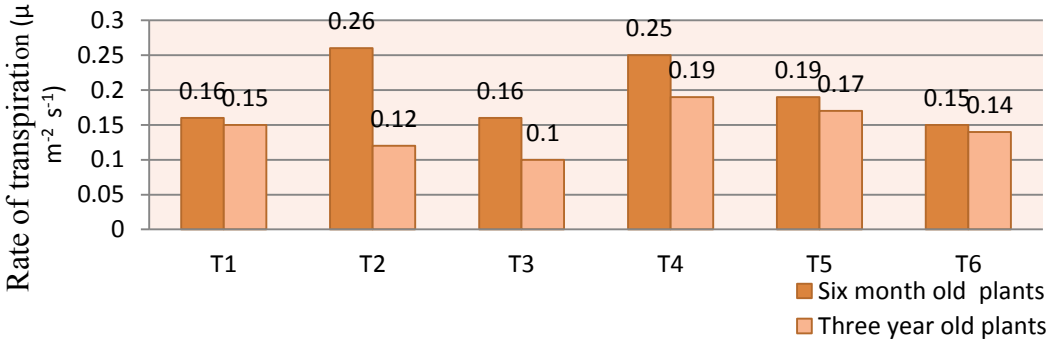


Fig. 74. Influence of growing systems on rate of transpiration (at night time) in six month old and three year old plants of *Dendrobium* cv. Earsakul

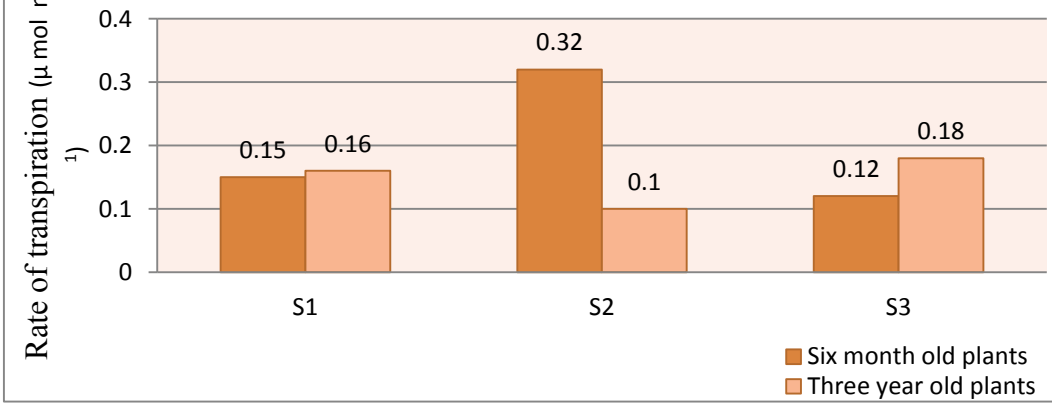
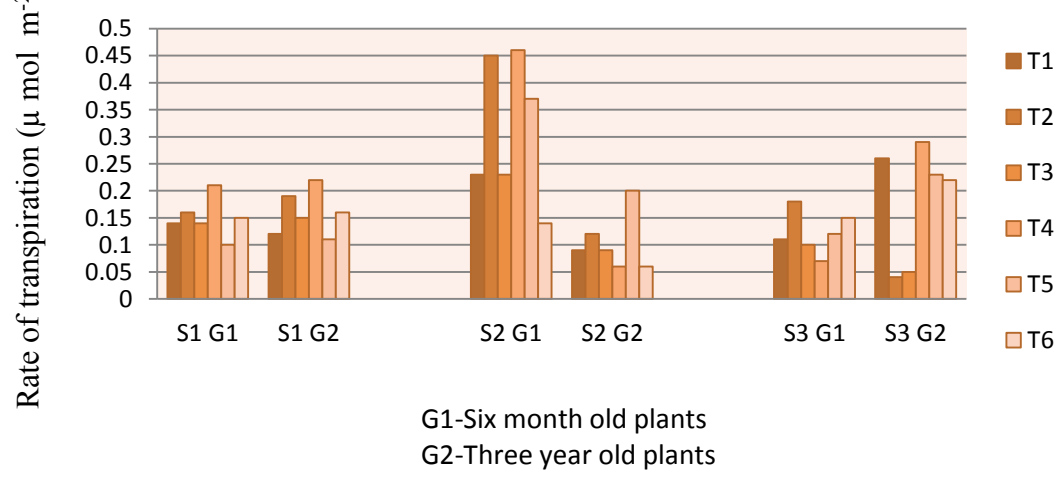


Fig. 75. Influence of treatment interactions on rate of transpiration (at night time) in six month old and three year old plants of *Dendrobium* cv. Earsakul



performed well under fan and pad system for recording highest photosynthetic rate.

5.3.8 Transpiration rate at night time

The treatment POP + PGPRE + Bone meal in six month old plants recorded highest rate of transpiration during night (Tables 10 and Fig. 73). The *P. indica* and plant growth promoters access to more growth and more water and hence promoted higher rate of transpiration.

Top ventilated polyhouse recorded highest rate of transpiration in six month old plants (Fig. 74). This could be due to higher temperature, lower relative humidity would result in gradient in vapour pressure deficit resulting in higher rate of transpiration. The results in the present study was parallel with the findings of Nagoaka *et al*. (1984) and Samasya (2000) in *Dendrobium*.

The combination of POP + OM + VW + PGPRE + Bone meal + GR and top ventilated polyhouse in six month old plants, POP + OM + VW + PGPRE + Bone meal + GR and fan and pad system in three year old plants recorded highest transpiration rate during night time (Fig. 75). This might be due to reason that positive influences of plant growth promoter's favours for better growth of the plants *i.e.* number of leaves per plant, leaf area, number of stomata were higher in earlier results. Higher temperature and lower relative humidity prevailing in side top ventilated polyhouse favour for higher transpiration rate in six month old plants.

5.3.9 Transpiration rate at day time

The combination of POP + OM + VW + PGPRE + Bone meal in six month old plants and NPK + GR + OM + VW + PGPRE + Bone meal in three year old plants recorded significantly higher rate of transpiration during day time (Tables 10, 11 and Fig. 76). This might be due to positive influence of all applied plant growth promoters favour for luxurious growth of the plants there by resulted

in increased rate of transpiration during day time and *i.e.* the indication for healthy growth of the plants.

Among systems of growing, top ventilated polyhouse in six month old plants and two level shade house in three year old plants recorded maximum rate of transpiration during day time (Fig. 77). The reasons for highest transpiration rate under top ventilated polyhouse are higher temperature, high light intensity and low relative humidity. In high light intensity, the water present in mesophyll cells diffuses rapidly resulting in increase in humidity of internal air and this increases the rate of transpiration (Cho and Kwack, 1996). In three year old plants also, the environmental conditions prevailing in two level shade house would have influenced higher rate of transpiration during day time.

The combination of NPK + GR and top ventilated polyhouse in six month old plants, NPK + GR + OM + VW + PGPRE + Bone meal and two level shade house in three year old plants recorded significantly highest rate of transpiration during day time (Fig. 78).

5.3.10 Diffusive resistance

The treatment NPK + GR + OM + VW + PGPRE + Bone meal in six month old plants and NPK + GR in three year old plants recorded significantly higher diffusive resistance (Tables 12, 13 and Fig. 79). It is evident that the rate of transpiration during day time was low in earlier results in the treatment NPK + GR + OM + VW + PGPRE + Bone meal in six month old plants (Table 10) and NPK + GR in three year old plants (Table 11). The rate of transpiration is lower and the diffusive resistance was generally higher. This is most likely because of the lower water absorption by the plants. These results are in conformity with the findings of Stancato *et al*. (2002) in *Cattleya*.

Two level shade house in six month old plants and top ventilated polyhouse in three year old plants recorded higher diffusive resistance (Fig. 80). The favourable environmental conditions of the systems which might have

Fig. 76. Influence of plant growth promoters (treatments) on rate of transpiration (at day time) in six month old and three year old plants of *Dendrobium* cv. Earsakul

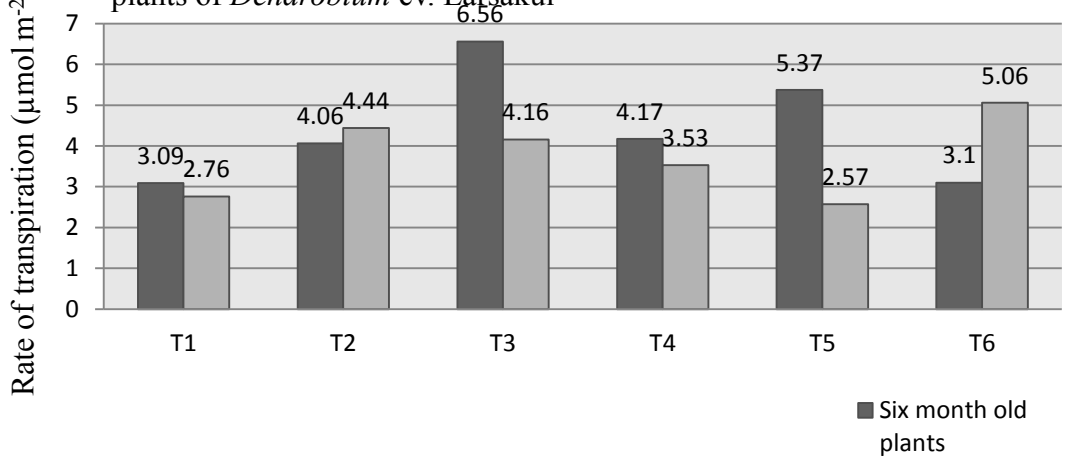


Fig. 77. Influence of growing systems on rate of transpiration (at day time) in six month old and three year old plants of *Dendrobium* cv. Earsakul

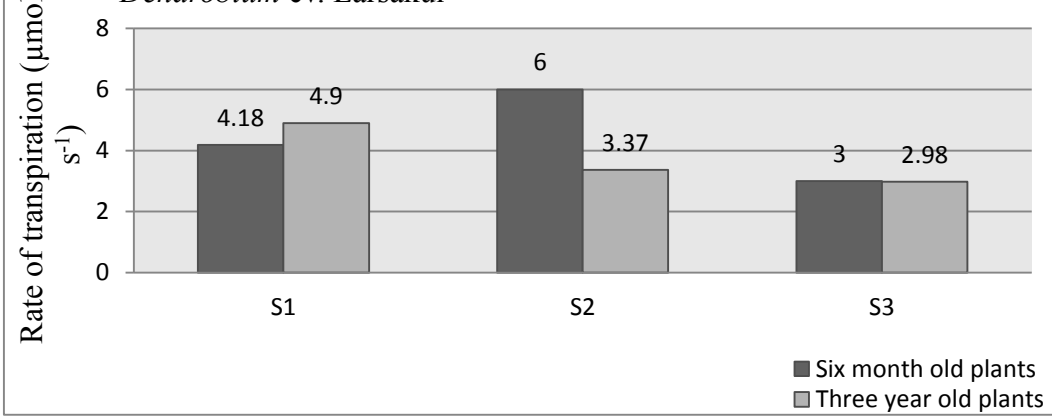


Fig. 78. Influence of treatment interactions on rate of transpiration (at day time) in six month old and three year old plants of *Dendrobium* cv. Earsakul

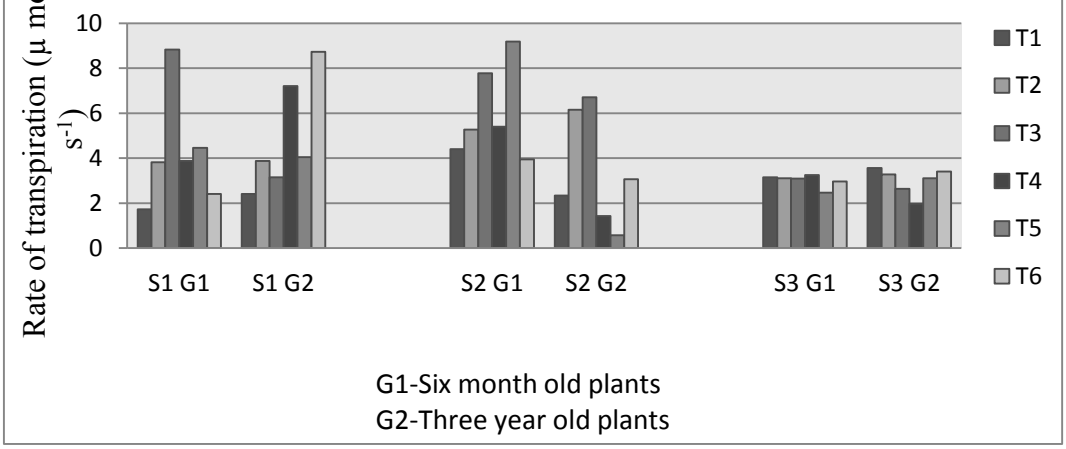


Fig. 79. Influence of plant growth promoters (treatments) on diffusive resistance in six month old and three year old plants of *Dendrobium* cv. Earsakul

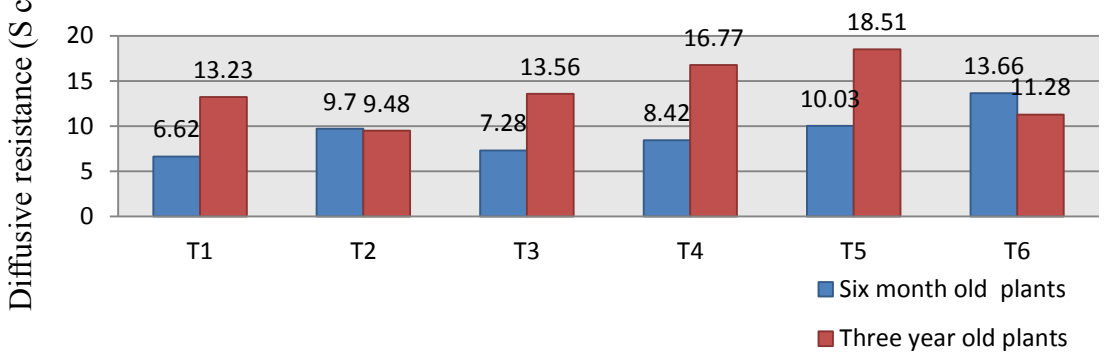


Fig. 80. Influence of growing systems on diffusive resistance in six month old and three year old plants of *Dendrobium* cv. Earsakul

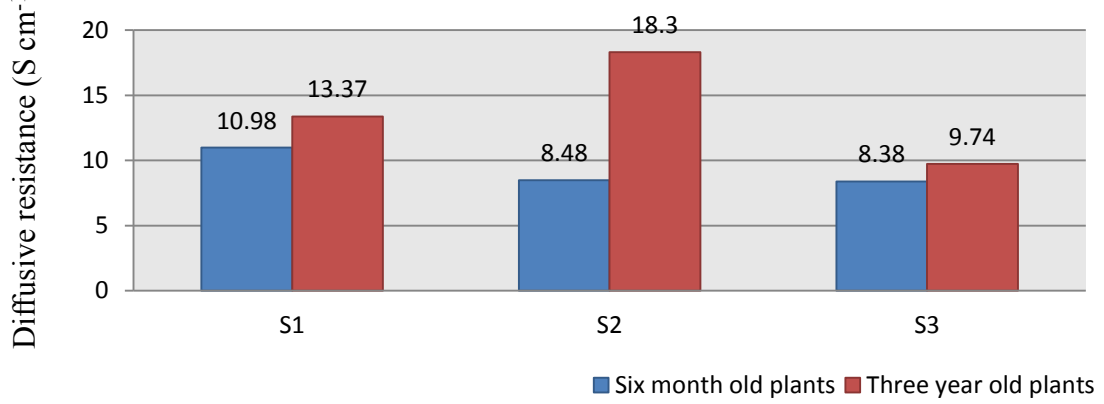
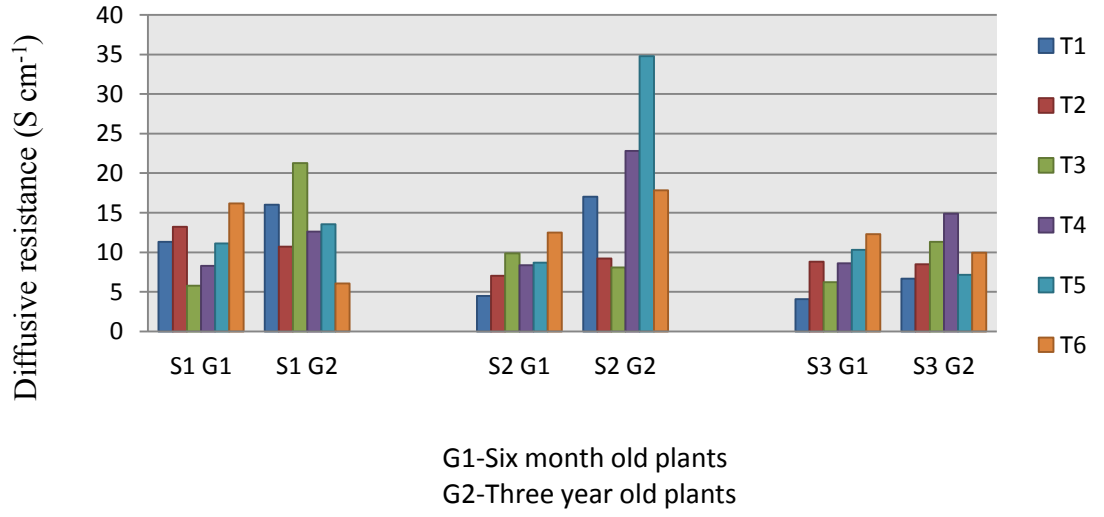


Fig. 81. Influence of treatment interactions on diffusive resistance in six month old and three year old plants of *Dendrobium* cv. Earsakul



resulted in higher diffusive resistance in two level shade house and top ventilated polyhouse.

The combination of NPK + GR + OM + VW + PGPRE + Bone meal and two level shade house in six month old plants, NPK + GR and top ventilated polyhouse in three year old plants had significant influence on diffusive resistance (Fig. 81). This might be due to the influence of plant growth promoters and systems of growing influenced diffusive resistance.

5.3.11 Chlorophyll content

The effect of treatments on chlorophyll 'a' content was not significant in both stages of plants (Tables 12, 13 and Fig. 82). Top ventilated polyhouse had significant influence on chlorophyll 'a' content in three year old plants (Fig. 83). The combination of NPK + GR + OM + VW + PGPRE + Bone meal and two level shade house in six month old plants, POP + OM + VW + PGPRE + Bone meal and top ventilated polyhouse in three year old plants recorded significantly higher chlorophyll 'a' content (Fig. 84).

The treatment NPK + GR recorded significantly higher chlorophyll 'b' content in three year old plants (Fig. 82). Among systems of growing, two level shade house had maximum influence on chlorophyll 'b' content irrespective of the age of the plants (Fig. 83). The combination of POP + OM + VW + PGPRE + Bone meal + GR and NPK + GR responding more influence on chlorophyll 'b' content in two level shade house in both stages of the plants (Fig. 84).

The ratio of chlorophyll 'a' to chlorophyll 'b' in the chloroplast is normally 3:1. It is known that the chlorophyll a to b ratio is higher in high-light growth conditions than in low - light growth conditions (*i.e*. more chlorophyll b in shade plants). Chlorophyll 'b' absorbs light at different wavelengths than chlorophyll 'a' and extends the range of light that could be used for photosynthesis.

Fig. 82. Influence of plant growth promoters (treatments) on chlorophyll content in six month old and three year old plants of *Dendrobium* cv. Earsakul

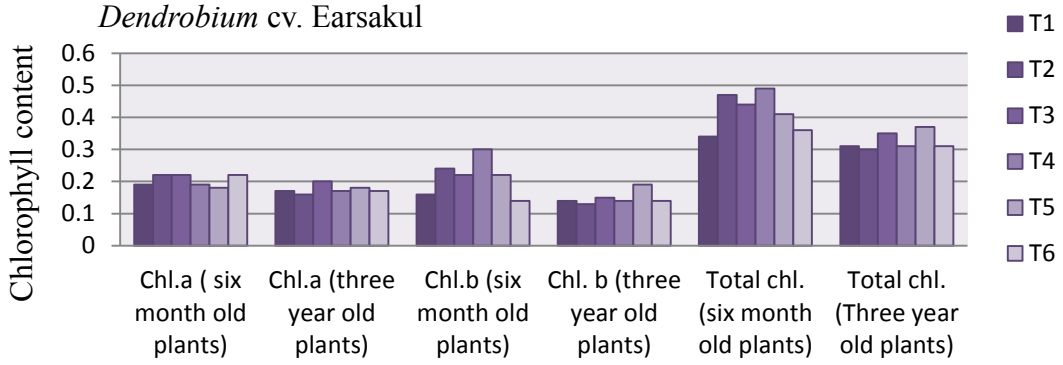


Fig. 83. Influence of growing systems on chlorophyll content in six month old and three year old plants of *Dendrobium* cv. Earsakul

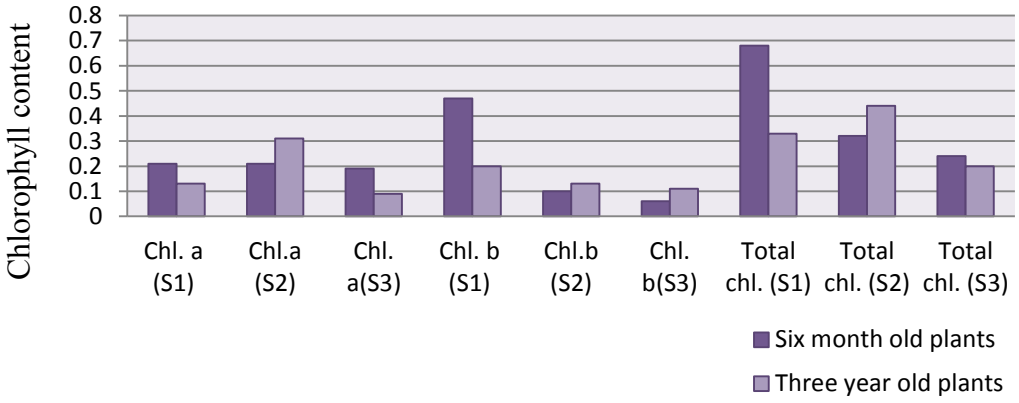
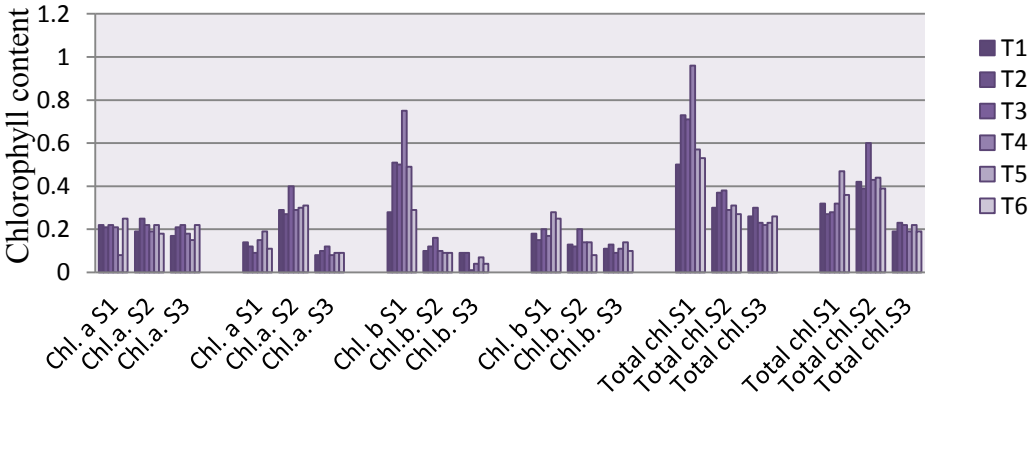


Fig. 84. Influence of TxS interaction on chlorophyll a, b and total chlorophyll content in six month old and three year old plants of *Dendrobium* cv. Earsakul



It is inferred that, application of different plant growth promoters had no significant effect on total chlorophyll content in both stages of plants (Fig. 82). The application of plant growth promoters did not showed variation on total chlorophyll content of leaves. Two level shade house in six month old plants and top ventilated polyhouse in three year old plants recorded significantly higher total chlorophyll content (Fig. 83). The reason might be explained that due to favourable weather conditions in the systems, the growth of the plants are luxurious because of the higher total chlorophyll content.

The combination of POP + OM + VW + PGPRE + Bone meal + GR and two level shade house in six month old plants, POP + OM + VW + PGPRE + Bone meal and top ventilated polyhouse in three year old plants recorded significantly higher total chlorophyll content (Fig. 84). This is explained that, when there is a higher total chlorophyll content and naturally higher the plant growth, higher rate of photosynthesis, more transpiration occur as per previous results and hence the result for higher total chlorophyll content in the leaves. The amount of chlorophyll present had a direct relationship with the rate of photosynthesis because it is the pigment which is photoreceptive and is directly involved in trapping the light energy.

5.4 Root parameters

5.4.1 Number of roots per plant

The treatment NPK + GR + OM + VW + PGPRE + Bone meal recorded significantly higher number of roots in both stages of plants (Tables 14, 15 and Fig. 85). The phosphorus nutrient in the early stages of growth is beneficial for producing more number of roots per plant. The plants having higher number of shoots and beneficial effects of *P. indica* which enhanced the better root system which in turn helps in rapid growth of the plant and ultimately plants are having maximum number of roots per plant. These results are in conformity with the findings of Dhinesh (2009) in *Dendrobium*.

Among systems of growing, top ventilated polyhouse had significant influence on number of roots per plant irrespective of the age of the plants (Fig.

Fig. 85. Influence of plant growth promoters (treatments) on number of roots per plant in six month old and three year old plants of *Dendrobium* cv. Earsakul

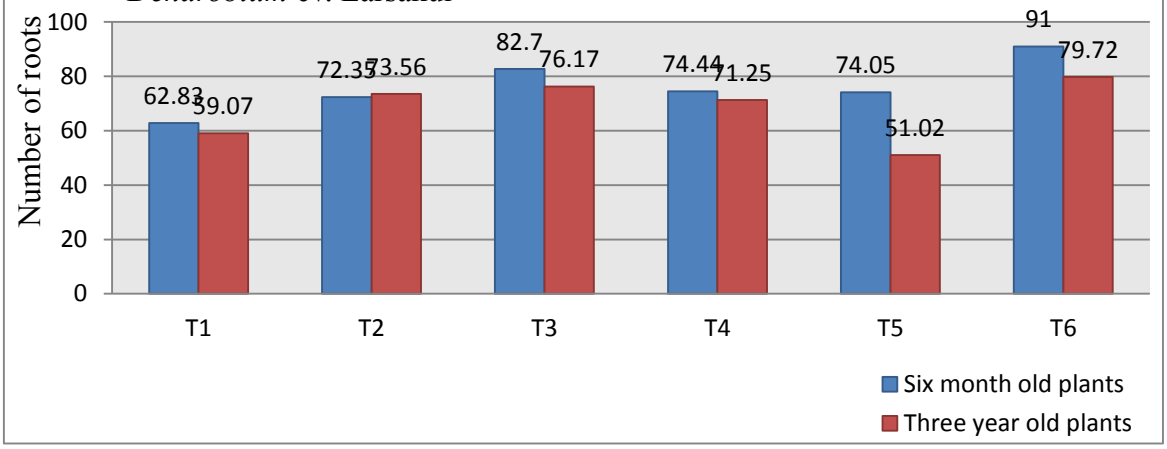


Fig. 86. Influence of growing systems on number of roots per plant in six month old and three year old plants of *Dendrobium* cv. Earsakul

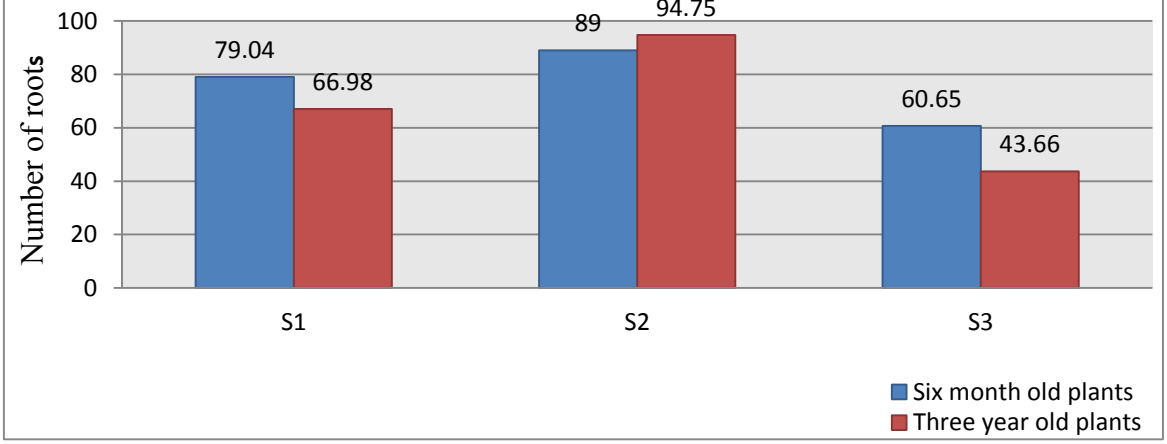
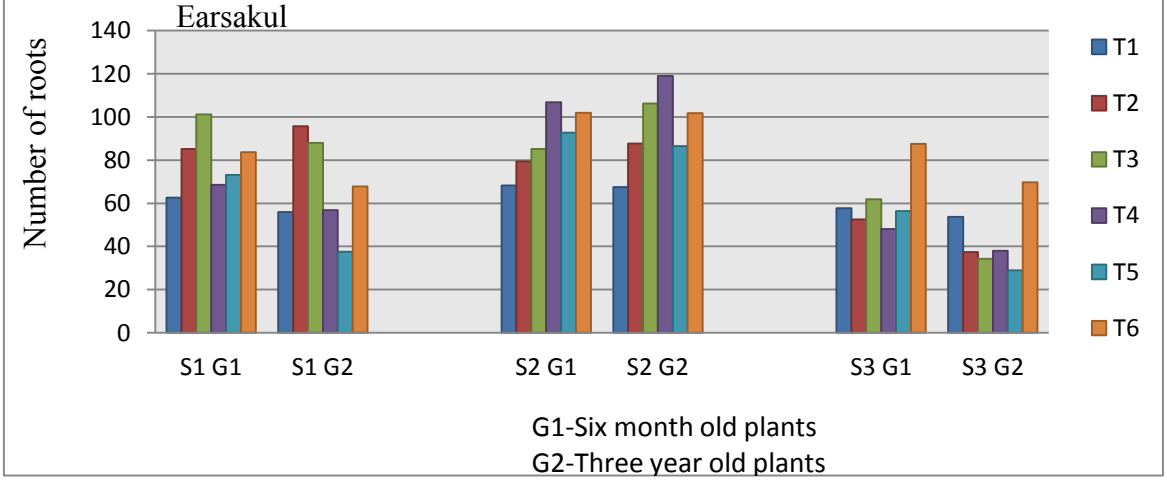


Fig. 87. Influence of treatment interactions on number of roots per plant in six month old and three year old plants of *Dendrobium* cv. Earsakul



86). The earlier results indicated that plant height, number of leaves, number of shoots were high in plants grown under top ventilated polyhouse. Hence in the same corollary, this result could be explained that system of growing influencing the number of roots per plant.

The combination of POP + OM + VW + PGPRE + Bone meal + GR and top ventilated polyhouse recorded significantly higher number of roots per plant in both stages of plants (Fig. 87). The result of the study clearly indicated that application of *P. indica* influencing the production of number of roots per plant under top ventilated polyhouse.

5.4.2 Root length

The treatment POP + OM + VW + PGPRE + Bone meal + GR in six month old plants and POP + OM + VW + PGPRE + Bone meal in three year old plants recorded significantly higher root length (Tables 14, 15 and Fig. 88). The reason might be due to that the *P. indica* made the P available to the plants which in turn increase the length of the roots.

Top ventilated polyhouse had significant influence on root length irrespective of the age of the plants (Fig. 89). The plants under top ventilated polyhouse exhibited increased plant height, more number of leaves and number of shoots. This may be the reason for more root length observed in top ventilated polyhouse.

The combination of POP + OM + VW + PGPRE + Bone meal + GR in six month old plants and POP + OM + VW + PGPRE + Bone meal in three year old plants recorded significantly higher root length in top ventilated polyhouse (Fig. 90).

5.4.3 Root volume

Among various plant growth promoters, NPK + GR + OM + VW + PGPRE + Bone meal recorded highest root volume in both stages of plants (Tables 14, 15 and Fig. 91). The treatment NPK + GR + OM + VW + PGPRE +

Fig. 88. Influence of plant growth promoters (treatments) on root length (cm) in six month old and three year old plants of *Dendrobium* cv. Earsakul

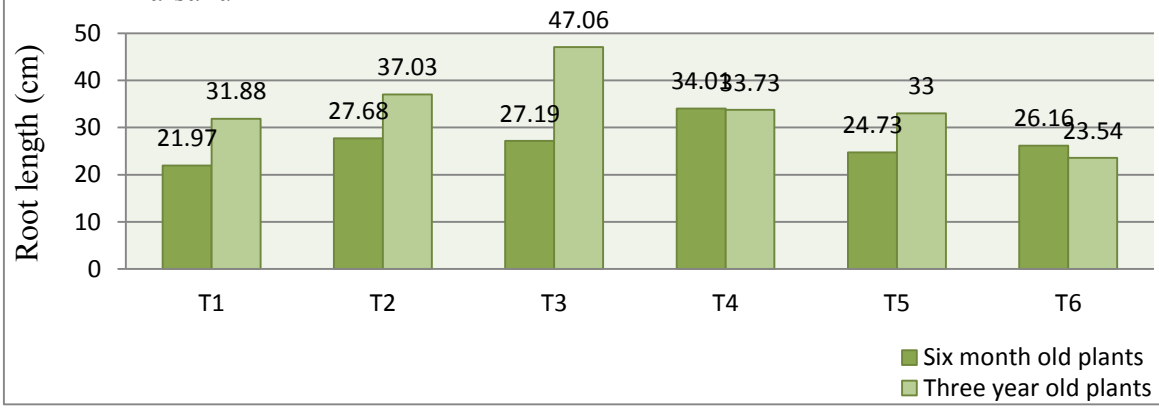


Fig. 89. Influence of growing systems on root length (cm) in six month old and three year old plants of *Dendrobium* cv. Earsakul

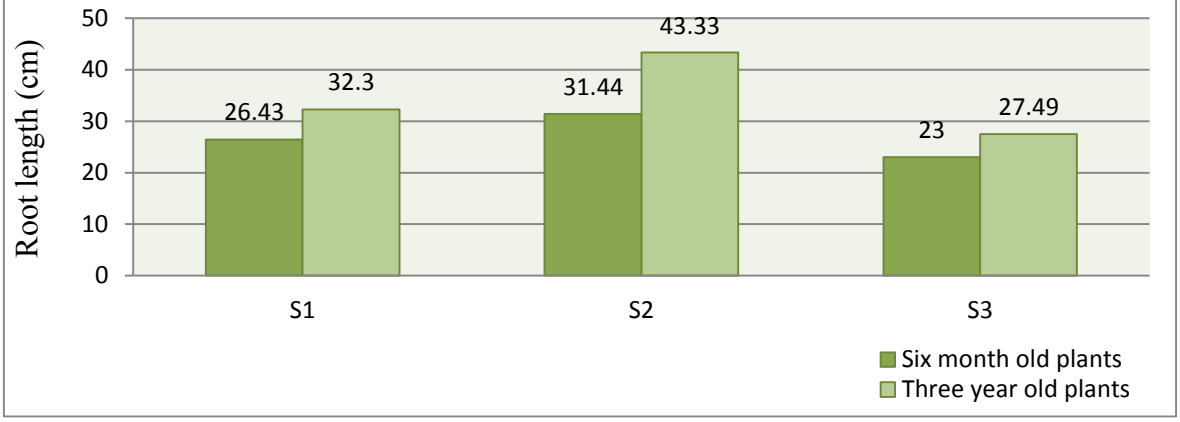


Fig. 90. Influence of treatment interactions on root length in six month old and three year old plants of *Dendrobium* cv. Earsakul

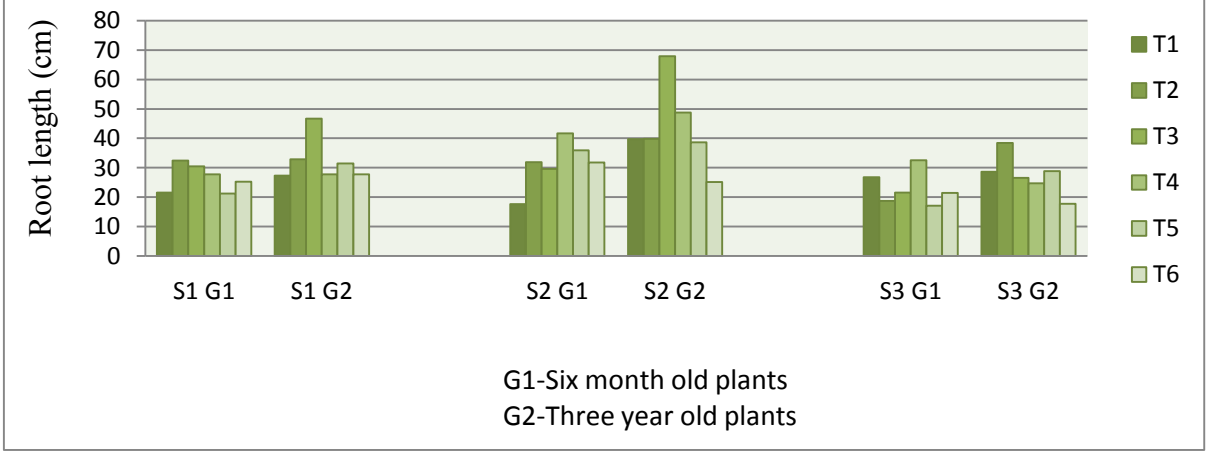


Fig. 91. Influence of plant growth promoters (treatments) on root volume in six month old and three year old plants of *Dendrobium* cv. Earsakul

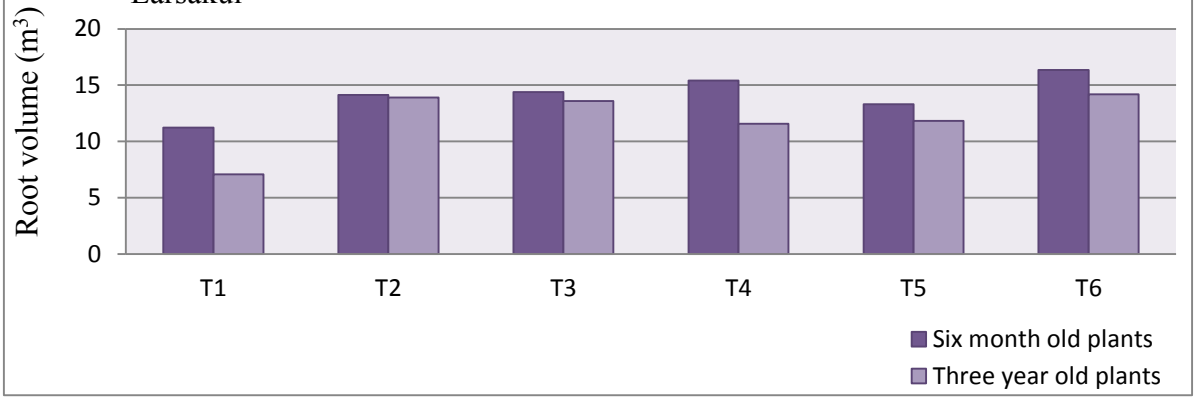


Fig. 92. Influence of growing systems on root volume in six month old and three year old plants of *Dendrobium* cv. Earsakul

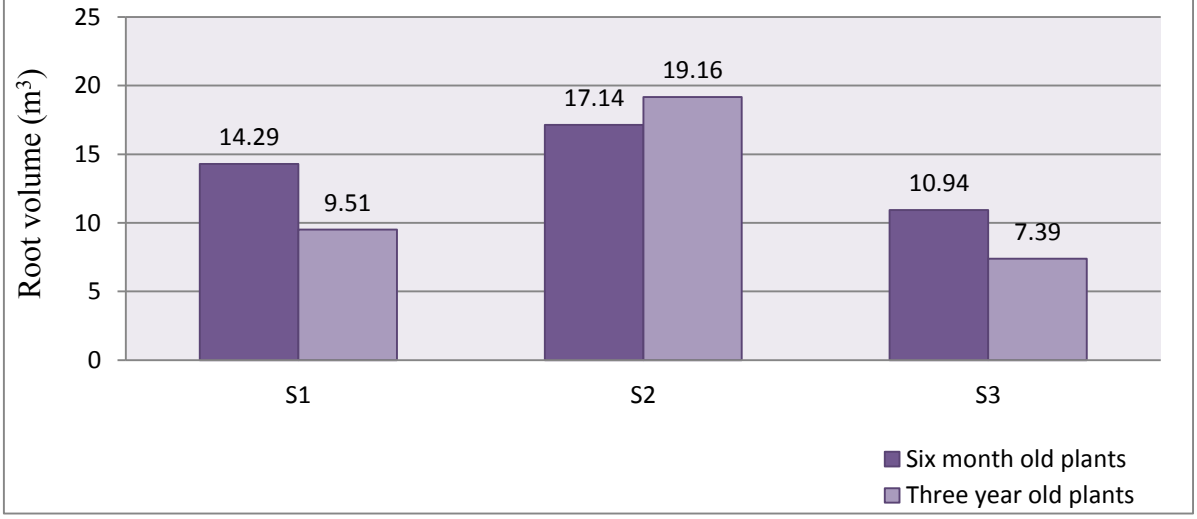
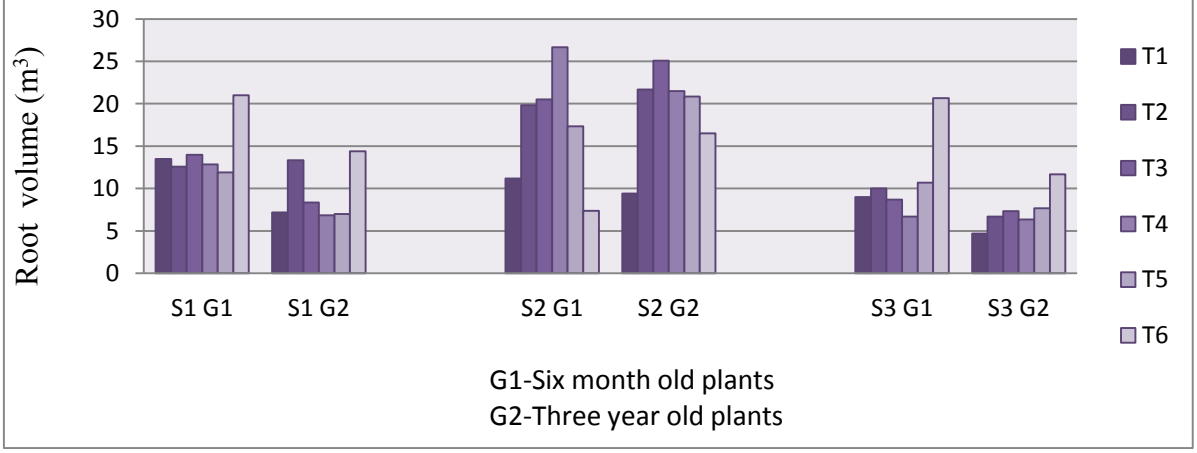


Fig. 93. Influence of treatment interactions on root volume in in six month old and three year old plants of *Dendrobium* cv. Earsakul



Bone meal recorded highest number of roots per plant in both stages of plants and this might be the reason for highest root volume in six month and three year old plants. The results are in conformity with the findings of Dhinesh (2009) in *Dendrobium*.

Top ventilated polyhouse had significant influence on root volume irrespective of the age of the plants (Fig. 92). Congenial environmental conditions

favoured better root growth which in turn more root volume. Plants grown under top ventilated polyhouse recorded maximum number of roots and root length. This resulted in high root volume in top ventilated polyhouse.

The combination of POP + OM + VW + PGPRE + Bone meal + GR in six month old plants and POP + OM + VW + PGPRE + Bone meal in three year old plants recorded significantly higher root volume in top ventilated polyhouse (Fig. 93).

5.4.4 Root colonization of *Piriformospora indica*

Root colonization study revealed that treatment POP + OM + VW + PGPRE + Bone meal + GR in six month old plants, NPK + GR + OM + VW + PGPRE + Bone meal in three year old plants recorded highest root colonization of *P. indica.* (Tables 14, 15 and Fig. 94). Enhanced root production, root volume and root colonization of *P. indica* was observed in treatment combination involving *P. indica*. The positive influence of *P. indica* for the above root parameters was clearly evident from this study. In the present study, *P. indica* had a positive effect on root parameters, which confirm with the observation of Dhinesh (2009) in *Dendrobium*.

Top ventilated polyhouse had significant influence on root colonization of *P. indica* irrespective of the age of the plants (Fig. 95). Higher temperature is the main reason for higher root colonization in the system of growing. It was reported that *P. indica* at higher temperature (25-35 ^{0}C) resulted in higher mycelial growth (Varma *et al*., 1999) and the higher temperature prevailing in the top ventilated

Fig. 94. Influence of plant growth promoters (treatments) on root colonization in six month old and three year old plants of *Dendrobium* cv. Earsakul

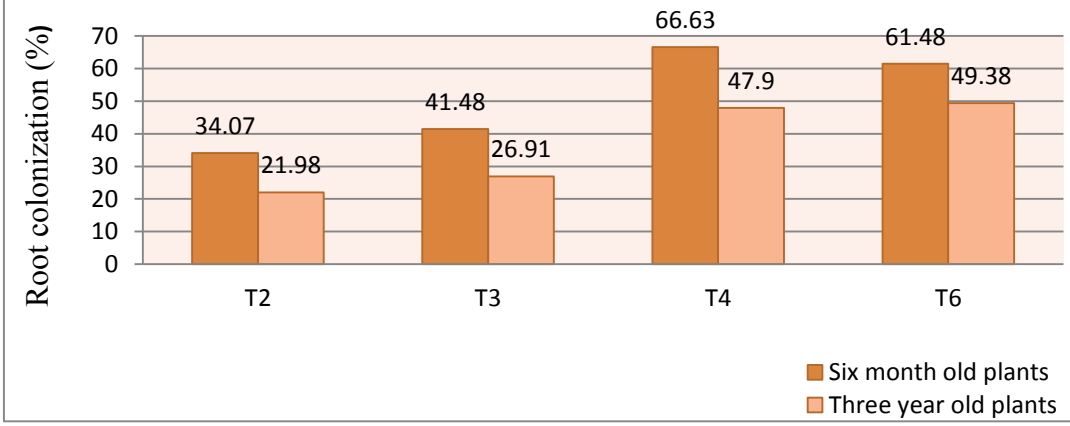


Fig. 95. Influence of growing systems on root colonization in six month old and three year old plants of *Dendrobium* cv. Earsakul

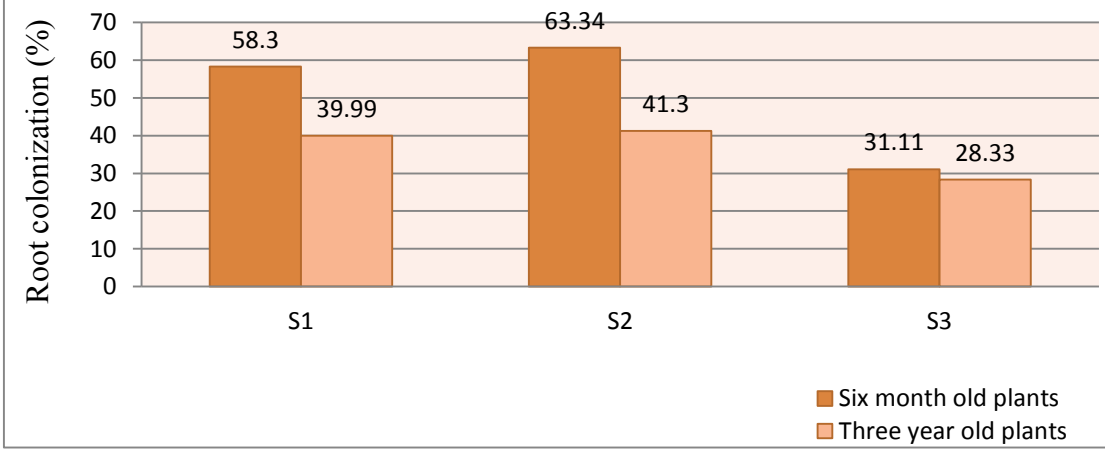
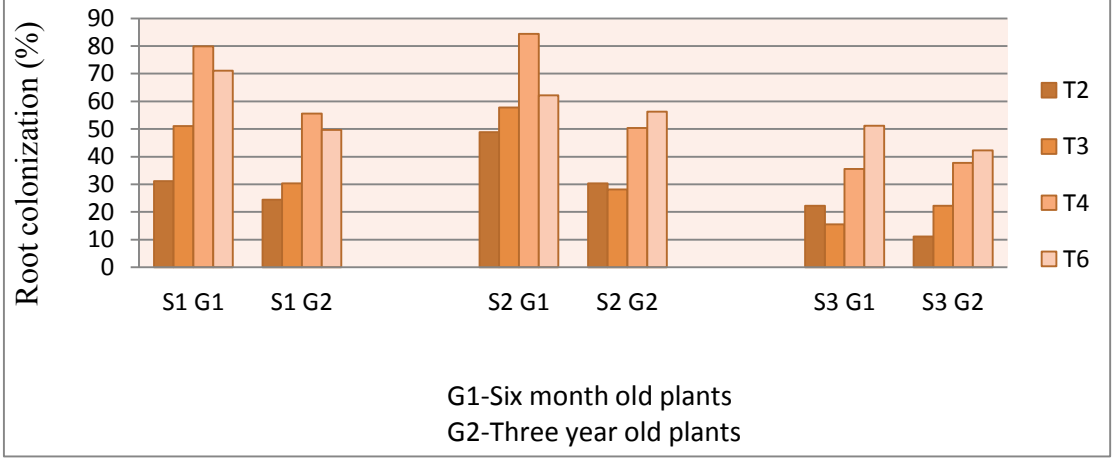


Fig. 96. Influence of treatment interactions on root colonization in six month old and three year old plants of *Dendrobium* cv. Earsakul



polyhouse (29.25 to 35.95 ^{0}C) might be the possible reason for higher root colonization.

The combination of POP + OM + VW + PGPRE + Bone meal + GR and NPK + GR + OM + VW + PGPRE + Bone meal had more positive influence on root colonization of *P. indica* in top ventilated polyhouse irrespective of age of the plants (Fig. 96). The results inferred and further confirmed the results of experiments of plant growth promoters and systems of growing independently.

5.5 Nutrient content

5.5.1 Nitrogen

The treatment POP + OM + VW + PGPRE + Bone meal + GR in six month old plants, POP + OM + VW + PGPRE + Bone meal in three year old plants recorded significantly higher N content (Tables 16, 17 and Fig. 97). The N content available in organic mixture, package of practices of recommendations (POP), vermiwash in the plant growth promoters would have supplemented N content in the plants.

Top ventilated polyhouse recorded significantly higher N content in six month old plants (Fig. 98). At higher light intensities, the percentage of nitrogen uptake by the plant was increased. This may be because of high light intensity which substantially increased the total number of expanded leaves, dry matter and ultimately more nitrogen content. This is in confirmation with the findings of Kubota and Yoneda (1993) in *Phalaenopsis*.

The treatment combination of POP + OM + VW + PGPRE + Bone meal + GR and top ventilated poly house in six month old plants, POP + OM + VW + PGPRE + Bone meal and two level shade house in three year old plants recorded highest N content (Fig. 99).

Fig. 97. Influence of plant growth promoters (treatments) on nitrogen content in six month old and three year old plants of *Dendrobium* cv. Earsakul

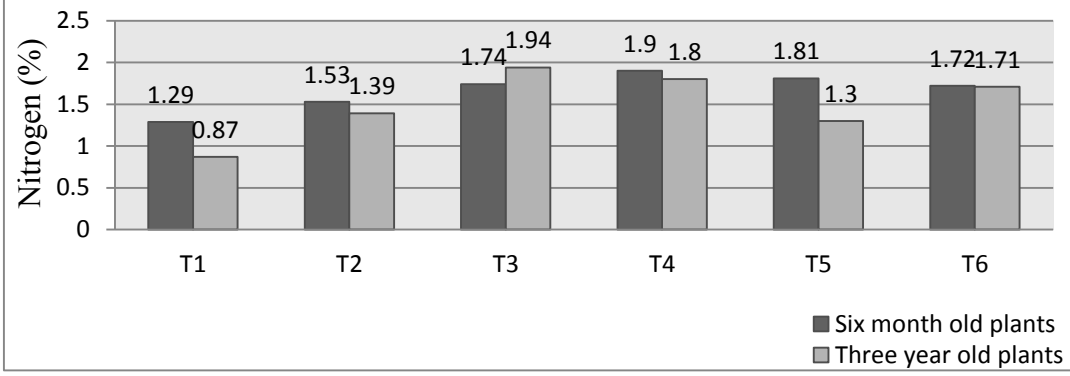


Fig. 98. Influence of growing systems on nitrogen content in six month old and three year old plants of *Dendrobium* cv. Earsakul

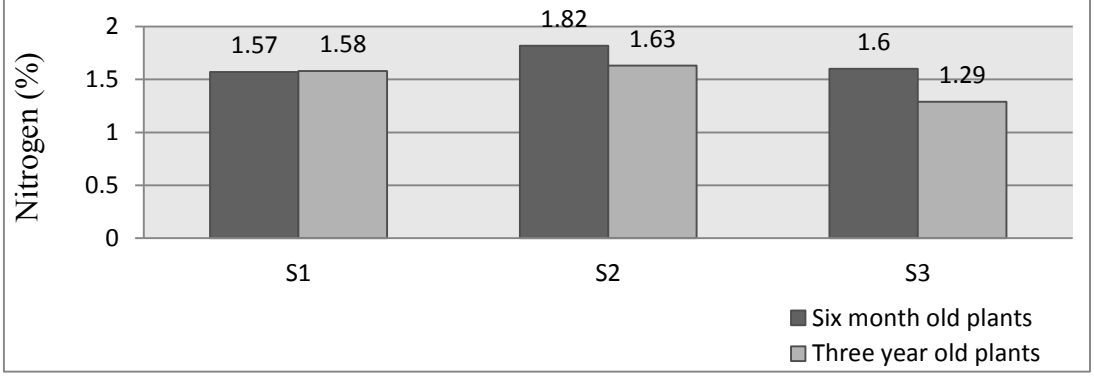
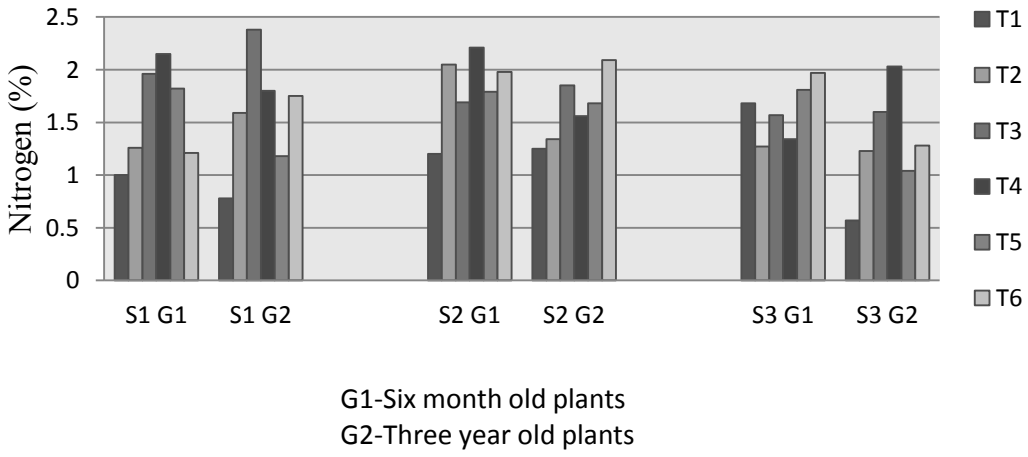


Fig. 99. Influence of treatment interactions on nitrogen content in six month old and three year old plants of *Dendrobium* cv. Earsakul



5.5.2 Phosphorus

The treatment POP + OM + VW + PGPRE + Bone meal + GR in six month old plants, POP + OM + VW + PGPRE + Bone meal in three year old plants recorded significantly higher P content (Tables 16, 17 and Fig. 100). This may be due to the presence of *P.indica* in both the cases of plant growth promoters would have made P available to the plants.

Among systems of growing, top ventilated polyhouse recorded significantly higher P content in both stages of plants (Fig. 101). This may be due to favourable environmental conditions under top ventilated polyhouse.

The treatment combination POP + OM + VW + PGPRE + Bone meal + GR and top ventilated polyhouse recorded highest P content in six month old plants (Fig. 102).

5.5.3 Potassium

The treatment POP + OM + VW + PGPRE + Bone meal + GR recorded significantly higher K content irrespective of age of the plants (Tables 16, 17 and Fig. 103). The application of NPK at the time of vegetative and flowering phase with 3:1:1 and 1:2:2 respectively resulted in high K content in the plants. Similar findings were made by Nair (2001) in *Dendrobium.*

Top ventilated polyhouse recorded highest K content in three year old plants (Fig. 104). This result further confirmed that the absorption rate of K might be more due to environmental conditions under top ventilated polyhouse.

The treatment combination POP + OM + VW + PGPRE + Bone meal + GR in six month old plants, NPK + GR + OM + VW + PGPRE + Bone meal in three year old plants recorded significantly higher K content in top ventilated polyhouse (Fig. 105).

Fig. 100. Influence of plant growth promoters (treatments) on phosphorus content in six month old and three year old plants of *Dendrobium* cv. Earsakul

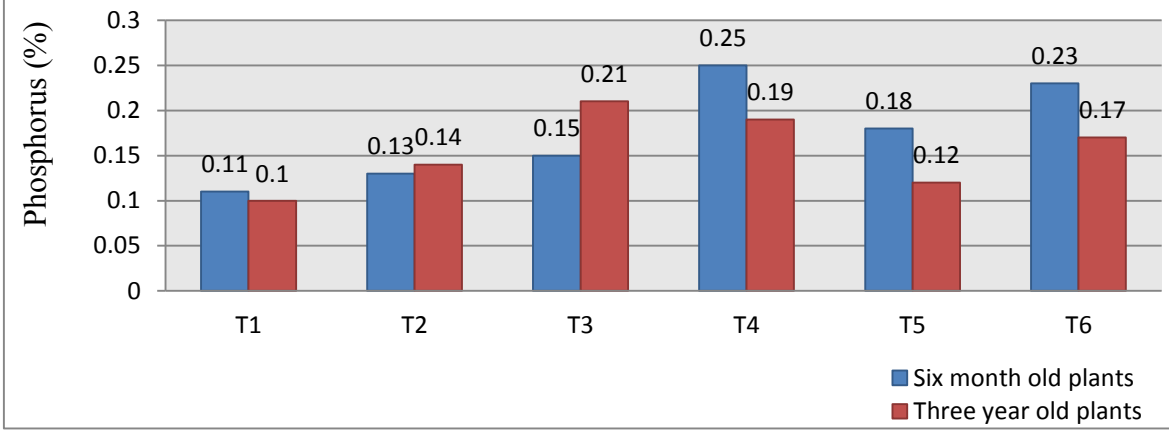


Fig. 101. Influence of growing systems on phosphorus content in six month old and three year old plants of *Dendrobium* cv. Eatrsakul

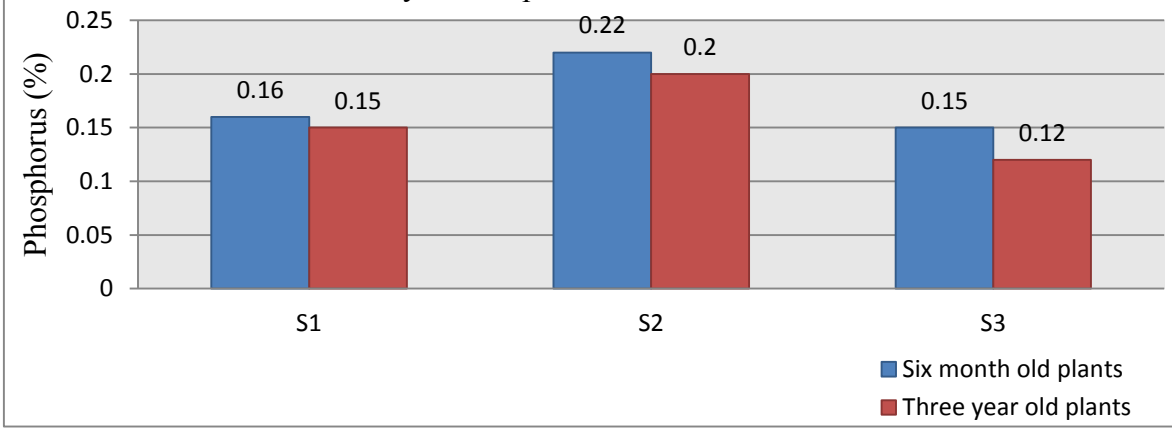


Fig. 102. Influence of treatment interactions on phosphorus content in six month old and three year old plants of *Dendrobium cv*. Earsakul

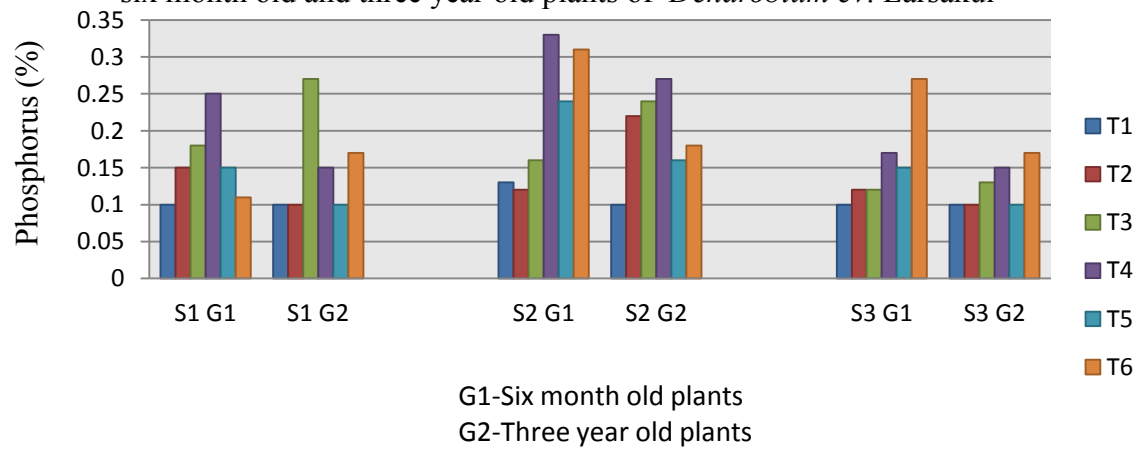


Fig. 103. Influence of plant growth promoters (treatments) on potasssium content in six month old and three year old plants of *Dendrobium* cv. Earsakul

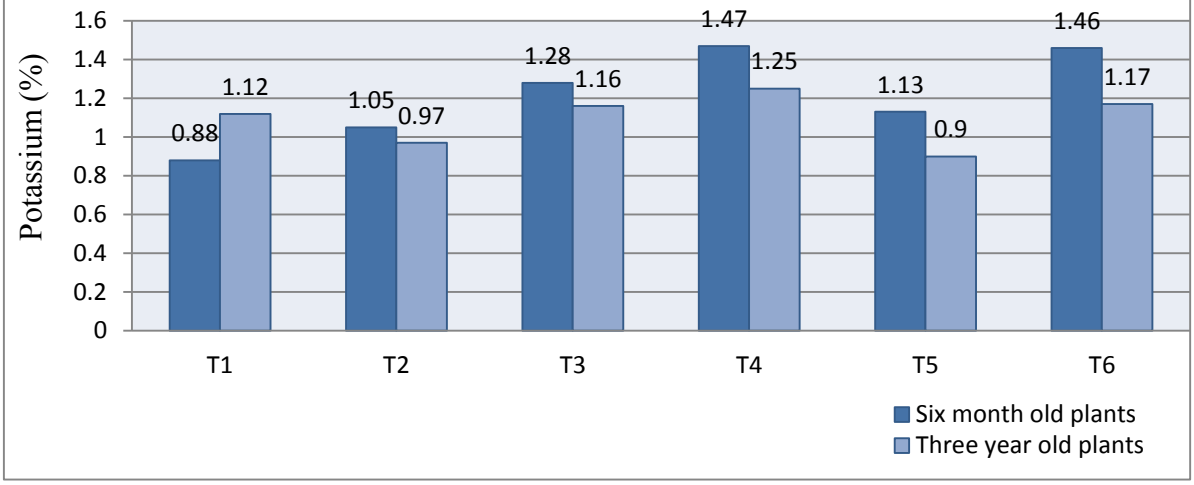


Fig. 104. Influence of growing systems on potassium content in six month old and three year old plants of *Dendrobium* cv. Earsakul

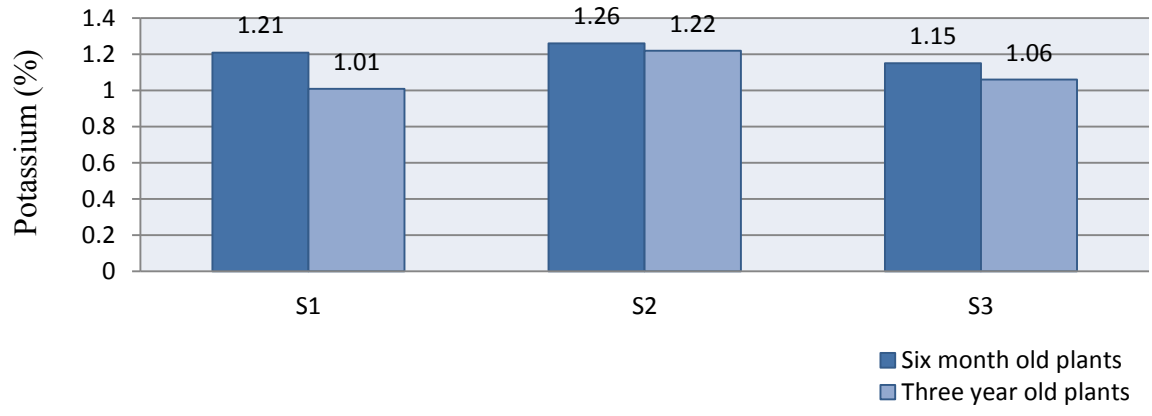
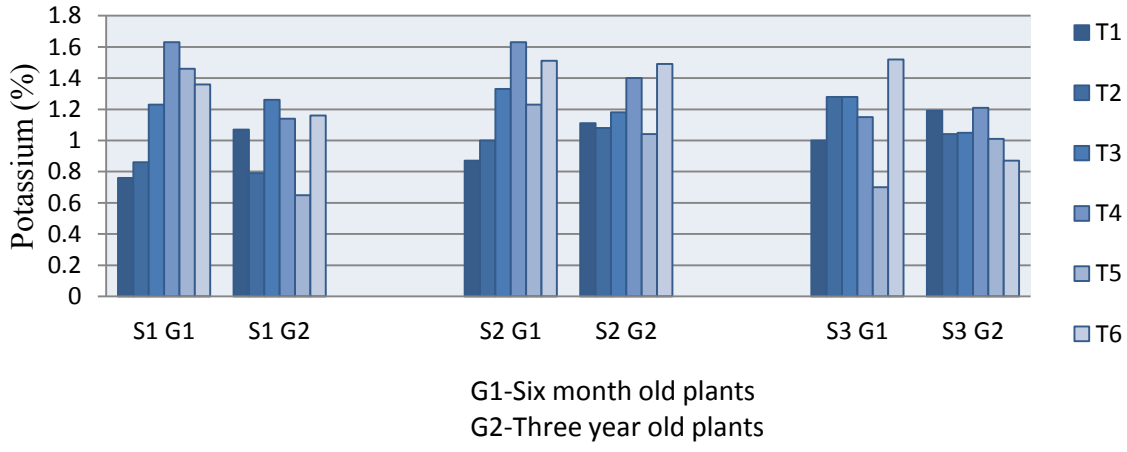


Fig. 105. Influence of treatment interactions on potassium content in six month old and three year old plants of *Dendrobium* cv. Earsakul



5.6 Radioisotope labelling (^{32}P) to study the functional linkage between the host and *Piriformospora indica*

Plant nutrition is often dependent on mutualistic associations with other organisms. Mycorrhizal associations (mutualistic interaction between vascular plant roots and fungi, whereby roots benefit from enhanced water and nutrient uptake and the fungi gain ready access to translocating photosynthates) are likely to favour nutrient uptake in epiphytic plants (Lesica and Antibus, 1990).

It has been reported that mycorrhizal orchids can acquire more N, P and water than non-mycorrhizal controls (Alexander *et al*., 1984; Yoder *et al*., 2000; Cameron *et al*., 2006, 2007). Thus, understanding the relationship between orchids and mycorrhizal fungi is of great important. Rare and endangered species of orchids have been propagated symbiotically; with the purpose of conservation or reintroduction (Zettkler and McInnis, 1992).

^{32}P experiments suggested that the *P. indica* fungus is important for phosphorus acquisition by the roots. Mycelium could utilize a wide variety of inorganic and organic phosphate chemicals and produced acid phosphatases at the tip of the hyphae (Singh *et al*., 2003a,b).

Studies on *P. indica* have shown fungal-mediated uptake of radio-labelled phosphorus from the medium and its translocation to the host in an energy-dependent process, evident by a sharp increase in its content in the shoot. *P. indica* produces significant amounts of acid phosphatases for the mobilization of broad range of insoluble, condensed or complex forms of phosphates, enabling the host plant the accessibility of adequate phosphorus from immobilized reserves in the soil (Singh *et al*., 2000).

The investigation for radioisotope labelling (^{32}P) to study the functional linkage between the host and *P. indica* was conducted to know the role of fungi in transferring ^{32}P to the host roots.

Autoradiography showed that the orchid roots absorbed ^{32}P from the source *i.e.* when labelled $N:P_2O_5:K_2O$ (1:2:2) nutrient solution applied to the roots inoculated with non labelled fungus. The image of the root indicated that, ^{32}P had moved through root from the source of application and translocated into the root tissues (Plate 14 and 15). Plants treated with treatments *viz*., labelled $KH_2{}^{32}PO_4$ applied to the roots inoculated with non-labelled fungus and labelled $KH_2{}^{32}PO_4$ applied to the roots without fungus did not give any image.

Radio assay showed variation in radioactive counts of ^{32}P in different parts of the plant. The radioactivity was higher in pseudobulb portion than in roots and leaves (Table 18). This is in conformity with the findings of Sheehan *et al*. (1967) in *Cattleya* 'Trimose'.

The highest radioactivity was recorded in the leaves where labelled $KH_2{}^{32}PO_4$ applied to the roots inoculated with non-labelled fungus. However, plants which are treated with labelled $N:P_2O_5:K_2O$ (1:2:2) nutrient solution applied to the roots inoculated with non labelled fungus showed radioactivity of 235.18 cpm g^{-1} (Table 18). This would suggest that the fungus acted as the extension of the root system and enhancing the nutrient absorption.

The radio assay study in the plants which are inoculated with labelled fungus indicated that, among plant parts, radioactivity was higher in pseudobulb portion in the treatments labelled fungus applied to the roots (1.29 µCi concentration) and labelled fungus applied to the roots (2.58 µCi concentration). While, highest radioactivity of 530.11 cpm g^{-1} was recorded in roots compared to leaves and pseudobulb. The above findings were in agreement with Finlay and Read (1986a; 1986b) who showed that ectomycorrhizal (ECM) hyphae were the principle route for ^{14}C and ^{32}P transfer to the Pinus seedlings. The results obtained in this study are endorsed by Singh *et al*. (2000), Alexander *et al*. (1984), Cameron *et al*. (2007) in *Goodyera repens*, Yadav *et al*. (2010) in maize and Kumar *et al*. (2011) in maize. It is very well explained by Decordenoy (1904) who reported that mycorrhiza is highly evolved, symbiotic associations between soil

fungi and plant roots. Similar type of findings was also made by Eason *et al*. (1991). Yadav *et al*. (2010) reported that *P. indica* plays a role in phosphate transport to the host plant. The mycorrhiza plays an important role in the life cycle of plants of the family orchidaceae. Mycorrhiza in *Vanilla* roots was first recorded by him and observed the infection of fungi on the roots adhering to their nutrients *via* the fungus. The mechanism underlying phosphate transfer from the fungus to the plant remains unknown, and it is speculated that the process occurs at the plant-fungus interface. However, the physiological pathways responsible for P flow through orchid mycorrhizal networks and to the partner orchid are to be investigated.

5.7 Anatomical studies in roots for structural linkage between the host (*Dendrobium* cv. Earsakul) and PGPRE (*Piriformospora indica*)

After inoculation, in *Dendrobium* cv. Earsakul roots, hyphae of the *P. indica* entered into the tissue of the root through the root tip (Plate 16 a). Hyphae, first touching the root surface (Plate 16 b) and entered through velamen tissue (Plate 16 c). The hyphal growth of the fungus was detected on the root surface between the outer cell layers of the cortex and within the cortical cells (Plate 16 d). The fungus produced chlamydospores at the apex of undifferentiated hyphae (Plate 16 e) and within the cortical cells of the root tissue (Plate 16 f). The fungal hyphae invade the cortical cells and form tightly interwoven coils called 'pelotons' characteristic of orchid mycorrhizae. In the cortical cells of the roots, development of intracellular hyphal coils and round bodies could be observed (Plate 16 g, h). Hyphae multiplied within the cortical tissues and never traversed through endodermis (Plate 16 i, j). These are in agreement with findings of Karimi *et al*. (2011) in barley, Verma *et al*. (1998) in maize, Varma *et al*. (2001) in maize and Stein *et al*. (2008) in *Arabidopsis*. *P. indica* did not invade the stellar tissue or traverse upwards into the shoot because of stellar tissue is a hardier one and the fungus is a endosymbiont.

5.8 Correlation

Canonical correlation studies in six month old plants revealed that there was a significant correlation between growth and flower characters in all stages of growth under two level shade house (Table 19 and Plate 17). It was observed that during all periods, there was significant correlation between growth and flower characters under top ventilated poly house. Correlation between growth and flower characters was not significant under fan and pad system. Positive influence of nutrients, *P. indica* and congenial environment inside the growing systems favoured for better growth which in turn resulted for flower characters in six month old plants. In three year old plants, no significant correlation was observed under two level shade house in all stages of growth (Table 19 and Plate 18). When viewed independently, it was noted that at 18 MAP and 24 MAP, significant correlation was existed under top ventilated polyhouse and fan and pad system. It can be concluded that negative correlation of growth and flower characters was noticed in all stages of growth in two level shade house and during initial period of growth in top ventilated polyhouse and fan and pad system. Therefore, the grower should aim to increase the growth parameters and yield through proper nutrition of the plant.

With regard to correlation of growth and root characters, in six month old plants, in all periods, significant correlation was observed between growth and root parameters under two level shade house and top ventilated polyhouse (except 12 MAP in top ventilated polyhouse) (Table 20 and Plate 17). Under fan and pad system, correlation was significant during the later stage of the crop growth (18, 24 MAP). The results revealed that, positive influence of nutrients, *P. indica* and congenial environmental factors favoured better growth and root production in six month old plants under two level shade house and top ventilated polyhouse and therefore positive correlation was existed between growth and root parameters. In three year old plants, between growth and root parameters, during 12 MAP and 24 MAP, significant correlation was observed in two level shade house and top ventilated polyhouse, respectively (Table 20 and Plate 18). In early

stage of growth (6 MAP), correlation was significant in fan and pad system. Plants which received the combination of nutrients, *P. indica* and comparatively higher temperature, lower relative humidity and higher light intensity resulted in luxurious vegetative growth thereby root growth and hence correlation between growth and root characters was significant in two level shade house and top ventilated polyhouse.

With regard to N, P and K, except during 6 MAP, 12 MAP in two level shade house and 12 MAP in fan and pad system, correlation between growth characters and N, P and K content was significant in six month old plants (Table 21 and Plate. 17). Results indicated that growth characters *viz*., plant height, number of leaves per plant, number of shoots, girth of shoot and internodal length were better in plants grown under top ventilated polyhouse. Therefore the N, P and K contents in the plants was also maximum. Microbial association is also reason for more nutrient absorption. In three year old plants, except during 18 MAP under top ventilated polyhouse, correlation was not significant under three growing systems (Table 21 and Plate. 18).

In overall, it was observed that, correlation of growth parameters with flower characters, root parameters and N, P and K contents was almost significant (except in some periods) in six month old and three year old plants under top ventilated polyhouse. Similar type of finding was reported by Nair *et al*. (2002b).

5.9 Incidence of pests and diseases

During the entire period of study, there was not much severe incidence of pests and diseases. However, snails and slugs were observed during rainy season which is a common phenomenon in orchids cultivated in Kerala. Bacterial diseases were also observed during early stages of growth which was controlled by using suitable control measures.

Summary

6. Summary

The study on 'Growth and physiological response of *Dendrobium* cv. Earsakul in different growing conditions' was conducted with the overriding objective of analysing the response of *Dendrobium* cv. Earsakul to the combination of nutrients, plant growth regulators and plant growth promoting root endophyte (PGPRE) under three growing systems and to examine the symbiotic association between the host and PGPRE.

The study was undertaken at College of Horticulture, Vellanikkara with humid tropical climate of Kerala from April 2011 to March 2013. Commercially cultivated orchid hybrid variety *Dendrobium* cv. Ersakul plants of six month and three year old tissue culture plants were used for the study. Pots with potting media like tile bits, charcoal, and coconut fibre pieces were used as potting media. Three system of growing namely two level shade house, top ventilated polyhouse and pan and pad system were used. The plant growth promoters namely, organic and inorganic nutrients, PGPRE, growth regulators were used as material for the study. The experiment was laid in CRD with six treatments and three replications. Observations on growth characters, flower characters, physiological parameters, content of nutrients, root parameters, symbiotic interactions and pest and disease incidence were also observed.

The salient findings of the study could be summarized as follows.

The treatment combination POP + OM + VW + PGPRE + Bone meal (T_3) recorded significantly maximum plant height when compared to all the treatments in six month and three year old plants.

The top ventilated polyhouse (S_2) had the maximum influence on plant height irrespective of the age of the plants.

Interaction of various plant inputs and systems of growing did not have significant influence on plant height irrespective of the age of the plant.

The combination of POP + OM + VW + PGPRE + Bone meal + GR (T_4) recorded maximum number of leaves per plant irrespective of the age of the plants.

The top ventilated polyhouse (S_2) had the significant influence on production of leaves per plant irrespective of the age of the plants.

The combination of POP + OM + VW + PGPRE + Bone meal + GR (T_4) and top ventilated polyhouse (S_2) recorded significantly higher number of leaves per plant irrespective of age of the plant.

The combination of POP + OM + VW + PGPRE + Bone meal (T_3) recorded maximum number of shoots per plant in six month old plants whereas in three year old plants, the combination of POP + PGPRE + Bone meal (T_2) was recorded maximum shoots per plant.

The top ventilated polyhouse (S_2) had significant influence on production of number of shoots per plant irrespective of the age of the plants.

The combination of POP + OM + VW + PGPRE + Bone meal (T_3) and top ventilated polyhouse (S_2) in six months old plants was recorded maximum number of shoots per plant. Whereas in three year old plants, the combination of POP + OM + VW + PGPRE + Bone meal + GR (T_4) and top ventilated polyhouse (S_2) recorded significantly higher number of shoots per plant.

The treatment combination POP + OM + VW + PGPRE + Bone meal (T_3) recorded maximum girth of the shoot in both stages of plants.

The top ventilated polyhouse (S_2) in six months old plants and two level shade house (S_1) in three year old plants had the maximum influence on girth of shoot.

Interaction of plant inputs and systems of growing did not have significant influence on girth of shoot.

In six month old plants, the internodal length did not vary significantly among different treatments. Whereas in three year old plants, combination of POP + OM + VW + PGPRE + Bone meal (T_3) recorded maximum internodal length at later stage of crop growth.

The top ventilated polyhouse (S_2) had the maximum internodal length irrespective of the age of the plants.

In the interaction of plant inputs and systems of growing, NPK + GR + OM + VW + PGPRE + Bone meal (T_6) and top ventilated polyhouse recorded maximum internodal length in six month old plants. But in three year old plants, interaction was not explicit in all stages of growth.

The treatment combination POP + OM + VW + PGPRE + Bone meal + GR (T_4) recorded early flowering in three year old plants. But in six months old plants, days to flowering did not vary significantly among the different treatments.

The top ventilated polyhouse (S_2) had significant influence on days to flowering irrespective of the age of the plants.

In six month old plants, the combination of POP + OM + VW + PGPRE + Bone meal (T_3) in top ventilated polyhouse (S_2) recorded minimum time for days to flowering. However in three year old plants, POP + OM + VW + PGPRE + Bone meal + GR (T_4) took minimum days for flowering in top ventilated polyhouse (S_2).

The combination of NPK + GR + OM + VW + PGPRE + Bone meal (T_6) took minimum days for first flower opening in six month old plants.

The days to first flower opening was not significantly influenced by growing systems irrespective of the age of the plants.

The combination of NPK + GR + OM + VW + PGPRE + Bone meal (T_6) in two level shade house (S_1) took minimum days for first flower opening in six

month old plants. However, in three year old plants, the interaction was not significantly influenced the days to first flower opening.

The combination of POP + OM + VW + PGPRE + Bone meal + GR (T_4) took minimum days for last flower opening in three year old plants.

The plants grown in two level shade house (S_1) recorded minimum days for last flower opening in three year old plants.

The combination of NPK + GR + OM + VW + PGPRE + Bone meal (T_6) in top ventilated polyhouse (S_2) took minimum days for last flower opening in both stages of plants.

The combination of POP + OM + VW + PGPRE + Bone meal + GR (T_4) in six month old plants, the combination of NPK + GR + OM + VW + PGPRE + Bone meal (T_6) in three year old plants recorded significantly longer spike length.

The top ventilated polyhouse (S_2) had significant influence on length of the spike irrespective of the age of the plants.

The combination of POP + OM + VW + PGPRE + Bone meal + GR (T_4) in top ventilated polyhouse (S_2) in six month old plants, the combination of NPK + GR + OM + VW + PGPRE + Bone meal (T_6) in top ventilated polyhouse (S_2) in three year old plants recorded significantly higher spike length.

The combination of POP + OM + VW + PGPRE + Bone meal + GR (T_4) in six month old plants and the combination of NPK + GR + OM + VW + PGPRE + Bone meal (T_6) in three year old plants recorded significantly higher number of flowers per spike.

The top ventilated polyhouse (S_2) had significant influence number of flowers per spike irrespective of the age of the plants

The combination of POP + OM + VW + PGPRE + Bone meal (T_3) in top ventilated polyhouse recorded maximum number of flowers in six month old plants. In three year old plants, the combination of NPK + GR + OM + VW +

PGPRE + Bone meal (T_6) in top ventilated polyhouse recorded significantly higher number of flowers.

Size of the flower did not vary significantly among different treatments, growing systems and interactions in both six month old and three year old plants.

The combination of NPK + GR + OM + VW + PGPRE + Bone meal (T_6) in six month old plants and the combination of POP + OM + VW + PGPRE + Bone meal + GR (T_4) recorded significantly higher number of spikes per plant.

The top ventilated polyhouse (S_2) recorded significantly higher number of spike per plant irrespective of the age of the plants.

The treatment POP + OM + VW + PGPRE + Bone meal + GR (T_4) responding more influence on number of spikes per plant in top ventilated polyhouse (S_2) in six month old plants and two level shade house in three year old plants.

The combination of POP + OM + VW + PGPRE + Bone meal + GR (T_4) recorded significantly higher vase life in both stages of plants.

The top ventilated polyhouse (S_2) recorded significantly higher vase life irrespective of the age of the plants.

The combination of POP + OM + VW + PGPRE + Bone meal + GR (T_4) in top ventilated polyhouse (S_2) recorded significantly higher vase life.

The combination of POP + OM + VW + PGPRE + Bone meal + GR (T_4) recorded significantly higher leaf area irrespective of the year of the plants.

The top ventilated polyhouse (S_2) had maximum influence on leaf area in six month old plants.

The combination of POP + OM + VW + PGPRE + Bone meal (T_3) in top ventilated polyhouse (S_2) in six month old plants, POP + OM + VW + PGPRE +

Bone meal + GR (T_4) in two level shade house in three year old plants recorded significantly higher leaf area.

The combination of POP + OM + VW + PGPRE + Bone meal (T_3) in six month old plants, POP + OM + VW + PGPRE + Bone meal + GR (T_4) in three year old plant recorded significantly higher DMP.

The top ventilated polyhouse (S_2) had maximum influence on DMP irrespective of age of the plants.

The combination of POP + OM + VW + PGPRE + Bone meal (T_3) in top ventilated polyhouse in six month old plants and POP + OM + VW + PGPRE + Bone meal + GR (T_4) in top ventilated house in three year old plants recorded higher DMP.

The combination of POP + OM + VW + PGPRE + Bone meal (T_3) in six month old plants, POP + OM + VW + PGPRE + Bone meal + GR (T_4) in three year old plant recorded significantly higher CGR.

The top ventilated polyhouse in six month old plants and two level shad house in three year old plants recorded maximum CGR.

The combination of NPK + GR + OM + VW + PGPRE + Bone meal (T_6) and two level shade house in six month old, POP + OM + VW + PGPRE + Bone meal + GR (T_4) and two level shade house in three year old plants recorded higher CGR.

The combination of POP + OM + VW + PGPRE + Bone meal + GR (T_4) recorded significantly higher RGR in six month old plants.

Growing systems had no significant effect on RGR in both stages of plants.

The combination of POP + OM + VW + PGPRE + Bone meal + GR (T_4) and fan and pad system in six month old plants, NPK + GR + OM + VW +

PGPRE + Bone meal (T_6) and two level shad house in three year old plants recorded maximum RGR.

Treatments had no significant effect on NAR at both stages of plant growth.

The top ventilated polyhouse in six month old plants and two level shade house in three year old plants recorded higher NAR.

The combination of NPK + GR + OM + VW + PGPRE + Bone meal (T_6) responding more influence on NAR in top ventilated ployhouse in six month old plants and two level shade house in three year old plants.

The combination of POP + OM + VW + PGPRE + Bone meal + GR (T_4) in six month old plants and POP + OM + VW + PGPRE + Bone meal (T_3) in three year old plants recoded higher number of stomata.

The fan and pad system recorded highest number of stomata in both the stages of plants.

In top ventilated polyhouse (S_2), the combinations POP + PGPRE + Bone meal (T_2) in six month old plants and POP + OM + VW + PGPRE + Bone meal + GR (T_4) in three year old plants responding more influence on number of stomata.

The combination of POP + OM + VW + PGPRE + Bone meal (T_3) in six month old plants recorded significantly higher rate of photosynthesis.

The top ventilated polyhouse in six month old plants and fan and pad system in three year old plants recorded highest photosynthetic rate.

The combination of POP + OM + VW + PGPRE + Bone meal (T_3) and top ventilated polyhouse in six month old plants, POP + OM + VW + PGPRE + Bone meal + GR (T_4) and fan pad system in three year old plants recorded maximum rate of photosynthesis.

The combination of POP + PGPRE + Bone meal (T_2) in six month old plants recorded highest rate of transpiration during night.

The top ventilated polyhouse (S_2) recorded highest rate of transpiration in six month old plants.

The treatment POP + OM + VW + PGPRE + Bone meal + GR (T_4) responded more influence on rate of transpiration in top ventilated polyhouse in six month old plants and fan and pad system in three year old plants.

The combination of POP + OM + VW + PGPRE + Bone meal (T_3) in six month old plants and NPK + GR + OM + VW + PGPRE + Bone meal (T_6) in three year old plants recorded significantly higher rate of transpiration during day time.

The top ventilated polyhouse in six month old plants and two level shade house in three year old plants recorded maximum rate of transpiration during day time.

The combination of NPK + GR (T_5) and top ventilated polyhouse in six month old plants, NPK + GR + OM + VW + PGPRE + Bone meal (T_6) and two level shade house recorded significantly higher rate of transpiration during day time.

The treatment NPK + GR + OM + VW + PGPRE + Bone meal (T_6) in six month old plants and NPK + GR (T_5) in three year old plants recorded significantly higher diffusive resistance.

The two level shade house in six month old plants and top ventilated polyhouse in three year old plants recorded higher diffusive resistance.

The treatment NPK + GR + OM + VW + PGPRE + Bone meal (T_6) and two level shade house in six month old plants, NPK + GR (T_5) and top ventilated polyhouse in three year old plants had significant influence on diffusive resistance.

The effect of treatments on chlorophyll ‘a’ content was found to be non significant in both stages of plants.

The top ventilated polyhouse (S_2) had significant influence on chlorophyll 'a' content only in three year old plants.

The combination of NPK + GR + OM + VW + PGPRE + Bone meal (T_6) and two level shade house in six month old plants, POP + OM + VW + PGPRE + Bone meal (T_3) and top ventilated polyhouse in three year old plants recorded significantly higher chlorophyll 'a' content.

The NPK + GR (T_5) recorded significantly higher chlorophyll 'b' content in three year old plants.

The two level shade house had maximum influence on chlorophyll 'b' content irrespective of the age of the plants.

The treatment POP + OM + VW + PGPRE + Bone meal + GR (T_4) and NPK + GR (T_5) responding more influence on chlorophyll 'b' content in two level shade house in both stages of the plants.

Treatments had no significant effect on total chlorophyll content in both stages of growth.

The two level shade house in six month old plants and top ventilated polyhouse in three year old plants recorded significantly higher total chlorophyll content.

The treatment POP + OM + VW + PGPRE + Bone meal + GR (T_4) and two level shade house in six month old plants, POP + OM + VW + PGPRE + Bone meal(T_3) and top ventilated polyhouse (S_2) in three year old plants recorded significantly higher total chlorophyll content.

The combination of NPK + GR + OM + VW + PGPRE + Bone meal (T_6) recorded significantly higher number of roots in both stages of plants.

The top ventilated polyhouse had significant influence on number of roots per plant irrespective of the age of the plants.

The treatment POP + OM + VW + PGPRE + Bone meal + GR (T_4) and top ventilated polyhouse (S_2) recorded significantly higher number of roots per plants in both stages of plants.

The treatment POP + OM + VW + PGPRE + Bone meal + GR (T_4) in six month old plants and POP + OM + VW + PGPRE + Bone meal (T_3) in three year old plants recorded significantly higher root length.

The top ventilated polyhouse had significant influence on root length irrespective of the age of the plants.

The six month old plants, the combination of POP + OM + VW + PGPRE + Bone meal + GR (T_4) and POP + OM + VW + PGPRE + Bone meal (T_3) in three year old plants recorded significantly higher root length in top ventilated polyhouse (S_2).

The treatment NPK + GR + OM + VW + PGPRE + Bone meal (T_6) recorded highest root volume in both stages of plants.

The top ventilated polyhouse (S_2) had significant influence on root volume irrespective of the age of the plants.

The combination of POP + OM + VW + PGPRE + Bone meal + GR (T_4) in six month old plants and POP + OM + VW + PGPRE + Bone meal (T_3) in three year old plants recorded significantly higher root volume in top ventilated polyhouse.

The treatment POP + OM + VW + PGPRE + Bone meal + GR (T_4) in six month old plants, NPK + GR + OM + VW + PGPRE + Bone meal (T_6) in three year old plants recorded highest root colonization of *P. indica.*

The top ventilated polyhouse (S_2) had significant influence on root colonization of *P. indica* irrespective of the age of the plants.

The treatment POP + OM + VW + PGPRE + Bone meal + GR (T_4) and NPK + GR + OM + VW + PGPRE + Bone meal (T_6) responding more influence

on root colonization of *P. indica* in top ventilated polyhouse irrespective of age of the plants.

The treatment POP + OM + VW + PGPRE + Bone meal + GR (T_4) in six month old plants, POP + OM + VW + PGPRE + Bone meal (T_3) in three year old plants recorded significantly higher N content.

The top ventilated polyhouse recorded significantly higher N content in six month old plants.

The treatment POP + OM + VW + PGPRE + Bone meal + GR (T_4) and top ventilated polyhouse (S_2) in six month old plants, POP + OM + VW + PGPRE + Bone meal (T_3) and two level shade house in three year old plants recorded highest N content.

The treatment POP + OM + VW + PGPRE + Bone meal + GR (T_4) in six month old plants, POP + OM + VW + PGPRE + Bone meal (T_3) in three year old plants recorded significantly higher P content.

The top ventilated polyhouse (S_2) recorded significantly higher P content in both stages of plants.

The treatment POP + OM + VW + PGPRE + Bone meal + GR (T_4) and top ventilated polyhouse recorded highest P content in six month old plants.

The treatment POP + OM + VW + PGPRE + Bone meal + GR (T_4) recorded significantly higher K content irrespective of age of the plants.

The top ventilated polyhouse (S_2) recorded highest K content in three year old plants.

The treatment POP + OM + VW + PGPRE + Bone meal + GR (T_4) in six month old plants, NPK + GR + OM + VW + PGPRE + Bone meal (T_6) in three year old plants recorded significantly higher K content in top ventilated polyhouse (S_2).

The radioactivity was higher in pseudobulb portion than in roots and leaves of the *Dendrobium* cv. Earsakul.

The highest radioactivity of 530.11 cpm g^{-1} was recorded in roots of the treatment labelled fungus applied to the roots (1.94 µCi concentration) compared to leaves and pseudobulb. The treatment labelled fungus applied to the roots (1.29 µCi concentration) and labelled fungus applied to the roots (2.58 µCi concentration) recorded lower radioactivity of 253.07 cpm g^{-1} and 245.36 cpm g^{-1}, respectively in roots.

In the *P indica* inoculated plants, the hyphal growth of the fungus was detected on the root surface between the outer cell layers of the cortex and within the cortical cells. The fungal hyphae invade the cortical cells and form tightly interwoven coils called 'pelotons' characteristic of orchid mycorrhizae. In the cortical cells of the roots, development of intracellular hyphal coils and round bodies could be observed.

It was observed that during all periods, there was significant relationship between growth and flower characters under top ventilated poly house (S_2).

With regard to growth and root characters, in six month old plants, in all periods, significant correlation was observed between growth and root parameters under two level shade house and top ventilated polyhouse.

Relationship between growth characters and N,P,K content was significant in two level shade house, top ventilated polyhouse and fan and pad system.

It was concluded that plant growth promoters POP + OM + VW + PGPRE + Bone meal + GR and top ventilated polyhouse had maximum influence on plant growth, yield parameters and physiological parameters like leaf area, DMP, CGR and RGR. The canonical correlation further reinforced the results that plant growth and yield of the plant was significantly influenced. The nutrient contents of N, P and K were higher in plants grown under top ventilated polyhouse. The association of *P. indica* in root system of *Dendrobium* cv. Earsakul was highly

significant and the *P. indica* fungus enhances higher root absorption and facilitates the growth parameters significantly.

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Appendix

WEATHER DATA

Appendix – I

Monthly mean temperature (^{0}C) during the experiment from April 2011 to March 2013 in different growing systems.

Month	Maximum (8 am)			Minimum (8 am)			Maximum (2.30 pm)			Minimum (2.30 pm)		
	S_1	S_2	S_3	S_1	S_2	S_3	S_1	S_2	S_3	S_1	S_2	S_3
April,11	31.3	35.4	24.2	22.0	25.9	22.7	33.2	41.2	27.4	22.8	24.0	18.3
May 11	32.6	34.4	26.6	23.3	24.6	22.7	37.9	39.9	29.4	24.4	29.0	22.0
June 11	26.9	29.9	25.2	22.8	24.3	18.7	32.0	34.4	28.7	26.7	28.1	21.9
July 11	26.2	28.7	24.1	22.2	23.5	18.4	32.3	33.8	32.2	25.6	27.1	21.8
Aug. 11	26.1	28.2	22.2	21.3	23.0	20.4	33.2	35.2	31.7	22.8	24.0	22.0
Sep. 11	27.1	27.2	25.4	23.8	24.8	18.4	28.0	33.2	26.6	23.4	24.7	19.3
Oct. 11	27.7	28.2	25.2	24.4	24.8	16.7	31.6	33.0	27.8	24.0	24.9	22.6
Nov. 11	28.0	29.2	24.8	20.3	25.4	18.8	34.0	35.5	32.7	25.0	26.2	22.9
Dec. 11	26.7	27.5	25.0	24.9	25.6	22.9	34.4	37.4	31.4	24.9	25.7	23.1
Jan. 12	26.0	26.2	24.0	24.0	25.2	21.7	34.5	35.0	32.2	24.8	26.0	23.3
Feb. 12	27.0	28.6	24.3	19.6	25.5	18.2	36.7	41.7	34.3	24.0	25.6	21.9
Mar. 12	28.9	30.2	25.5	22.0	26.0	18.8	36.3	38.4	34.3	24.1	25.7	21.8
Mean	**27.8**	**29.5**	**24.7**	**22.6**	**24.9**	**19.8**	**33.6**	**36.6**	**30.7**	**24.3**	**25.9**	**21.7**
April 12	30.6	32.0	26.1	22.2	24.3	18.8	35.5	37.7	29.0	26.2	28.0	21.0
May 12	29.1	31.0	25.7	22.4	23.6	19.7	33.8	36.2	29.9	24.9	26.7	21.2
June 12	25.8	26.8	24.9	21.3	22.4	18.8	33.6	35.4	28.8	19.6	21.8	18.0
July 12	26.7	27.7	26.2	19.4	22.3	18.2	30.8	31.3	26.8	19.7	21.0	18.8
Aug. 12	27.2	26.9	24.9	21.0	21.1	18.3	31.4	31.7	27.2	18.2	23.5	18.0
Sep. 12	28.3	28.5	25.2	18.4	22.9	18.0	31.6	33.4	27.8	18.3	20.9	18.2
Oct. 12	27.7	29.5	24.4	20.2	22.6	18.4	33.0	35.1	28.2	18.4	20.6	18.0
Nov. 12	26.3	28.6	22.0	18.6	18.8	18.1	31.4	33.2	26.0	18.6	22.6	18.2
Dec. 12	25.8	27.6	23.4	18.4	21.6	19.4	31.3	32.8	29.0	22.0	23.7	19.2
Jan. 13	25.2	27.7	22.4	18.4	20.7	18.0	36.5	38.3	28.9	24.0	25.9	20.3
Feb. 13	28.0	30.0	24.7	21.7	22.0	18.0	36.9	39.9	29.0	22.1	26.7	19.9
Mar. 13	29.0	32.0	24.6	20.4	22.9	19.1	37.2	39.2	31.6	25.7	26.4	19.1
Mean	**27.4**	**29.0**	**24.5**	**20.2**	**22.1**	**18.5**	**33.6**	**35.3**	**28.5**	**21.4**	**23.9**	**19.1**

WEATHER DATA

Appendix – II

Monthly mean relative humidity (%) during the experiment from April, 2011 to March, 2013 in different growing systems.

Month	Maximum (8 am)			Minimum (8 am)			Maximum (2.30 pm)			Minimum (2.30 pm)		
	S_1	S_2	S_3	S_1	S_2	S_3	S_1	S_2	S_3	S_1	S_2	S_3
April,11	77.0	75.5	82.2	20.0	18.0	33.2	59.0	52.0	70.3	24.0	13.7	38.8
May 11	78.0	75.6	80.3	46.6	42.4	50.4	61.2	54.2	68.8	33.8	39.0	44.0
June 11	77.7	76.8	86.6	42.7	22.8	63.0	61.7	56.0	72.0	22.0	36.6	40.2
July 11	82.5	76.9	93.3	64.1	42.3	66.0	68.9	65.1	78.6	38.0	36.3	41.0
Aug. 11	74.7	72.2	86.6	66.5	65.2	69.8	71.2	63.0	78.8	22.0	33.8	38.8
Sep. 11	75.5	74.2	83.3	56.0	47.1	64.0	56.7	54.0	68.8	22.1	44.6	48.4
Oct. 11	73.7	71.5	84.5	65.7	43.8	45.3	62.0	60.5	73.0	42.3	41.7	44.0
Nov. 11	77.3	75.3	88.5	42.5	43.8	45.4	65.7	58.8	74.0	41.1	41.8	43.7
Dec. 11	73.0	67.0	84.0	35.5	35.6	45.0	54.0	49.4	71.6	35.3	35.4	38.8
Jan. 12	76.0	75.4	79.0	36.5	36.3	39.9	56.6	48.2	72.7	36.8	37.6	41.4
Feb. 12	74.0	72.2	78.3	12.3	21.3	48.7	54.0	43.9	69.0	20.0	18.0	42.0
Mar. 12	68.2	66.0	83.0	46.0	22.7	64.4	44.7	42.5	75.0	20.1	18.2	41.0
Mean	**75.6**	**73.2**	**84.1**	**44.5**	**36.8**	**52.9**	**59.6**	**53.9**	**72.7**	**29.8**	**33.0**	**41.8**
April 12	66.0	52.3	72.0	44.8	23.3	57.6	54.0	44.5	68.4	24.0	13.8	44.4
May 12	78.4	65.4	84.0	46.7	34.7	51.0	48.7	46.7	76.0	31.0	22.9	38.2
June 12	74.0	64.3	87.0	54.0	42.0	61.0	57.0	50.3	74.0	34.2	32.8	44.9
July 12	73.0	60.4	86.7	43.2	28.2	48.6	54.2	42.5	66.2	22.2	34.0	41.4
Aug. 12	82.5	63.9	96.2	18.3	22.0	29.5	60.2	41.0	75.0	22.3	18.0	29.6
Sep. 12	76.8	62.6	94.5	43.8	28.0	44.1	57.2	48.2	69.0	28.0	19.0	31.0
Oct. 12	70.2	65.4	88.3	45.9	24.2	46.6	61.0	46.6	73.2	32.1	18.8	43.0
Nov. 12	66.0	62.0	86.7	24.0	18.2	44.0	53.3	59.6	68.8	32.6	21.5	38.9
Dec. 12	68.2	59.4	77.2	20.0	17.8	22.1	31.0	49.3	64.0	28.8	12.2	33.0
Jan. 13	76.0	71.1	86.7	24.4	22.0	27.3	35.2	42.9	65.3	22.0	17.9	24.4
Feb. 13	64.0	62.1	82.0	27.3	20.1	40.0	29.8	35.9	64.4	18.0	14.0	20.0
Mar. 13	64.1	58.4	79.0	24.7	22.3	44.4	33.1	58.0	69.0	22.4	22.7	24.6
Mean	**71.6**	**62.2**	**85.0**	**34.8**	**25.2**	**43.0**	**47.9**	**47.1**	**69.4**	**26.5**	**20.6**	**34.4**

WEATHER DATA

Appendix – III

Monthly mean light intensity (lux) during the experiment from April 2011 to March 2013 in different growing systems and at outside.

Month	12.30 pm			
	S_1	S_2	S_3	Outside systems
April,11	25556	29164	7643	82351
May 11	20682	29222	8452	77542
June 11	9488	9676	6642	32646
July 11	7764	9876	4582.1	34277
Aug. 11	7765	12329.3	4873	37427
Sep. 11	13949.8	14343.8	3858	35612
Oct. 11	22149	25716	5645	46672
Nov. 11	21456	24698	5756	57437
Dec. 11	26798	27941	3789	68760.8
Jan. 12	28111	32362	4471	84754
Feb. 12	31102	31115	9667	85742
Mar. 12	27123	30382	11726	87903
Mean	**20162**	**23068.8**	**6425.34**	**60927**
April 12	25556	29152	9545	89073
May 12	20682	28131	5785	69796
June 12	9959	10026	5825	42318
July 12	8169	8703	5402	24880
Aug. 12	6022	7574	3944	24866
Sep. 12	10016	12192	5248	40885
Oct. 12	9839	11776	4234	43342
Nov. 12	11727	13518	3821	55269
Dec. 12	14747	22088	3883	46828
Jan. 13	15102	26047	3467	57659
Feb. 13	24387	29811	4610	64337
Mar. 13	26414	31237	6253	72332
Mean	**15218.33**	**19187.92**	**5168.08**	**52632.08**

WEATHER DATA

Appendix – IV

Monthly mean temperature (^{0}C) and relative humidity (%) during the experiment from April 2011 to March 2013 at outside growing systems.

Month	Temperature (^{0}C)				Relative humidity (%)			
	Max. (8 am)	Min. (8 am)	Max. (2.30 pm)	Min. (2.30 pm)	Max. (8 am)	Min. (8 am)	Max. (2.30 pm)	Min. (2.30 pm)
April,11	36.6	24.8	42.0	27.4	68.8	42.3	44.0	26.0
May 11	34.8	25.8	43.8	26.9	64.4	42.5	38.0	36.7
June 11	32.0	26.8	37.7	26.3	64.0	38.0	68.0	31.0
July 11	32.1	24.5	33.0	22.8	69.1	34.3	64.4	34.2
Aug. 11	29.3	23.8	34.0	23.8	64.8	33.9	65.0	41.2
Sep. 11	28.6	24.0	32.0	24.8	72.8	34.2	68.2	34.7
Oct. 11	33.5	24.8	35.1	24.7	70.8	33.0	64.4	38.8
Nov. 11	26.4	25.6	34.4	24.9	71.1	32.5	53.2	24.6
Dec. 11	33.4	24.9	37.4	22.8	74.0	35.5	54.0	21.2
Jan. 12	33.3	22.8	38.4	23.6	72.1	34.9	44.6	28.0
Feb. 12	30.0	20.7	41.2	28.0	72.5	18.5	45.4	17.0
Mar. 12	34.5	25.5	44.4	26.6	59.8	10.0	33.5	23.0
Mean	**32.04**	**24.5**	**37.78**	**25.21**	**68.68**	**32.46**	**53.55**	**29.7**
April 12	35.9	24.0	42.9	29.2	68.3	22.8	39.1	16.8
May 12	31.9	24.8	43.8	31.9	71.3	26.0	45.8	18.2
June 12	28.5	21.9	34.9	21.9	73.4	48.0	48.8	34.8
July 12	31.9	22.0	38.0	22.0	77.0	38.0	54.3	22.8
Aug. 12	30.1	21.3	37.0	22.7	68.9	41.0	48.8	23.2
Sep. 12	32.1	21.5	38.5	21.9	71.0	34.3	33.9	22.7
Oct. 12	32.4	21.9	39.5	21.5	66.0	28.0	44.5	23.2
Nov. 12	32.5	19.7	39.0	26.6	58.9	32.9	44.0	26.8
Dec. 12	27.5	22.0	38.8	28.0	61.2	17.0	44.5	16.9
Jan. 13	28.7	24.9	39.6	26.1	66.8	19.6	42.0	22.0
Feb. 13	31.3	25.0	41.8	27.3	54.0	17.0	47.0	22.8
Mar. 13	31.0	26.3	43.0	25.5	49.0	17.7	37.0	14.2
Mean	**31.15**	**22.94**	**39.73**	**25.38**	**65.48**	**28.53**	**44.14**	**22.03**

WEATHER DATA

Appendix V

Yearly mean of temperature (^{0}C) in different growing systems

Year	Maximum (8 am)			Minimum (8 am)			Maximum (2.30 pm)			Minimum (2.30 pm)		
	S_1	S_2	S_3	S_1	S_2	S_3	S_1	S_2	S_3	S_1	S_2	S_3
1st year	27.8	29.5	24.7	22.6	24.9	19.8	33.6	36.6	30.7	24.3	25.9	21.7
2nd year	27.4	29.0	24.5	20.2	22.1	18.5	33.6	35.3	28.5	21.4	23.9	19.1
Yearly mean of relative humidity (%) in different growing systems												
1st year	75.6	73.2	84.1	44.5	36.8	52.9	59.6	53.9	72.7	29.8	33.0	41.8
2nd year	71.6	62.2	85.0	34.8	25.2	43.0	47.9	47.1	69.4	26.5	20.6	34.4

Yearly mean of light intensity (lux) inside and outside of the growing systems

Year	12.30 pm			
	S_1	S_2	S_3	Outside systems
1st year	20162	23068.8	6425.34	60927
2nd year	15218.33	19187.92	5168.08	52632.08

Yearly mean of temperature (^{0}C) and relative humidity (%) at outside growing systems

Year	Temperature (^{0}C)				Relative humidity (%)			
	Max. (8 am)	Min. (8 am)	Max. (2.30 pm)	Min. (2.30 pm)	Max. (8 am)	Min. (8 am)	Max. (2.30 pm)	Min. (2.30 pm)
1st year	32.04	24.5	37.78	25.21	68.68	32.46	53.55	29.7
2nd year	31.15	22.94	39.73	25.38	65.48	28.53	44.14	22.03

Temperature (^{0}C) in different growing systems and outside

Growing systems	Minimum temperature (0C)				Maximum temperature (0C)			
	8 am		2.30 pm		8 am		2.30 pm	
	Inside	Outside	Inside	Outside	Inside	Outside	Inside	Outside
S_1	21.38	23.71	22.92	25.30	27.68	31.59	33.63	38.76
S_2	23.49		24.94		29.25		35.95	
S_3	19.22		20.45		24.63		29.62	

Relative humidity (%) in different growing systems and outside

Growing systems	Minimum relative humidity				Maximum relative humidity			
	8 am		2.30 pm		8 am		2.30 pm	
	Inside	Outside	Inside	Outside	Inside	Outside	Inside	Outside
S_1	39.65	30.49	28.12	25.87	73.61	67.08	53.77	48.85
S_2	30.99		26.83		67.75		50.55	
S_3	47.96		38.15		84.58		71.08	

Light intensity

Growing systems	12.30 pm	
	Inside	Outside
S_1	17690.2	56779.53
S_2	21128.3	
S_3	5796.7	

Weather parameters

Temperature (^{0}C)

In general, among growing systems, temperature range difference between outside and systems of growing is changed. At 8 am, difference in minimum temperature between outside systems and S_1 is 2.33 ^{0}C and S_2 is 0.22 ^{0}C and in S_3 it is 4.49 ^{0}C. At 2.30 pm, range difference between outside systems and S_1 is 2.38 ^{0}C, S_2 is 0.36 ^{0}C and S_3 is 4.85 ^{0}C. It was observed that, at 8 am, maximum temperature difference between outside and systems of growing are 3.91 ^{0}C in S_1, 2.34 ^{0}C in S_2, 6.96 ^{0}C in S_3 and at 2.30 pm, 5.13 ^{0}C in S_1, 2.81 ^{0}C in S_2 and 9.14 ^{0}C in S_3.

It was further noticed that, minimum temperature range of 23.49 ^{0}C to 24.94 ^{0}C and maximum temperature range of 29.25 ^{0}C to 35.95 ^{0}C was recorded in top ventilated poly house (S_2) compared to S_1 and S_3. Simultaneously, minimum temperature range of 19.22 ^{0}C to 20.45 ^{0}C and maximum temperature range of 24.63 ^{0}C to 29.62 ^{0}C was recorded in S_3. In general, top ventilated poly house (S_2) had higher minimum and maximum temperature compared to S_1 and S_3.

Relative humidity

It was noticed that, among growing systems, percent relative humidity difference at outside growing systems and S_2 is lesser compared to S_1 and S_3. The relative humidity range difference between S_3 and at outside is totally higher than in S_1 and S_2. The minimum RH range of 26.83 – 30.99 per cent and maximum RH range of 50.55 – 67.75 per cent was registered in top ventilated poly house (S_2). In general, the system S_2 had lower relative humidity compared to S_1 and S_3. Higher relative humidity was recorded in S_3.

Light intensity

The range difference between outside and fan and pad system is very higher. Among systems, S_2 had higher light intensity and the range difference in 35651.23 lux. Fan and pad system had lower light intensity.

APPENDIX VI

Martins rose Bengal media

Dextrose 10 g

Peptone 5 g

KH_2PO_4 1 g

MgSO4 0.5 g

Distil water 1000 ml

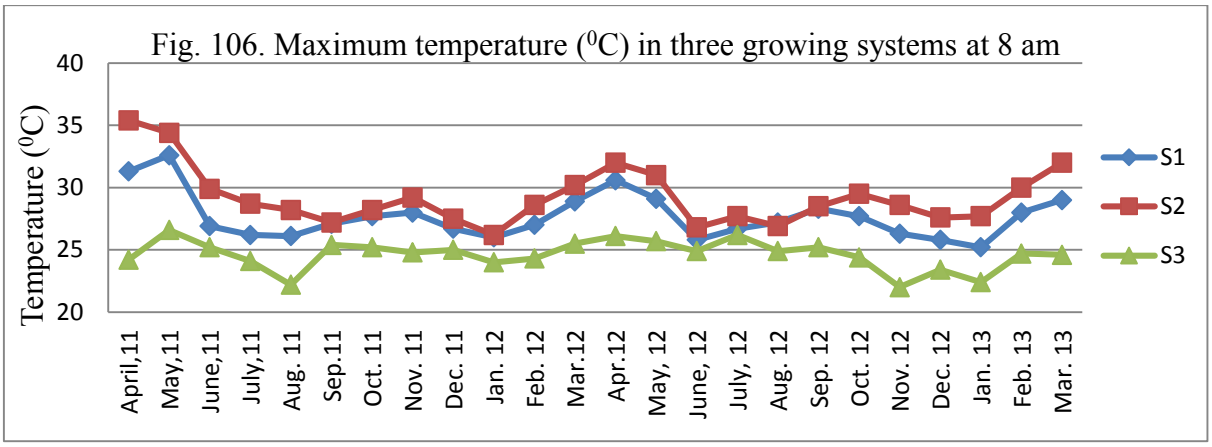


Fig. 106. Maximum temperature (^{0}C) in three growing systems at 8 am

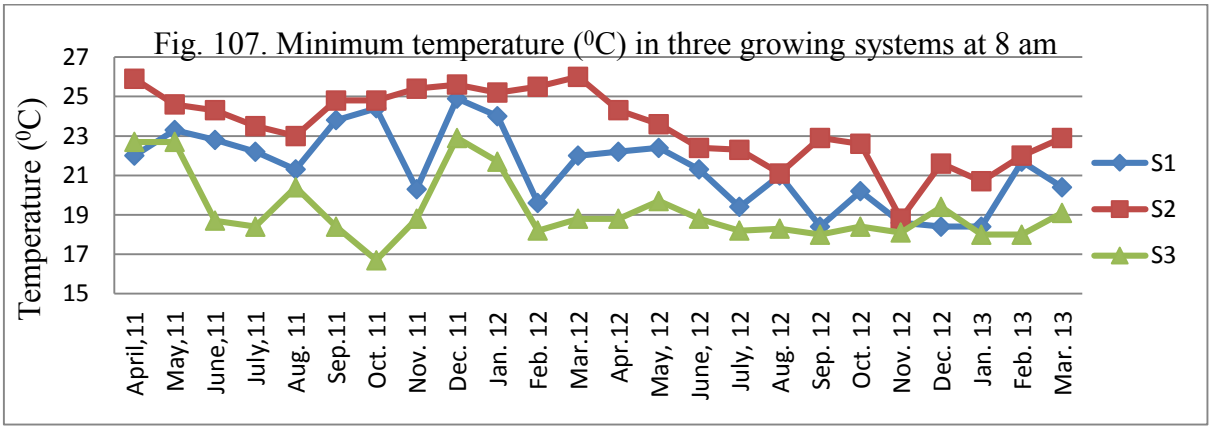


Fig. 107. Minimum temperature (^{0}C) in three growing systems at 8 am

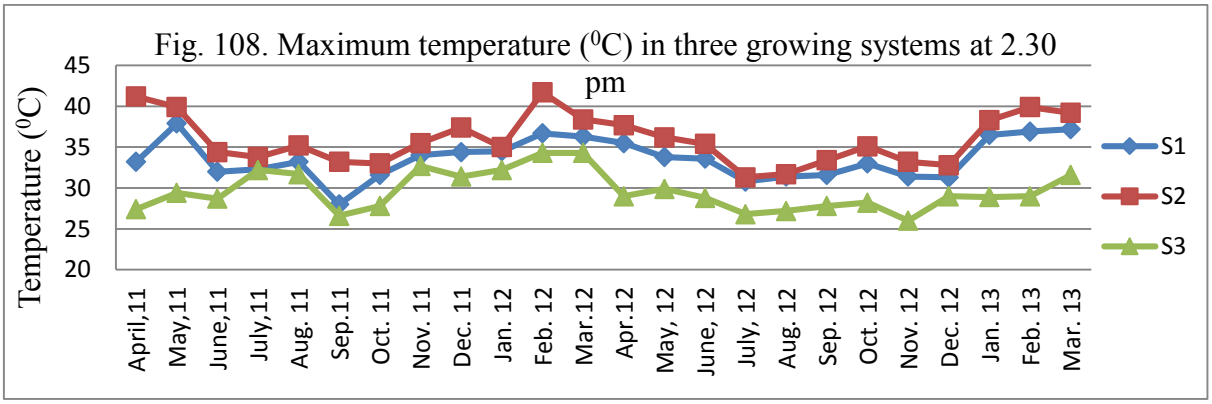


Fig. 108. Maximum temperature (^{0}C) in three growing systems at 2.30 pm

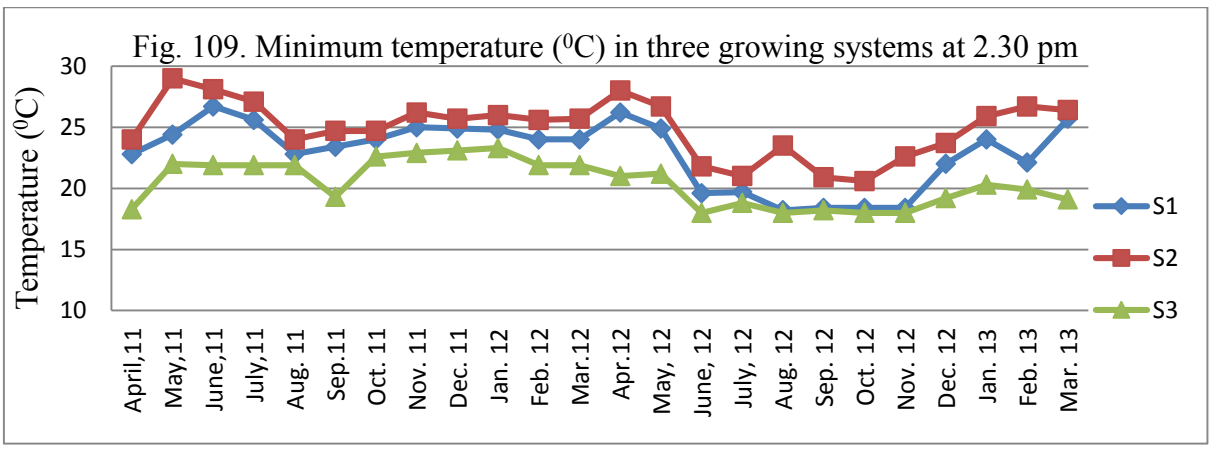


Fig. 109. Minimum temperature (^{0}C) in three growing systems at 2.30 pm

Fig. 110. Maximum relative humidity (%) in three growing systems at 8.0 am

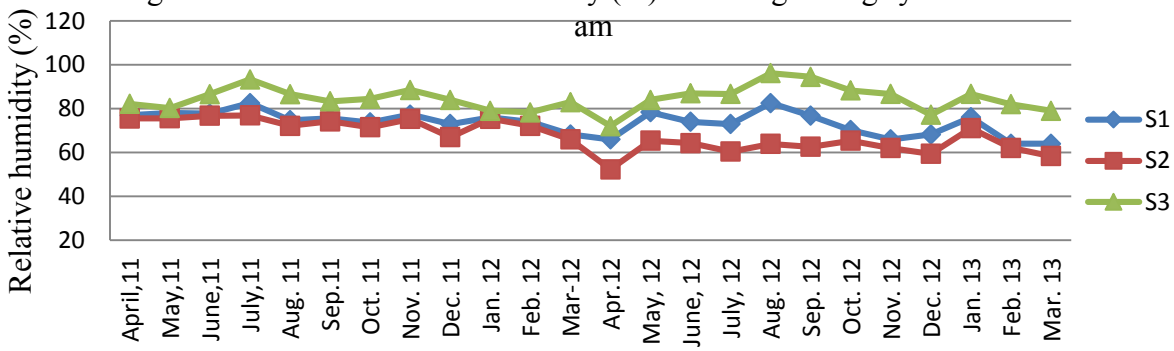


Fig. 111. Minimum relative humidity (%) in three growing systems at 8.0 am

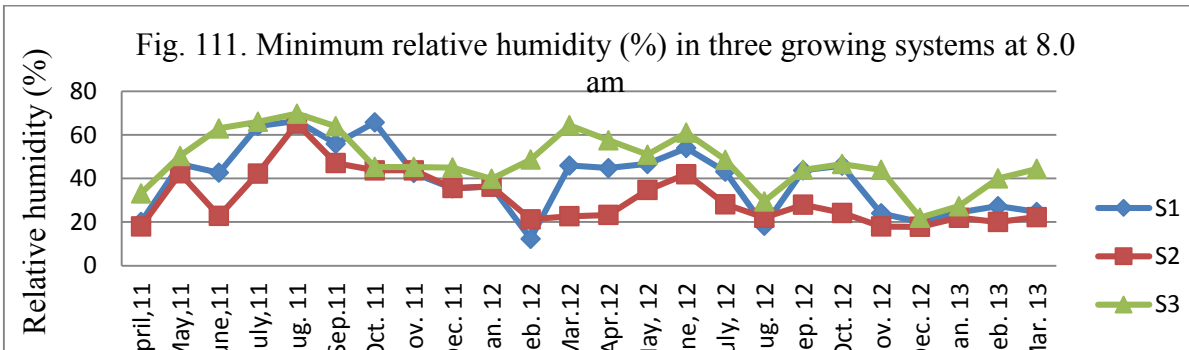


Fig. 112. Maximum relative humidity (%) in three growing systems at 2.30 pm

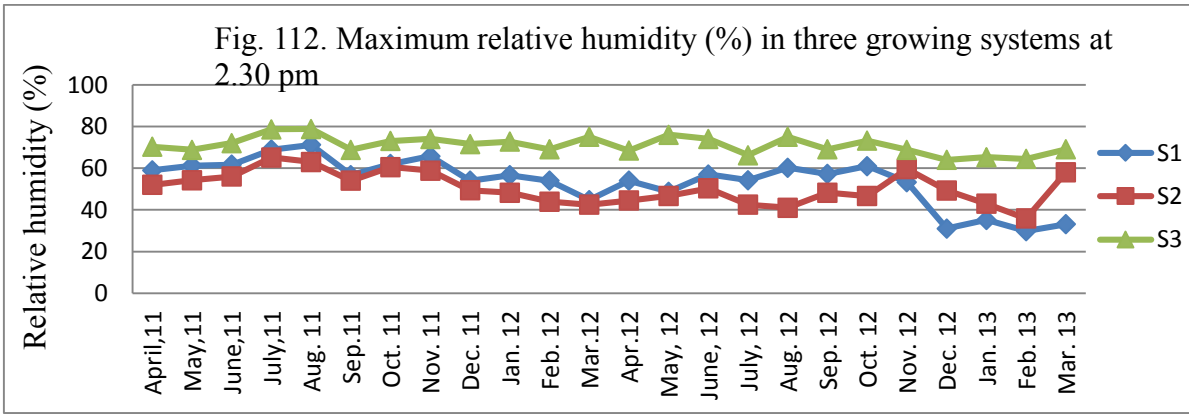


Fig. 113. Minimum relative humidity (%) in three growing systems at 2.30 pm

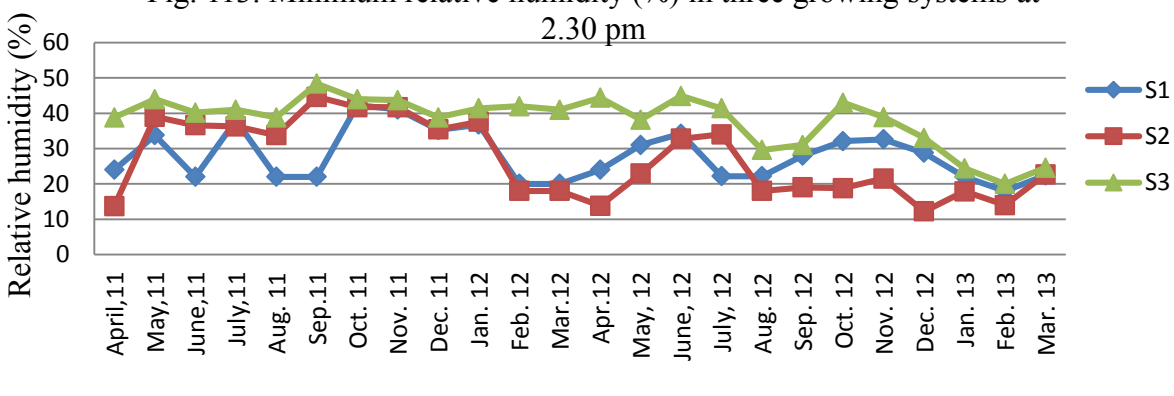


Fig. 114. Light intensity (lux) in three growing systems at 12.30 pm

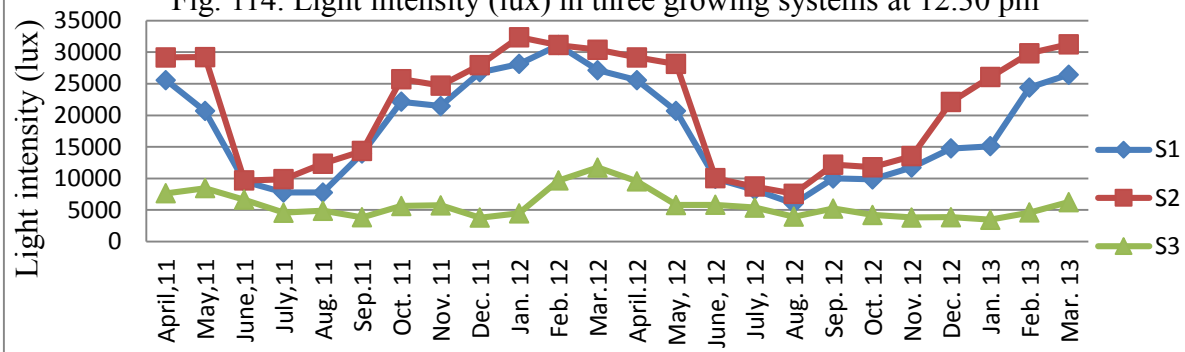


Fig. 115. Maximum temperature (^{0}C) at outside growing systems at 8.0 am

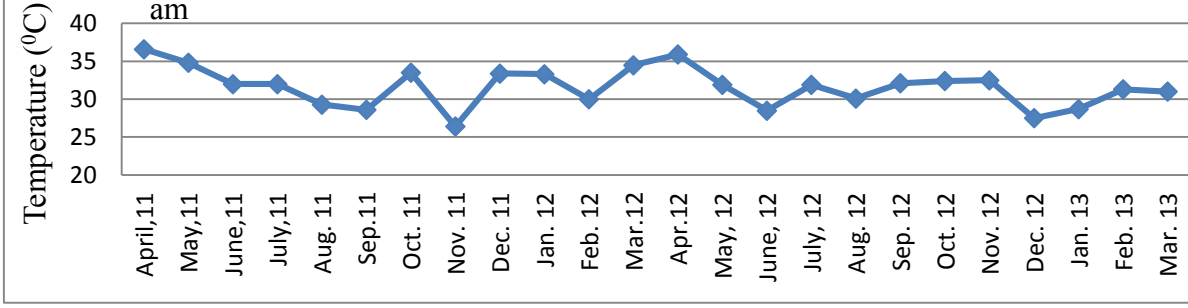


Fig. 116. Minimum temperature (^{0}C) at outside growing systems at 8 am

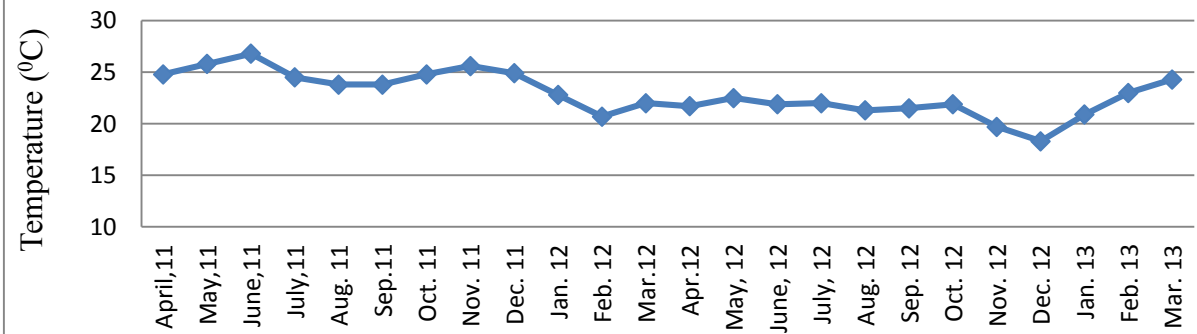


Fig. 117. Maximum temperature (^{0}C) at outside growing systems at 2.30 pm

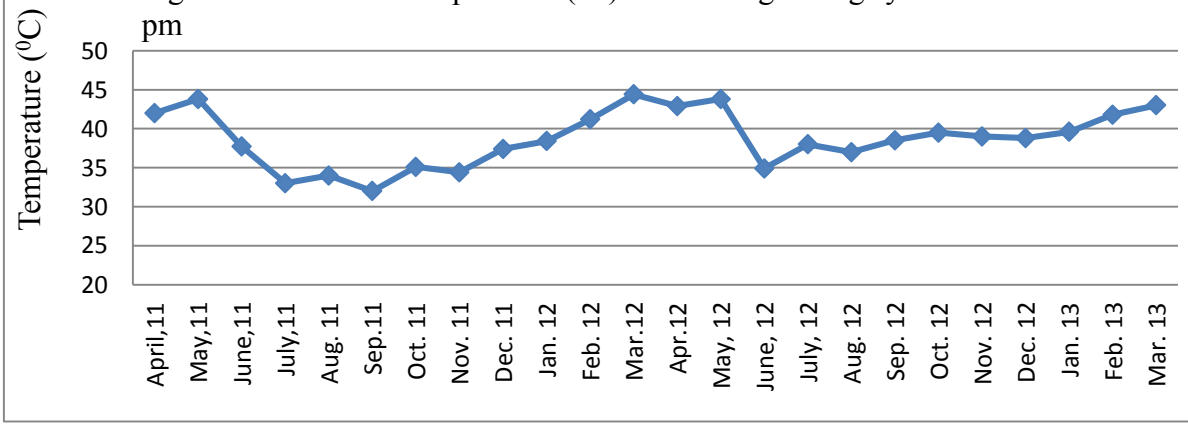


Fig. 118. Minimum temperature (^{0}C) at outside growing systems at 2.30 pm

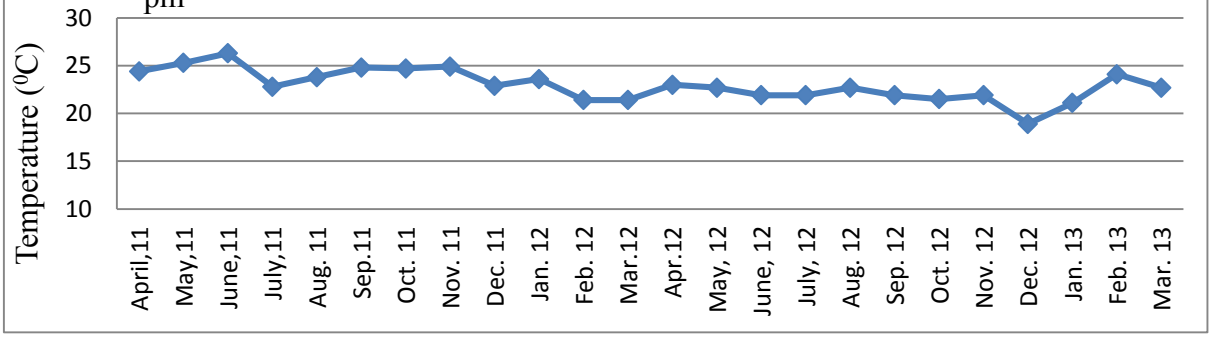


Fig. 119. Maximum relative humidity (per cent) at outside growing systems at 8 am

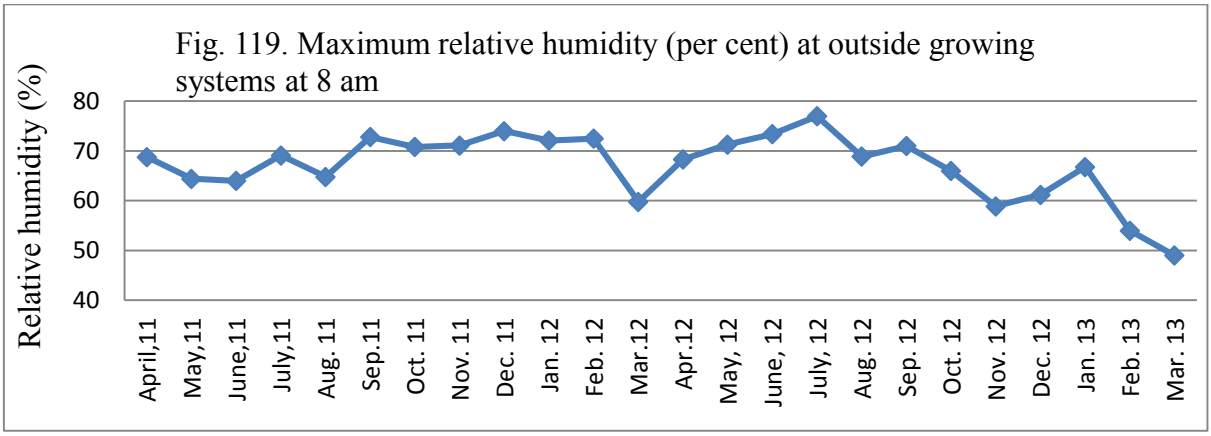


Fig. 120. Minimum relative humidity (per cent) at outside growing systems at 8 am

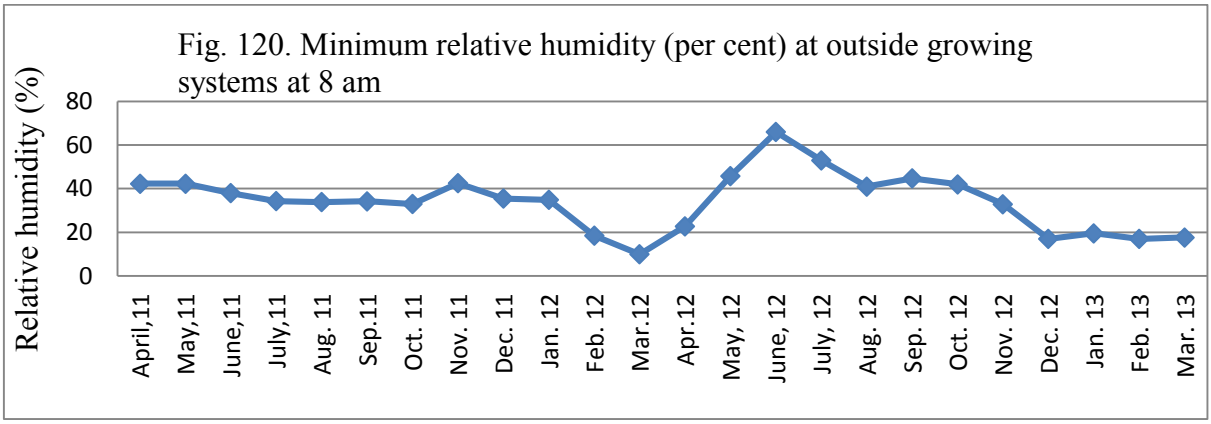


Fig. 121. Maximum relative humidity (per cent) at outside growing systems at 2.30 pm

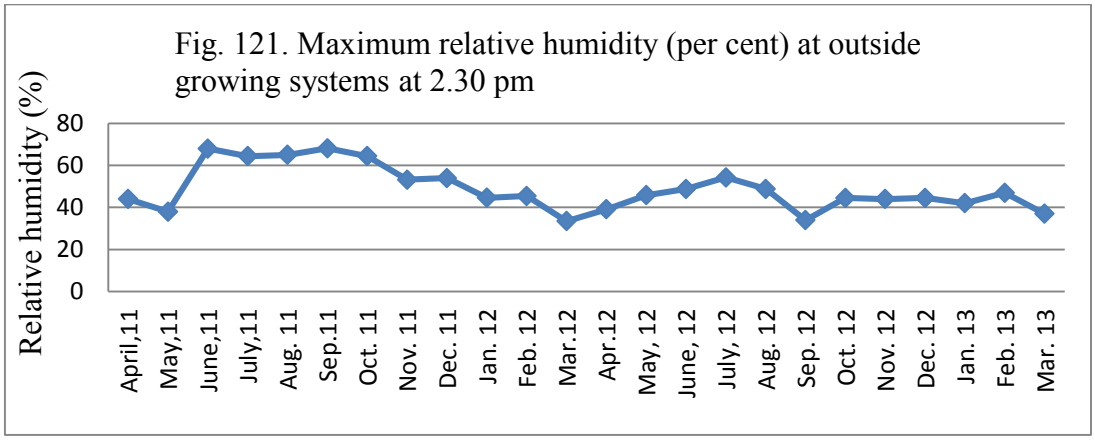


Fig. 122. Minimum relative humidity (per cent) at out side growing systems at 2.30 pm

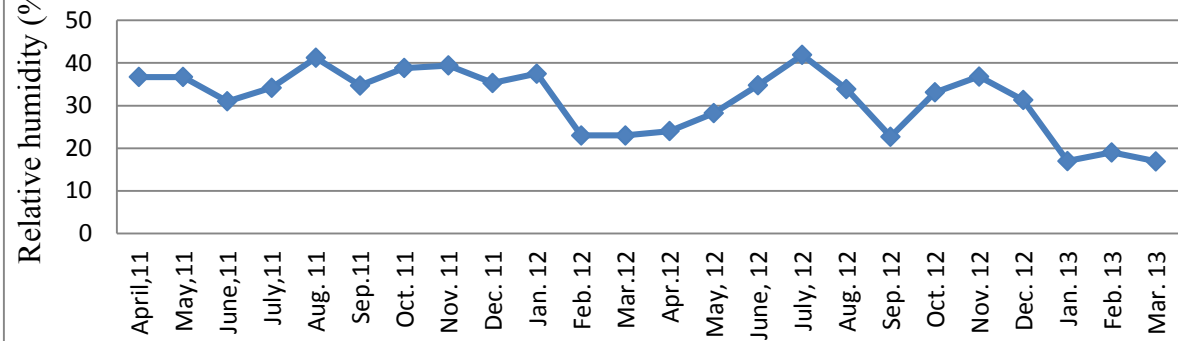


Fig. 123. Light intensity (lux) at out side growing systems

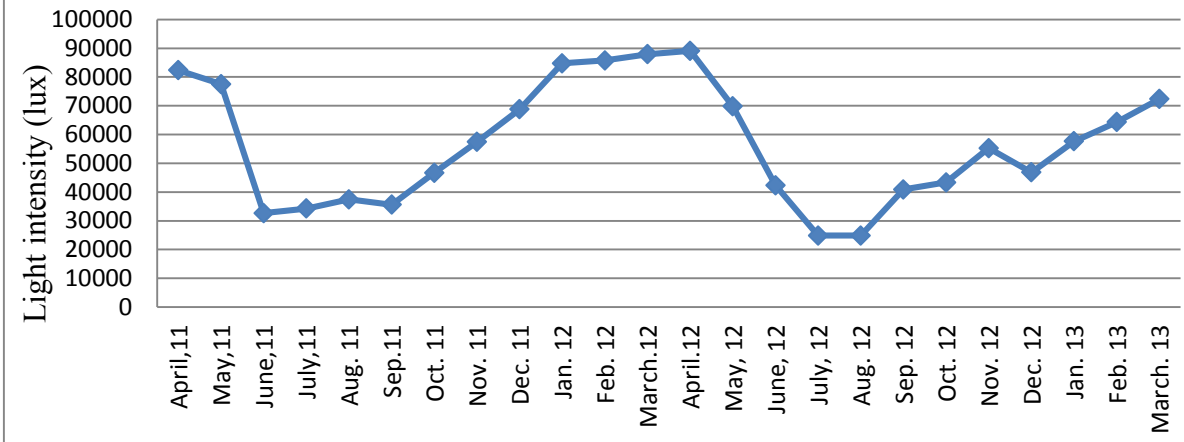


Fig. 124. Minimum and maximum temperature inside and outside of the growing systems at 8 am

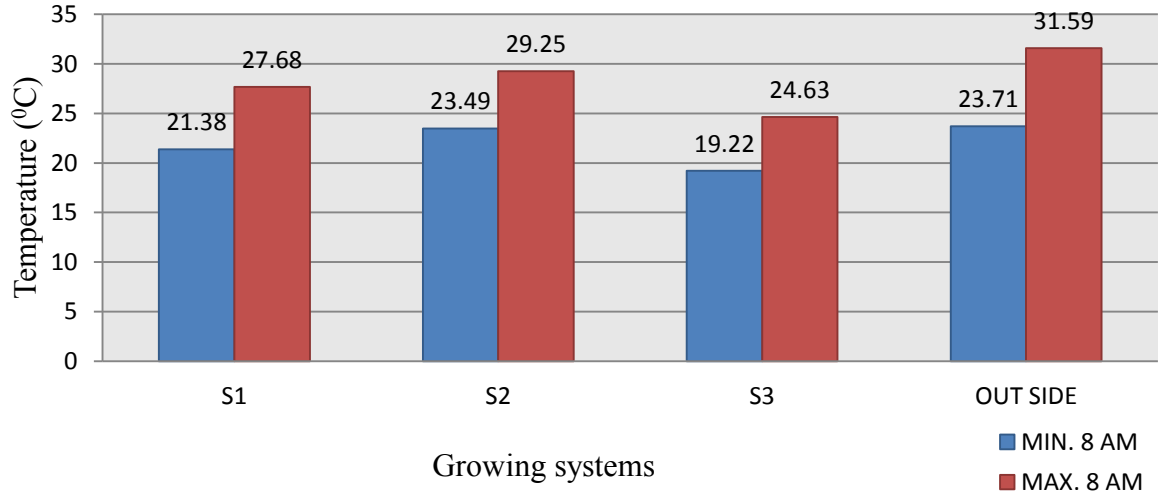


Fig. 125. Minimum and maximum temperature inside and outside of the growing systems at 2.30 pm

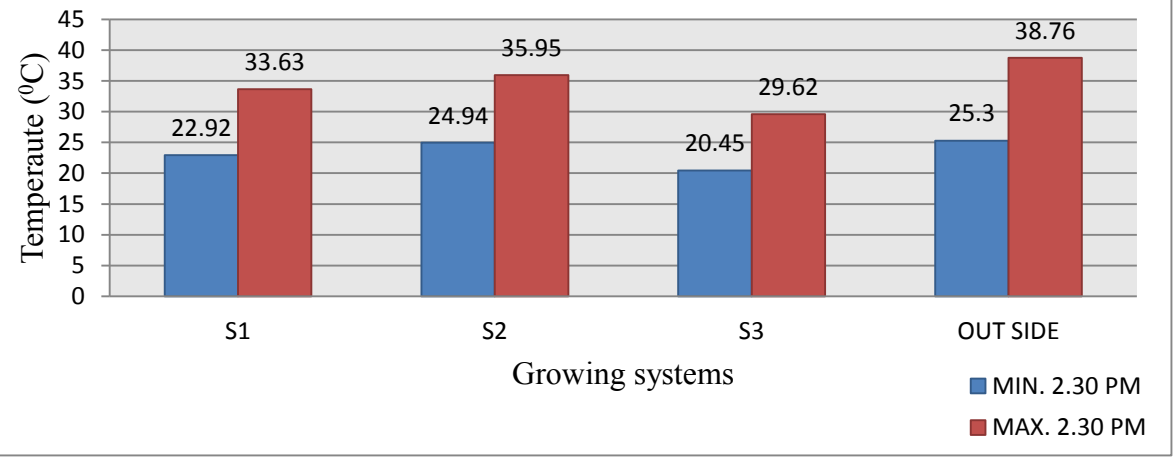


Fig. 126. Minimum and maximum relative humidity inside and outside of the growing systems at 8 am

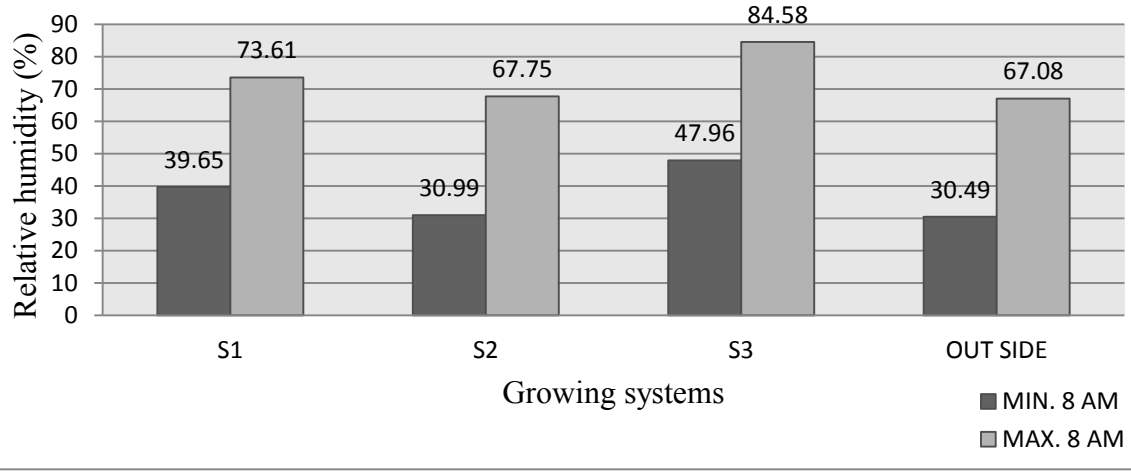


Fig. 127. Minimum and maximum relative humidity inside and outside of the growing systems at 2.30 pm

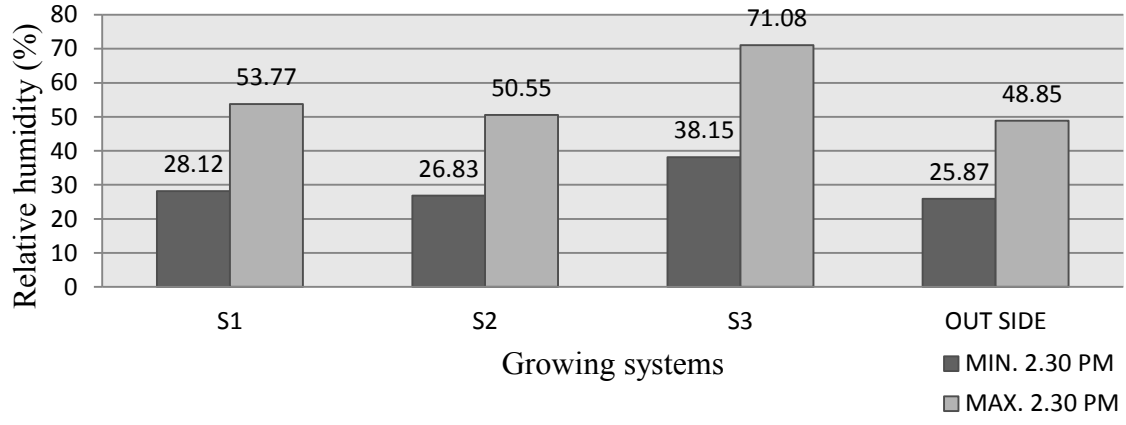
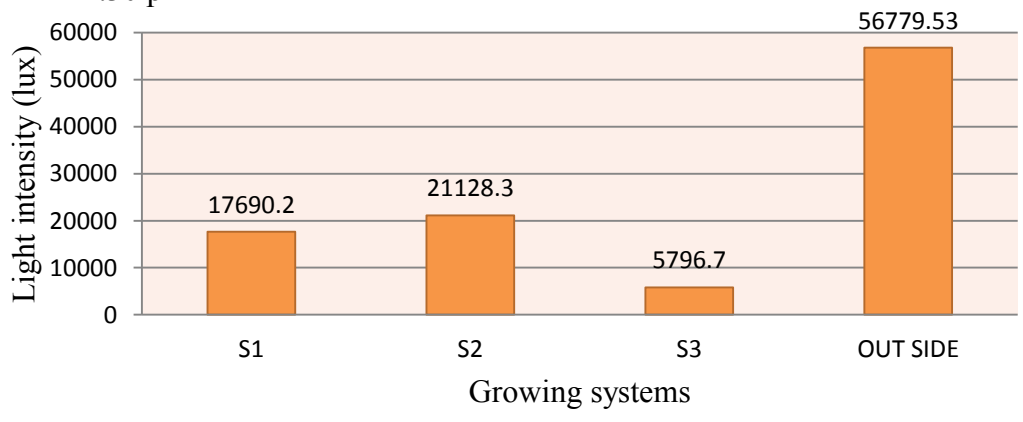


Fig. 128. Light intensity inside and outside of the growing systems at 12.30 pm



Abstract

GROWTH AND PHYSIOLOGICAL RESPONSE OF *Dendrobium* cv. EARSAKUL IN DIFFERENT GROWING CONDITIONS

By

M. RAJA NAIK

ABSTRACT OF THE THESIS

Submitted in partial fulfilment of the

requirement for the degree of

DOCTOR OF PHILOSOPHY IN HORTICULTURE

Faculty of Agriculture

Kerala Agricultural University

DEPARTMENT OF POMOLOGY AND FLORICULTURE

COLLEGE OF HORTICULTURE

VELLANIKKARA, THRISSUR – 680 656

KERALA, INDIA

2014

ABSTRACT

The study on 'Growth and physiological response of *Dendrobium* cv. Earsakul in different growing conditions' was conducted at College of Horticulture, Vellanikkara, Kerala from April 2011 to March 2013. The main objective was to assess the response of combination of nutrients, plant growth regulators and plant growth promoting root endophyte (PGPRE) in two age groups of *Dendrobium* cv. Earsakul plants (six month old and three year old at planting time) under three growing systems *viz.,* two level shade house (S_1), top ventilated polyhouse (S_2) and fan and pad system (S_3). Attempts were also made to examine the symbiotic association between the host and PGPRE.

Among growth characters, plant height, number of shoots per plant, girth of shoot and internodal length were highest in the treatment POP + OM + VW + PGPRE + Bone meal (T_3). Number of leaves per plant was also the highest in the treatment POP + OM + VW + PGPRE + Bone meal + GR (T_4) irrespective of the age of the plants. Among the three systems of growing, maximum growth characters were recorded in top ventilated polyhouse (S_2). Number of leaves and shoots per plant were the highest in the treatment combination of POP + OM + VW + PGPRE + Bone meal + GR (T_4) and top ventilated polyhouse (S_2).

The treatment POP + OM + VW + PGPRE + Bone meal + GR (T_4) resulted in longer spike (31.34 cm), more number of flowers per spike (6.54) and longer vase life (30.00 days), whereas, the treatment NPK + GR + OM + VW + PGPRE + Bone meal (T_6) was the best with respect to time taken for first flower opening and number of spikes per plant (2.62) in six month old plants. In three year old plants, the treatment POP + OM + VW + PGPRE + Bone meal + GR (T_4) was the best with respect to time taken for flowering, days to last flower opening, number of spikes (2.63) and vase life (28.26 days), whereas, length of the spike (30.46 cm) and number of flowers (5.08) were the highest in the treatment NPK + GR + OM + VW + PGPRE + Bone meal (T_6). Among systems of growing, plants grown under top ventilated polyhouse (S_2) had maximum flower characters. Interaction effect of POP + OM + VW + PGPRE + Bone meal + GR

(T_4) and top ventilated polyhouse (S_2) was significantly superior in flower characters irrespective of the age of the plants.

Leaf area, relative growth rate and number of stomata were highest in six month old plants, whereas, dry matter production and crop growth rate were highest in three year old plants in the treatment POP + OM + VW + PGPRE + Bone meal + GR (T_4). Dry matter production, crop growth rate, rate of photosynthesis and transpiration rate during day time were highest in the treatment POP + OM + VW + PGPRE + Bone meal (T_3) in six month old plants. Among the systems of growing, maximum values for physiological parameters were recorded in top ventilated polyhouse. The interaction of plant growth promoters and systems of growing had significant effect on physiological parameters.

Highest number of roots, root volume and root colonization (in three year old plants) resulted from the treatment NPK + GR + OM + VW + PGPRE + Bone meal (T_6) in both stages of plants, whereas, POP + OM + VW + PGPRE + Bone meal + GR (T_4) resulted in highest root length and root colonization in six month old plants. Among systems of growing, plants grown in top ventilated polyhouse (S_2) recorded highest number of roots per plant, root length, root volume and root colonization. The combination of POP + OM + VW + PGPRE + Bone meal + GR (T_4) and top ventilated polyhouse recorded highest number of roots, root length, root volume and root colonization of *Piriformospora indica*.

Highest N, P and K contents in six month old plants was recorded in the treatment POP + OM + VW + PGPRE + Bone meal + GR (T_4), whereas POP + OM + VW + PGPRE + Bone meal (T_3) recorded highest N and P contents in three year old plants. Among systems of growing, plants grown in top ventilated polyhouse recorded highest N, P and K contents. Interaction POP + OM + VW + PGPRE + Bone meal + GR (T_4) and top ventilated poly house recorded highest N, P and K contents in six month old plants.

Autoradiography showed that orchid roots absorbed ^{32}P from labelled nutrient solution N: P_2O_5:K_2O (1:2:2). Radio assay study revealed that radioactivity was highest in pseudobulbs than in roots and leaves. In anatomical studies, *P. indica* fungus association was confined to cortical tissues. Hyphae multiplied within cortical tissues and never traversed to aerial portion of the plant.

It was concluded that plant growth promoters POP + OM + VW + PGPRE + Bone meal + GR and top ventilated polyhouse had maximum influence on plant growth, yield parameters and physiological parameters like leaf area, DMP, CGR and RGR. The canonical correlation further reinforced the results that plant growth and yield of the plant was significantly influenced. The nutrient contents of N, P and K were highest in plants grown under top ventilated polyhouse. The association of *P. indica* in root system of *Dendrobium* cv. Earsakul was highly significant and the *P. indica* fungus enhances higher root absorption and facilitates the growth parameters significantly.