ECOPHYSIOLOGICAL STUDIES OF TERRESTRIAL ORCHIDS OF MEGHALAYA WITH SPECIAL REFERENCE TO *Paphiopedilum* SPECIES

By

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I certify that the thesis entitled **"Eco-physiological studies of terrestrial orchids of Meghalaya with special reference to *Paphiopedilum* species"** submitted by Miss Sabina Rynjah, for the degree of Doctor of Philosophy of North-Eastern Hill University, Shillong embodies the record of original investigation by her under my supervision. She has been duly registered and the thesis presented is worthy of being considered for the award of the **Ph.D. Degree.** The work has not been submitted for any degree of any other university.

29th December, 1993
Shillong

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PREFACE

The thesis embodies the results of an ecophysiological study of two species of a terrestrial orchid *Paphiopedilum*, commonly known as `Lady's slipper'. The two species, *P. insigne* and *P. villosum* which are endemic to the north-eastern region of the country and have great ornamental value are fast dwindling in their natural haunts due to over-exploitation and destruction of forests. The present study aimed at collecting relevant information and experimental data regarding distribution, morphology, phenology and ecological responses of these two species at certain climatic conditions and edaphic variables of environmental complex.

The thesis has been divided into 11 chapters. Chapter 1-5 include the General Introduction, Review of Literature, Study Site, Geographical Distribution and Morphology, Phenology and Anatomy of *Paphiopedilum*. Chapter 6-10 deal with the growth responses of these two species to watering, substrate quality, light intensity, soil nutrients level and offshoot density. Each of the above chapters has a brief introduction, method of study, results and a brief discussion.

A synthesis of the results of the entire study has been presented in the General Discussion which is followed by the summary and references.

Rynjah
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(SABINA RYNJAH)

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Chapter 1

GENERAL INTRODUCTION

Orchids are a unique group of flowering plants that show a wide range of diversity in size, structure, number, colour and fragrance of flowers. There are approximately 750 genera (Khoshoo 1986), and 20,000 species of orchids in the world (Cribb 1986). They are distributed all over the world, except the Antartica, and constitute one of the largest family of the flowering plants (Rittershausen and Rittershausen 1984, Khoshoo 1986).

In India, Orchidaceae is the second largest family of the flowering plants, next to the Gramineae (Jain 1986). About 1300 species of orchids occur in the north-eastern region of the country.

Orchids are popularly known as showy ornamental plants on account of their fascinating and long lasting flowers. Even the cut flowers remain fresh for a long time.

Credit for growing orchids for ornamental purposes goes to the Britishers. During the first half of the 18^{th} century, when the British Empire expanded around the world, orchids were collected and sent to England in large numbers. Some of them died during the journey before they could reach England, while many others survived, flourished and flowered in the expert hands of early orchid lovers. In 1832, John Lindley, Professor of Botany at the University of London, who was the foremost authority on orchids at that time, could not succeed in growing them under controlled conditions. However, during the same period Joseph Paxton, a gardener of the *Duke Of Devonshire*, demonstrated

that orchids can be grown and flowered successfully in the British Isle. After that time orchid growing became very popular in whole England.

During the second half of the 19th century, orchids were exported in large numbers to England from different countries in the tropics. They were auctioned for large sums of money in the sales room of Protheroe and Morris & Stevens in London. For example, at one time a single plant of *Odontoglossum crispum* was sold at a price of £1500. In 1851, the *Crystal Palace* in England on its opening day was adorned with two tons of Leopard Orchids (*Grammatophyllum speciosum*) imported from the East Indies. The trade of wild orchids at that time caused great damage to many species and they could never be recovered. Many orchid species now a days are not found in wild. For instance, the blue *Vanda* (*Vanda coerulea*) and the charming slipper orchids *Paphiopedilum fairieanum* have been missing from their former distributional ranges of Assam. *Odontoglossum crispum* and *O. pescatorei* of Columbia, *Cattleya* of Brazil, the white and pink *Vanda sanderiana* and the moth orchids, *Phalaenopsis schleriana* and *P. stuartiana* of Philippines have faced rarity.

Orchids with fantastic range of variation in their floral structure have attracted the attention of not only the botanists, but laymen as well. The orchid breeders took interest in propagating and producing new hybrids, as a result, wild orchids were in great demand. In England alone, nearly a quarter of 49 native species have become endangered and two species *Spiranthes aestivalis* and *Epipogium aphyllum* have been probably extinct. The ghost orchid *Epipogium aphyllum* has been missing for 3

consecutive years, while the monkey orchid *Orchis simia*, military orchid *Orchis militaris* and the lizard orchid *Himantoglossum hircinum* are all facing danger of becoming extinct. The lady's slipper orchid *Cypripedium calceolus* was reduced to a single plant in its sole remaining locality, as a result of its large scale removal from the wild over the years. Thus in order to protect and propagate as well as to introduce endangered European orchids in England, a programme was initiated at the Royal Botanic Garden, Kew some time in 1983 (Bailes *et al.* 1986).

Several orchid species were named after eminent early orchid growers. For instance, *Cymbidium dayanum*, *Paphiopedilum dayanum* etc. were named after John Day and a spectacular genus *Cattleya* was named by Lindley after William Cattleya who first grew the tropical orchids in England.

Scientific studies on orchids in India are lagging behind except for taxonomy, embryology, cytogenetics and a few tissue culture studies (Kataki 1963, 1976, Karanth *et al.* 1981, Sharma and Vij 1981, 1982, Sood 1984, Biswas 1986, Muralidhar and Mehta 1986, Vij and Shekhar 1986, Chaturvedi and Sharma 1986, Vij and Pathak 1990). The records of orchid growing in our country are indeed very poor. In this direction, sincere efforts have been made by Dr. Valluri at Bangalore, Dr. Govindachari at Madras, Professor Abraham at Trivandrum and some professional groups such as the Pradhans of Sikkim. Therefore, the knowledge about the biology of most of our orchids is still far from complete. Recently, collection, study and conservation programmes have been taken up by the Botanical Survey Of India, Orchid Research Station at Arunachal Pradesh and by the West Bengal Government.

In India orchid dealers are not so elaborately equipped for the propagation or breeding of orchids and the main source of their supply for commercial purposes is the forests. As a result, a near depletion and extinction of many attractive wild orchids have begun to take place from their natural haunts. Many of them are now endangered in the wild, those surviving the exploitation of the collectors, suffer from habitat destruction.

The north-eastern India is the richest geographical region for orchids in the country, yet our knowledge about orchids of this region is very poor, because the forests of this region are unexplored due to difficult terrain, adverse climatic conditions and even local conditions (Joseph 1986).

In India and even abroad, ecological studies on *Paphiopedilum species* have not been undertaken. A few physiological studies have been carried out by Nelson and Mayo (1977), Rutter and Willer (1979) and Assmann and Zeiger (1985). Studies on the ecology of other orchid species are also very few. A brief account of ecology of orchids has been given by Withner (1974). Rathore (1982) wrote an ecological note on *Cymbidium aloifolium*. Keddy *et al.* (1984) studied the ecology of *Cypripedium passerinum* while Calder *et al.* (1989) carried out ecological investigations on *Thelymitra epipactoides* F. Muell. A few studies on the habitat conditions and distribution of orchids have been carried out (Hegde 1982, Sara *et al.* 1985, William *et al.* 1985). Hutchings (1987) observed the population biology of *Ophrys sphegodes* Mill. Whigham (1984) studied the biomass and nutrient allocation in different plant parts of *Tipularia discolor*.

The genus *Paphiopedilum* commonly known as Lady's slipper bears attractive flowers and has high commercial value. The present ecological study has been done on two species of *Paphiopedilum* - *Paphiopedilum insigne* Pfitz. and *Paphiopedilum villosum* Stein. It includes detailed study of distribution, phenology, morphology, anatomy and effects of watering, substrate quality, light regime, interactive influence of light regime and soil nutrient level and offshoot density on the growth behaviour of both *P. insigne* and *P. villosum*. The results of these experiments have been presented and discussed in the following 1-11 chapters of the thesis.

Chapter 1. General introduction

Chapter 2. Review of literature

Chapter 3. Study site

Chapter 4. Geographical distribution of *Paphiopedilum*

Chapter 5. Morphology, phenology and anatomy of *Paphiopedilum*

Chapter 6. Effect of watering

Chapter 7. Effect of substrate quality

Chapter 8. Effect of light regime

Chapter 9. Effect of light intensity and soil nutrient level

Chapter 10. Effect of offshoot density

Chapter 11. General discussion

Summary

Chapter 2

REVIEW OF LITERATURE

In order to understand the growth, development and distribution of any plant species under natural conditions, it is necessary to examine their response to different factors of the environmental complex. In this respect little work has been done on orchids. Therefore, literature survey also included those studies on terrestrial plants which were related to the main theme of the present investigation. Few aspects of orchid ecology have been discussed by Withner (1974) and Helmut *et al.* (1981). However, studies dealing with the ecology of a particular orchid species are probably absent, except for the works of Keddy *et al.* (1984) on *Cypripedium passerinum* Rich., and Calder *et al.* (1989) on *Thelymitra epipactoides* F. Muell. Hutchings (1987) studied the population biology of spider orchid (*Orchis spegodes* Mill.) and Hegde (1982) studied the habitat distribution of orchids in Arunachal Pradesh. William *et al.* (1985) gave an account of the habitats of tropical orchids. Sara *et al.* (1985) described the habitat of four orchid species in Silver Lake Fen Complex.

Water present in soil determines the growth and reproduction of plants and therefore any change in soil moisture level affects the growth attributes and biomass production in plants (Downs and Hellmers 1975, Seliskar 1987, Chaghtai and Siddiqui 1987, Vandersman *et al.* 1988, Hester and Irvin 1989). Schulze *et al.* (1987) have discussed and explained the importance of plant water balance. Cunningham *et al.* (1979) reported that increased soil moisture during growth period, enhanced aboveground production in

Larrea tridentata, but reduced its allocation to reproduction. Foulds (1978) reported that soil moisture could affect the distribution pattern of *Trifolium repens*, *Lotus corniculatus* and *Medicaco lupulina*. Mueller-Dombois and Sims (1966) have discussed the effect of different water levels on the growth of three grass species in two different soil types while Vermeer (1986) studied the effect of nutrient addition and different water levels on species composition of Cirsio-Molinietum Siss *et* de Vries. Weerakoon and Lovett (1986) reported that when nitrogen and phosphorus were added separately to the soil, biomass production of *Salvia reflexa* was higher under drought while reverse result was obtained when nitrogen and phosphorus were added together. Kapuya *et al.* (1985) observed stunted growth in *Sorghum bicolor* under low moisture and low nutrient levels. Tripathi and Gupta (1981) found that the competitive ability of *Dicanthium annulatum* and *Bothriochloa pertusa* varies with the change in the soil moisture content.

Investigations on the effect of waterlogging on the growth and distribution of different plant species were undertaken by Jones and Etherington (1970) and Etherington (1984). Davies (1984) reported differences in the population of *Erica species* under waterlogging. Waterlogging as well as water stress both affected germination and growth of *Deschamsia cespitosa* and *Dactylis glomerata* (Rahman and Rutter 1980). Soil moisture stress influences ecological behaviour (McIntyre 1976, Heather and Hegarty 1979, Ong 1984, Muchow 1985, Stevenson and Laidlaw 1985, Yadav and Tripathi 1985, Ike 1986, Roziyn and Vander Werf 1986, Bauder 1989) and physiological activities in plants (Engin and

Sprent 1973, Misra and Singh 1982, Peters 1982, Rverson and Breen 1983, 1985, Sobrado and Turner 1986, Cid-Benevento and Werner 1986, Omaligo and Ene-Obong 1987). Trivedi and Tripathi (1982b) and Rai and Tripathi (1983) reported that soil texture and soil moisture may affect reproductive strategies of *Spergula arvensis* and *Plantago major* and population regulation of *Galinsoga parviflora*.

Classification of fertility level of soil is important for undertaking plant growth studies (Kalpage 1974). Gulmon and Turner (1978) observed differences in root and shoot growth of *Lycopersicum esculentum* L. when grown under contrasting soil types. Mooney (1966) and Noe and Blom (1981) observed differences in the distribution pattern of related species of *Erigeron* and *Plantago* under different soil types. Soils affect population biology (Snaydon and Bradshaw 1959, Rai and Tripathi 1983, Davies 1984) and reproductive strategies of different plant species (Hume and Cavers 1983, Trivedi and Tripathi 1982b). Whigham (1984) reported that, nutrients allocation in *Tipularia discolor* depends on the nutrients present in the soil as well as those which are assimilated/translocated during the growth period.

Different potting media for growing *Paphiopedilum villosum* and *Dendrobium moschatum* have been tested by Gupta and Singh (1986). Hawkes (1965) grew *Paphiopedilum* in a compost made of a mixture of *Osmunda* and chopped *Sphagnum*.

Nitrogen, phosphorus and potassium have been most frequently used either alone or in different combinations in the studies dealing with plant growth and development (Ingestad 1979, Campbell and Grime 1989, Inam *et al.* 1982, Rao *et al.* 1983,

McGraw 1985, Pratt 1985, Gupta and Gobind 1986, Bornkamm and Raghi-atry 1986, Omaligo *et al.* 1987, Heil and Bruggink 1987, Lamb and Klaussner 1988). Veerkamp and Kuiper (1982b) studied the effect of potassium and phosphorus on the growth of *Carex species*. Nitrogen use efficiency was studied by Elaine and Vitousek (1986), Patel and Singh (1986), Seeman *et al.* (1987) and Pandey and Dubey (1991). The effects of different nutrients viz., nitrogen, phosphorus and potassium on the growth of many plant species (in field and in the laboratory conditions) have been reported by McMaster *et al.* (1982), Davy and Bishop (1984), Erdei *et al.* (1986), Katiyar *et al.* (1987) and Ashraf *et al.* (1989). However, studies concerning the effect of application of nutrients to the potting media on orchids are lacking, with the exception of the works of Bhattacharjee (1981) on *Dendrobium moschatum*, Yadav and Bose (1986) on *Aerides multiflorum* Roxb. and Yoneda (1989) on the growth and flowering of *Epidendrum radicans* Pavon.

The importance of fungal association for the growth and development of orchid plants have been studied by many workers (Hijner and Arditti 1973, Warcup 1973, 1975, 1981, 1985, Jonsson and Nylund 1979, Terashita 1983, Dexheimer and Serrigny 1984, Alexander *et al.* 1984, Alexander and Hadley 1986, Katiyar *et al.* 1986, Salmia 1988, 1989, Jha *et al.* 1991).

Light intensity affects the growth of plant species in a variety of ways (Blackman and Wilson 1951, Fitter and Ashmore 1974, Westoby and Howell 1982, Read 1985, Solangaarachchi and Harper 1987 and Schwaegerle and Bazzaz 1987). Some workers have reported positive effects of high light intensity on the growth

of many plant species. Zimmermann (1976) found higher fresh weight production in *Portulaca oleracea* under high light intensity and the number of capsules was positively correlated with the amount of light received by the plants. Dennis *et al.* (1970) reported that high light intensity increased flowering in cultivated strawberries but had no effect on vegetative reproduction. Patterson (1980) studied the partitioning of biomass in plants and concluded that exposed habitat favoured allocation to reproduction. Longstreth and Mason (1984) reported the average dry weight of *Alternanthera philoxeroides* at high photon flux density (40 mol m^{-2} day^{-1}) was nine fold than those at the low (8 mol m^{-2} day^{-1}) PFD. Light intensity also induced variations in growth and dynamics of transplanted rametes of *Aster acuminatus*. The ramete growth and flowering were positively correlated with the amount of light in *Aster acuminatus* (Ashmun and Pitelka 1984, Pitelka *et al.* 1985). However, Khaleafa *et al.* (1982) reported that growth and nitrogen content in *Caulerpa prolifera* increased with the increase in light up to 2,500 lux, but decreased significantly under light intensity higher than 3,500 lux.

Apart from the effects of light, the influence of shading on plants have also been studied by a large number of workers. Clausen *et al.* (1940) found that very low light intensity highly reduced flower and seed production in *Achillea* species. Evan's and Hughes (1960) studied the effect of shading on *Impatiens parviflora*, Pandey and Sinha (1977) on *Crotalaria juncea*, Pakham and Willis (1977) on *Oxalis acetosella*, Morgan and Smith (1981b) on *Chenopodium album*, Pakham and Willis (1982) on *Galeobdolon*

luteum and Bourdot *et al.* (1984) on *Achillea millefolium*. *Elymus repens* and *Agrostis gigantea* responded to reduced light intensity by increased stem length but decreased aerial shoots (Skuterud 1984). Corre (1983) reported increased stem elongation in both sun and shade plants under shaded condition. Studies on plasticity of plant traits in response to light intensity were carried out by Bradshaw (1965), Hickman (1975) and Rice and Bazzaz (1989). Chabot and Chabot (1977) reported variation in leaf thickness of *Fragaria vesca* under different light intensities and observed thin leaves under lowest light condition. The combined effects of age and shade on photosynthetic capacity of *Trifolium repens* were studied by Woledge (1986). He found that photosynthetic rate increased for the first week till the fully expanded stage of leaf, thereafter it decreased with age and the rate of decrease was more rapid in bright sunlight than in the dim light. Grime (1965) investigated the shade tolerance in flowering plants .

In case of orchids, the studies dealing with the effects of light intensity and photoperiodism on growth and flowering are few. Bhattacharjee (1979) found that long day treatment stimulated vegetative growth in *Dendrobium phalaenopsis* Fitzg., *Phalaenopsis amabilis* Bl. and *Phalaenopsis schilleriana* Rchb.f., while short day induced early flowering by 50-59 days depending on the species. However, Healy *et al.* (1982) and Lin and Molnar (1983) reported that high light and long photoperiod may induce early flowering in *Alstroemaria* under low temperature.

The combined effect of light and nitrogen supply have been studied on a large number of plant species (Gulmon and Chu 1981,

Fernandes *et al.* 1985) and that of light and other nutrients application by Peace and Grubb (1982), Jurik *et al.* (1982), Larsson *et al.* (1986) and Neumaier *et al.* (1987). Diepenbrock (1981) studied the effect of light and nitrogen application along a temperature gradient on fatty acid composition in leaves of winter rape. Shading along with nutrient supply affected the growth of *Pteridium acquilinum* L. It was reported that when nitrogen, phosphorus and potassium were added together under reduced light intensity, fewer fronds were produced and these were different morphologically as well as anatomically from those plants which were grown under full sunlight (Daniel 1986). Populations of *Eupatorium adenophorum* and *E. riparium* were favoured by soil nitrogen, however, low nitrogen was required under low light intensity (Tripathi and Yadav 1982).

Physiological studies on orchids have attracted the attention of many workers. However, most of these studies deal with stomata, photosynthesis , carbondioxide assimilation, germination, and tissue culture, while other aspects remain unexplored. Rasmussen (1981) and Singh (1981) described the development and organisation of stomata in Orchidaceae. The structure and role of stomata in *Paphiopedilum* and *Phragmipedium* have been discussed by Nelson and Mayo (1977), Rutter and Willer (1979), Hew *et al.* (1980), Outlaw *et al.* (1982), Zeiger *et al.* (1985) and Assmann and Zeiger (1985). Photosynthesis and photosynthetic apparatus in orchids have been discussed by several workers (Wong and Hew 1973, Damsz 1980, Toshio 1982, Miura 1982, Gold *et al.* 1983, Grivet and Zeiger 1983, Lux and Hudak 1987). Fu and Hew (1982), Winter *et al.* (1983, 1985), Goh

et al. (1984), studied the crassulacean acid metabolism in orchids while their carbon metabolism was investigated by Neales and Hew (1975), Assmann and Zeiger (1983), Goh *et al.* (1983), Goh (1983) and Hadley (1984). Ethret and Mayo (1980) studied the effect of abscisic acid and vapour pressure deficit on *Paphiopedilum leeanum* leaf. Dighe *et al.* (1987) worked on the nitrogen fixation in *Vanda testacea* (Lindl) Reichb.

Elemental composition of orchids have been analysed by Yamaguchi (1979), Carlucci *et al.* (1980), Taguchi *et al.* (1981), Bergstrom *et al.* (1981), Renata and Stobiecka (1983), Kausch and Horner (1983) and Schlee and Ebel (1983). Uphoff (1982) determined the anthocyanin concentration of orchids during floral development. Arditti and Tarr (1979) and Cooper *et al.* (1982) worked on niacin biosynthesis in leaf disc of *Cattleya skinneri* as well as in other angiosperms. Kosakiv'ska *et al.* (1984) differentiated different orchid species on the basis of protein studies.

Olaturgi and Nengim (1980) reported the occurrence of tracheidal elements in Orchidaceae. Occurrence of viscin thread in *Zeuxine strateaumatica* was observed by Vijayaraghavan and Shukla (1981). Aliev *et al.* (1984) studied the reorganisation of lysosome in orchid leaves during space flight.

Orchid seeds take a pretty long time to germinate and germination percentage is usually low. In the beginning propagation of orchids through seeds was a difficult task. But with the discovery of a method of germination of orchid seeds in sterile flask containing agar and sugar as a medium by Knudson (1922) an American botanist,led to the mass propagation of orchid

through *in vitro* germination of both symbiotic and asymbiotic species (Harvais 1973, 1982, Warcup 1975, Clement 1977, Harrison 1977, Cheng and Chua 1981, Linden 1980, Arekal and Karanth 1980, Arditti *et al.* 1982, Henrich *et al.* 1981, Singh and Prakash 1985, Van Waes and Debergh 1986, Sharma and Tandon 1986, Manning and Studen 1987, Yam and Weatherhead 1988, Pierik *et al.* 1988).

Many workers used tissue culture techniques to save orchids from extinction (Yoneda *et al.* 1981, 1983, Kusumoto 1981, Vij *et al.* 1984, Hammatt and Evans 1985). Morel (1971) developed a method for meri-culture. This led to the propagation of orchids by meristem cultures (Illsley 1965, Sagawa 1966, Marston and Varaurai 1967, Mitra 1971, Kerbauy 1984, Sanchez 1988, Yoneda and Momose 1988). Morel (1971) described the principle of clonal propagation of orchid plants. Rao (1977) used tissue culture in orchid industry. Momose and Yoneda (1988) developed a technique to produce a protocorm like body by culturing a portion of floral stalk node bud of the inflorescence axis of *Phalaonepsis*.

Embryo culture technique for orchids in liquid medium was developed by Kerbauy and Handro (1981) and Singh and Prakash (1985).

Heavy metal toxicity in orchid culture in green house was reported by Irmer *et al.* (1982) while Ernst and Arditti (1984) observed phytotoxicity of surfactant on *Brassocattleya* seedlings. Hills *et al.* (1984) reported that phytoalexin (orchinol and loroglossol) inhibited the growth of *Cattleya aurantiana* seedlings. The effect of vitamins plus nitrogen and hormones on orchid seed germination and orchid seedlings was studied by O'Neil (1958), Mead and Bulard (1975) and Duan and Xie (1981).

Pollination ecology has been most extensively studied in orchids. It deals with the relationships of orchid flowers with their pollinators. The pollinators are generally bees and wasps, who visit the flowers for their food, accidentally carry pollen on their back and feet and pollinate another flower (Pjil and Dodson 1966, Nilsson 1983, Whigham and McWethy 1980, Brantjes 1981, Dierenger 1982, Stoutamire 1983, Ackerman 1983, Williams and Whitten 1983, Silva and Stort 1989). *Orchis galileae* (Bornm, *et* Schulze) Schltr., has been reported to produce no nectar, instead they produce a strong specific scent similar to sexual attractant that attracts male bees *Halictus marginatus* (Bino *et al.* 1982). *Cryptostylis excelsa* and *Ophrys* species also produce scent which attracts male pollinators (Graham 1984 and Borg Karlson *et al.* 1987). Pollination in orchids also takes place due to their mimicry with the flowers of other plant species.

Post-pollination changes in orchids have also been discussed in a large number of physiological studies (Arditti *et al.* 1971, Chadwick *et al.* 1981, Strauss and Arditti 1982, 1984). The occurrence of autogamy in orchids has been observed by Gandawidjaja and Arditti (1982) in *Phaius tankervilliae*, Graham (1984) in *Eulophia*, Catling (1980) in *Liparis loeselin*, Jansen *et al.* (1980) and Mehrhoff (1984) in *Encyclia cordigera* and *Isotria medealoides*. Schick (1988, 1989) described the anatomy and function of pollinating apparatus in monandrous orchid flowers. The relationship between pollinators and fruit production in neotropical orchids has been studied by Zimmermann and Aide (1989). Inter and intraspecific crossings have also been done in orchids (McConnel and Kamemoto 1983, Stort 1985, Stort *et al.*

1985, Peakal and James 1989).

Large number experiments done on plant population dynamics (Tamm 1972, Thomas and Dale 1975, Sagar and Mortimer 1976, Harper 1977, Jansen 1977, Kirby 1980, Lovett 1981c, Yadav and Tripathi 1981, Kushwaha *et al.* 1983b, Cook 1983, Hartnett and Bazzaz 1983, Reader 1985, Naoki and Todaki 1985), and population biology of different species (Nobel *et al.* 1979, Abrahamson 1980, Schellner *et al.* 1982, Pitelka *et al.* 1984), show that besides physical factors of environment, resource competition and other biotic interactions play an important role in growth and regulation of plant populations. Several field experiments confirm that significant reductions in plant growth and/or survival occur in presence of neighbours (Putwain and Harper 1970, Allen and Forman 1976, Dwivedi and Tripathi 1980, Fowler 1981, Silander and Antonovics 1982, Yadav and Tripathi 1984, Goldberg 1987).

Hooker (1894) identified and described the orchids of British India. Pradhan's (1976) and Rittershausen and Rittershausen's (1984) works help in identifying various types of orchid species. Summerhayes (1968) described the structure of orchid plant and differentiated its structure from other monocotyledons. Rao (1979) and Bose and Bhattacharjee (1985) discussed the importance and uses of different orchid species. Joseph (1982) worked on the orchids of Nilgiri. Indian orchids used for drugs and chemicals are described by Majumder *et al.* (1982, 1983), Handa (1986) and Majumder and Sen (1987). Drugs and medicinally important orchids of Europe and Japan have been reported by Namba *et al.* (1981), Namba and Lin (1981), Lin and Namba (1982).

Rapid depletion of orchid species from their natural habitats led several biologists or orchidologists to suggest preventive measures for their conservation (Kataki 1975 and Singh 1981). Cribb (1986) described the world's wild orchid crisis and gave detailed description of *Paphiopedilum urbanianum* and *P. hennisianum*. Hegde (1981a) described the 'Lost Orchids' and their conservation measures. Rao and Haridasan (1983) studied the threatened plants of Meghalaya and emphasised the need for their conservation. Jain and Kataki (1977) suggested afforestation programme for conservation of orchids. Varma and Sahni (1976) reported the rare orchids of north-eastern region and suggested methods to conserve them. Chudovska (1980) developed a technique for preservation of orchid flowers in herbarium without destroying their colouration.

Studies on taxonomy, physiology, anatomy and cytology of *Paphiopedilum* have been done by Rosso (1966), Rao (1974), Kataki (1976), Nelson and Mayo (1977), Adriansen (1980) Outlaw *et al.* (1982) Cribb (1986) and Biswas (1986).

A brief review of literature presented above, explicitly reveals that studies on the ecology of orchids in general and these two species in particular, are far and few between. In view of the above, a study on the eco-physiology of two species of *Paphiopedilum* was carried out to understand their growth behaviour under varied environmental conditions.

Chapter 3

STUDY SITE

The present investigation was carried out in and around Shillong (Lat. 25°34', Long 91°56'E and alt. 1500m), the capital of Meghalaya in north-eastern India. Field study was carried out in Upper Shillong (alt. 1700m) and pot experiments were conducted in net house in Mayurbhanj Campus, School of Life Sciences, North-Eastern Hill University, Shillong.

Climate

The climate of Meghalaya is very pleasant. It enjoys a monsoonic climate with an average annual rainfall of 2500cm. The average rainfall, temperature and relative humidity data recorded during the study period are given in Fig. 3.1. The climate of this state can be divided into four seasons (1) spring (March to April), (2)wet summer (May to September) (3) autumn (October to November) and (4) winter (December to February). The spring season is characterized by the gradual increase in temperature accompanied by occasional showers. The south-west monsoon blows over the state during the summer which is characterized by relatively high temperature, strong winds, heavy rainfall and high humidity. The autumn season experiences mild cold and dry weather. End of November marks the beginning of the winter season. During the winter season, temperature drops considerably and cold becomes severe. Thus the winter season is characterized by low temperature and dry weather although occasional showers are received through north-east monsoon. Clear winter days are

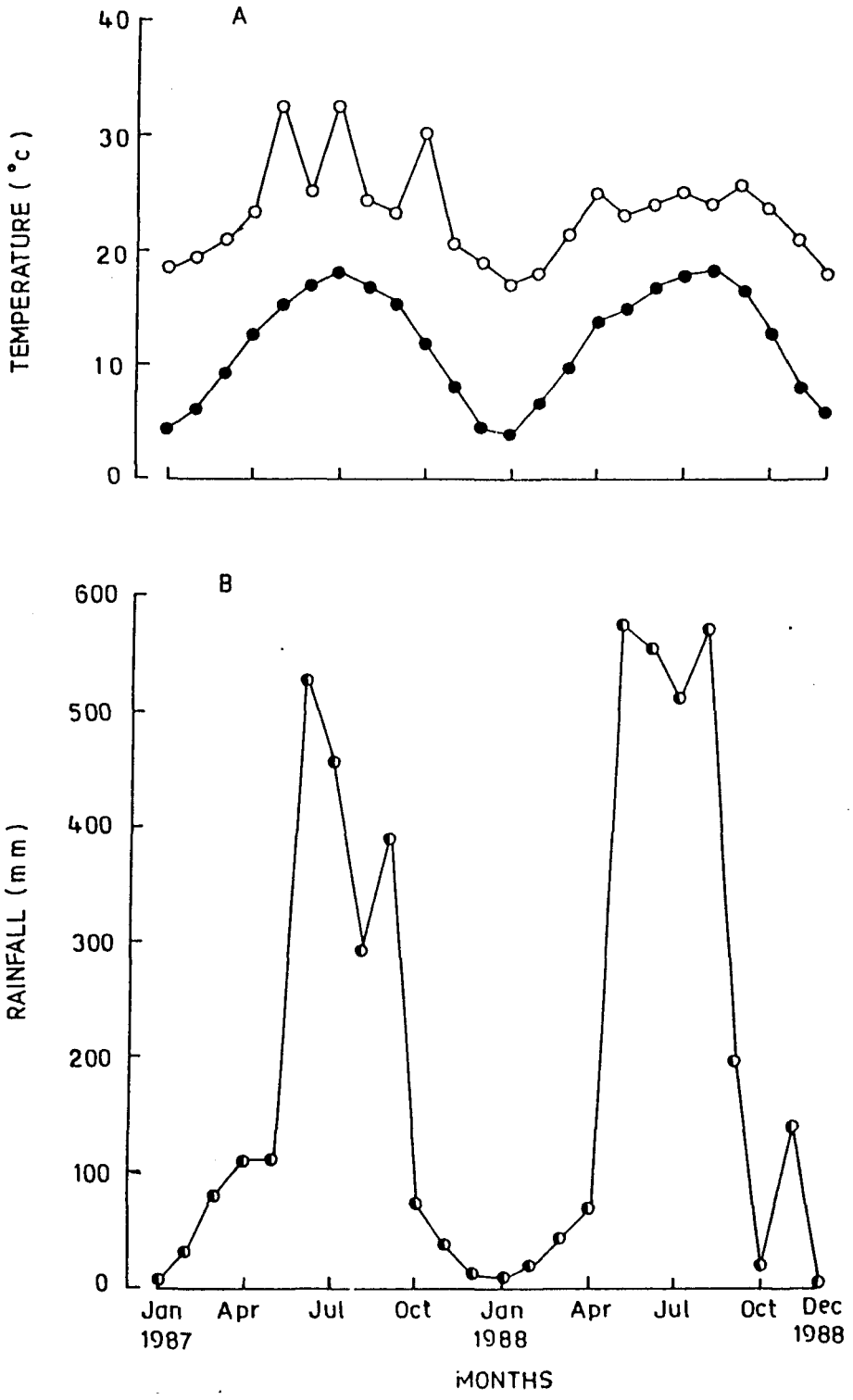


Fig. 3.1 Temperature (Fig. 3.1A) and rainfall (Fig. 3.1B) data for the study area during January 1987 to December 1988. —o— mean maximum temperature; —●— mean minimum temperature; —◐— average rainfall.

usually followed by frosty nights and the temperature sometimes drop to near the freezing point. The overall climate is suitable for the luxuriant growth of plants except during winter months when the temperature is low and air and soil are considerably dry.

Soil

The Meghalaya plateau comprising the Garo, Khasi and Jaintia Hills, has an evolutionary history of emergence, submergence and peneplanation. It is made up largely of Precambrian rocks acutely folded and steeply dipping, with an overturned fringe of Mesozoic and Tertiary sediments. The plateau has experienced the influence of an alternative phase of transgression and regression of the sea water from the Mesozoic to the early Tertiary times. It is believed that the hills of Shillong Plateau and its surroundings were uplifted from the sea bed called Tethys Sea during the Mesozoic to the early Tertiary time along with the origin of the Himalayas (Zimba 1991). Large portion of the hill areas of Meghalaya plateau is covered with lateritic soil having reddish brown colour and sandy loam to silty loam texture from the surface to the deeper layers. It has originated from the hard rocks representing gneises, schists, granite conglomerates, quartzites etc. The soil is acidic with pH ranging from 5.2-6.5 and rich in organic matters under forest cover.

Vegetation

The vegetation of Meghalaya is predominantly evergreen at upper elevation with patches of subtropical wet hill broad

leaved forest and vast stretching secondary pine (*Pinus kesiya*) forest. Besides, tropical moist forest at lower elevation, degraded forests, jhum fallows colonized by ruderal weeds, savanna like vegetation and patches of grasslands are conspicuous features of the state. The main occupation of the people of this region is agriculture. The tribal people generally practice shifting cultivation locally known as "Jhum" although they are now taking to settled agriculture on terraces and in the valleys in and around the urban centres.

Heavy rainfall during summer and high humidity in most parts of the year although favour luxuriant growth of great variety of mosses, lichens and epiphytic ferns and orchids, habitat destruction and decline in the broad leaved tree species in the forest and over-collection have adversely affected the orchid population in the state. The forest floor and rock crevices are the natural abode of the two species of *Paphiopedilum*, but destruction of the forests and their in indiscriminate collection have made them extremely rare in nature. They are now mostly found in the nurseries of the commercial growers and in the houses of orchid lovers.

Chapter 4

DISTRIBUTION OF PAPHIOPEDILUM

Lady's slipper orchids are worldwide in distribution barring Australia (Veitch & Sons 1894). Approximately 50 species of *Paphiopedilum* have been reported from different parts of the world (Table 4.1), and about 90 hybrids have been produced through intergeneric and interspecific hybridisations (Veitch & Sons 1894, Hooker 1894, Hawkes 1965, Rosso 1966, Pradhan 1976) (Table 4.2).

Paphiopedilum species grow in north-east India, Bangladesh (Sylhet) and Malay. In northern India, it is found chiefly in Khasi, Jaintia and Garo Hills of Meghalaya, and lower Himalayan ranges starting from Sikkim to eastern Assam and extending further eastward to Hongkong and on the mountain ranges of south China. From India, 9 species of *Paphiopedilum* (Fig. 4.1) and 4 species of *Cypriepedium* have been reported by Kataki (1984).

Paphiopedilum spp. occur between 1200m and 2000m elevation where rainfall is heavy and dry season is very short. They are mostly found growing below the rock ridges, in the rock crevices and on the forest floor, where there is accumulation of decaying organic matter. Some species e.g., *Paphiopedilum villosum* also grows as epiphytes in the forks of branches of trees. Sometimes the plants are found on decayed fibrous roots of ferns.

Paphiopedilum insigne Pfitz., was first reported by Wallich in 1819 from the Sylhet district (now in Bangladesh); (Kataki 1984). The plant was sent to England during 1819-1820 and grown in the Liverpool Botanic Garden where it bloomed for the first

Table: 4.1. Distribution of *Paphiopedilum* in the world.

NAMES	PLACE	TIME OF FLOWERING
P.phillipinense (Rchb.f.) Pfitz.	Phillipines	Not reported.
P.Sanderianum (Rchb.f.) Pfitz.	Do	Summer - Early Autumn.
P.amabile Hall.f.	Borneo	Spring - Early Summer.
P.appletonianum (Gower) Rolfe.	Himalayas, Assam & Thailand	Spring.
P.Argus (Rchb.f.) Pfitz.	Phillipines: Luzon & Negros	Spring - Early Summer.
P.barbatum (Idl.) Pfitz.	Thailand & Malay Peninsula	Spring -Autumn.
P.bellatulum (Rchb.f.) Pfitz	Burma & Thailand	Spring.
P.Bullerianum (Rchb.f.) Pfitz.	Borneo & Malay Peninsula	Summer.
P.callosum (Rchb.f.) Pfitz.	Thailand & Cambodia	Spring - Summer.
P.chamberlainianum (O'Brien) Pfitz.	Sumatra	Through out the year.
P.charlesworthii (Rchb.f.) Pfitz.	India,Burma & Arrakan mountain	Autumn.
P.ciliolare (Rchb.f.) Stein.	Phillipines: Luzon,Dinagot,Mindanao	Spring - Early Summer.
P.concolor (Par & Batem) Pfitz.	Thailand,Burma,Cambodia,Laos,Vietnam	Spring.
P.curtissii Rchb.f.	Sumatra	Spring - Summer.
P.fairieanum (Idl.) Stein.	Himalaya,Bhutan,Assam	Summer - Early Autumn.
P.glaucophylum J.J.Sim.	Java	Spring.
P.godefroyae (Godefr) Pfitz.	Burma, Thailand, Vietnam	Spring - Early Summer.
P.Haynaldianum (Rchb.f.)Pfitz.	Phillipines: Luzon	Spring.
P.hirsutissimum (Ldl.) Stein.	Himalaya,Assam.Khasi Hills	Spring.
P.Hookerae (Rchb.f.) Pfitz.	Borneo	Spring - Early Summer.
P.venustum (Wall.) Pfitz	Sikkim, Sylhet, Assam	Winter.
P.insigne (Wall.) Pfitz.	Himalayas,Meghalaya	Autumn - Spring.
P.javanicum (Reinw) Pfitz.	Java & Borneo	Summer - Autumn.
P.lawrenceanum (Rchb.f.) Pfitz.	North Borneo	Summer - Autumn.

Table 4.1 (contd.)

NAMES	PLACE	TIME OF FLOWERING
P.lowii (Ldl.) Pfitz.	Sarawak	Spring - Summer.
P.mastersianum (Rchb.f.) Pfitz.	Moluccas, Amboina	Not reported.
P.niveum (Rchb.f.) Pfitz.	Langkawi islands,Peninsular, Thailand, Tambilan islands, Borneo	Spring - Autumn.
P.parishii (Rchb.f.) Pfitz.	Burma, Thailand	Spring - Autumn.
P.Praestans (Rchb.f.) Pfitz.	New Guinea	Spring - Autumn.
P.Rothschildianum (Rchb.f.)Pfitz.	Sumatra, Borneo, New Guinea	Summer - Autumn.
P.spicerianum (Rchb.f.) Pfitz.	Assam	Autumn - Winter.
P.stonei (Hk.F.) Pfitz.	North Borneo, Sarawak	Summer - Autumn.
P.Tonsum (Rchb.f.) Pfitz.	Sumatra	Spring - Early Summer.
P.villosum (Ldl.) Stein.	Assam, Lushai hill, Burma, Thailand	Autumn - Spring.
P.Dayanum (Rchb.f.) Pfitz.	North East Borneo	Spring.
P.druryi (Bedd.) Stein.	India:Travancore	Spring.
P.exul (O'Brien) Pfitz.	Peninsular Thailand	Spring
P.nigritum (Rchb.f.) Pfitz.	Borneo	Spring - Summer.
P.purpuratum (Ldl.) Pfitz.	Hongkong,Chinese Coast	Summer - Autumn.
P.superbiens Rchb.f.	Island of the Strait of Malacca	Spring - Summer.
P.victoriae Mariae (Hk.f.) Rolfe.	Sumatra	Spring - Summer.
P.volonteanum (Sand.) Pfitz.	Borneo	Summer - Autumn.
P.acanodontum	Phillipines	Not reported.
P.hennisianum	Phillipines: Mindanao	Not Reported.
P.leucochilum	Thailand	Not reported.
P.esquirolei Schultr.	Not reported	Not reported.
P.sukhakulii Schoser & SEnghas.	Not reported	Not reported.

Sources: Hooker (1894), Veitch & Sons (1894), Hawkes (1965), Rosso (1966), Pradhan (1976), Rao (1979), Kataki (1986).

Table: 4.2. Parents, Hybrids and Hybridisers along with years.

Parents				Hybrids	Hybridisers	Year
P.villosum	x	*P.barbatum*	=	*P.Harrisianum*	Not known	1870
P.barbatum	x	*P.fairieanum*	=	*P.vexillarium*	Dominy	1870
P.barbatum	x	*P.insigne*	=	*P.Ashburtoniae*	Cross	1871
P.insigne	x	*P.venustum*	=	*P.crossianum*	Cross	1873
P.insigne	x	*P.fairieanum*	=	*P.Arthursianum*	Prof. Reichenbach	1874
P.venustum pardenum	x	*P.concolor*	=	*P.marshallianum*	Seden	1875
P.venustum	x	*P.lowii*	=	*P.pycnopterum*	Seden	1876
P.barbatum	x	*P.superbiens*	=	*P.superciliare*	Seden	1876
P.Hookerae	x	*P.barbatum*	=	*P.marmorophyllum*	Seden	1876
P.Dayanum	x	*P.barbatum*	=	*P.Swanianium*	William Swan	1876
P.villosum	x	*P.insigne Maulei*	=	*P.nitens*	Seden	1878
P.barbatum	x	*P.phillipinense*	=	*P.selligerum*	Seden	1878
P.spicerianum	x	*P.insigne*	=	*P.Leeanum*	Not kown	1878
P.argus	x	*P.villosum*	=	*P.vernixium*	Seden	1879
P.barbatum	x	*P.venustum*	=	*P.chloroneurum*	Robert Werner	1880
P.barbatum crossi	x	*P.lowii*	=	*P.Calanthum*	Seden	1880
P.villosum	x	*P.venustum*	=	*P.Meirax*	Robert Warner	1880
P.barbatum	x	*P.venustum*	=	*P.calophyllum*	B.S. William	1881
P.Hookerae	x	*P.purpuratum*	=	*P.gemmiferum*	J.C.Bowring	1881
P.Harrisianum	x	*P.insigne Maulei*	=	*P.electra*	Robert Warner	1882
P.villosum	x	*P.barbatum*	=	*P.Williamsianum*	Robert Warner	1882
P.niveum	x	*P.druryi*	=	*P.microchilum*	Seden	1882
P.lowii	x	*P.superbiens*	=	*P.macropterum*	Seden	1882
P.concolor	x	*P.barbatum*	=	*P.Tessselatum. porphyreum*	Seden	1883

Table 4.2 (contd.)

Parents				Hybrids	Hybridisers	Year
P.barbatum Crossii	x	*P.hirsutissimum*	=	*P.porphyrochlamis*	Seden	1884
P.barbatum	x	*P.insigne Chantinii*	=	*P.Laforcadei*	Bauer	1884
P.javanicum	x	*P.superbiens*	=	*P.javanico-superbiens*	M.Bleu	1885
P.villosum	x	*P.insigne*	=	*P.Sallierii*	J.C.Bowring	1885
P.Lawrenceanum	x	*P.spicerianum*	=	*P.radiosum*	Seden	1885
P.Harrisianum	x	*P.insigne Maulei*	=	*P.Oenathum*	Seden	1885
P.barbatum	x	*P.villosum Boxallii*	=	*P.apiculatum*	D.O.Drewett	1886
P.argus	x	*P.lawrenceanum*	=	*P.Io*	Norman C.Cookson	1886
P.villosum	x	*P.hirsutissimum*	=	*P.Germinyanum*	Seden	1886
P.superbiens	x	*P.Stonei*	=	*P.Morganiae*	Seden	1886
P.barbatum	x	*P.Druryi*	=	*P.orphanum*	Seden	1886
P.niveum	x	*P.barbatum*	=	*P.tautzianum*	Seden	1886
P.Harrisianum	x	*P.insigne Maulei*	=	*P.thibautianum*	Seden	1886
P.villosum	x	*P.druryi*	=	*P.winnianum*	Seden	1886
P.spicerianum	x	*P.superbiens*	=	*P.Hernianum*	F.Horn	1887
P.superbiens	x	*P.villosum*	=	*P.Mrs.Canham*	Not Known	1887
P.barbatum	x	*P.javanicum virens*	=	*P.pleistochlorum*	D.O. Drewett	1887
P.villosum	x	*P.venustum*	=	*P.plunarum*	Norman C.Cookson	1887
P.barbatum	x	*P.lawrenceanum*	=	*P.almum*	Norman C.Cookson	1887
P.lawrenceanum	x	*P.venustum*	=	*P.auroreum*	Norman C.Cookson	1887
P.superbiens	x	*P.venustum*	=	*P.carrierei*	M.Bauer	1887
P.villosum	x	*P.superbiens*	=	*P.charles Canham*	Rolfe	1887
P.Dayanum	x	*P.barbatum Crossii*	=	*P.delicatulum*	D.O.Drewett	1887
P.venustum	x	*P.Dayanum*	=	*P.caligare*	D.O.Drewett	1888

Table 4.2 (contd.)

Parents				Hybrids	Hybridisers	Year
P.lawrenceanum	x	*P.superbiens*	=	*P.Euryale Supra*	Seden	1888
P.barbatum	x	*P.stonei*	=	*P.euryandrum*	Seden	1888
P.Harrisianum	x	*P.insigne Maulei*	=	*P.Galatea*	Seden	1888
P.villosum Boxalli	x	*P.hirsutissimum*	=	*P.Godreffianum*	Norman C.Cookson	1888
P.spicerianum	x	*P.villosum*	=	*P.Lathamianum*	W.B.Latham	1888
P.villosum	x	*P.venustum*	=	*P.Measuresianum*	R.H.Measure	1888
P.villosum Boxalli	x	*P.venustum*	=	*P.pavoninum*	D.O.Drewett	1888
P.phillipinense	x	*P.barbatum*	=	*P.Peetersianum*	Not Known	1888
P.venustum	x	*P.spicerianum*	=	*P.polystigmaticum*	R.H.Measure	1888
P.insigne	x	*P.Leeanum*	=	*P.actaeus*	Not Known	1895
P.Leeanum	x	*P.spicerianum*	=	*P.Bruno 'Model' A M*	Messrs Veitch	1896
P.callosum var. Sanderae	x	*P.lawrenceanum* var.hyeanum	=	*P.Maudiae*	Charlesworth & Co	1900
P.Actaeus	x	*P.Astarte*	=	*P.F.C Puddle FCC*	F.C.Puddle	1932
P.rothschildianum	x	*P.delenatii*	=	*P.Delrosi*	Vacherot & Lecoufle	1961
P.Rollsight	x	*P.Canberra*	=	*P.Geelong*	Ratcliffe	1966
P.hirsutissimum	x	*P.barbatum*	=	*P.Fraseri*	Fraser	Not Known
P.niveum	x	*P.venustum*	=	*P.Madame Van Houtte*	Louis Van Houtte	Do
P.villosum	x	*P.purpuratum*	=	*P.concinum*	J.C.Bowring	Do
P.niveum	x	*P.lawrenceanum*	=	*P.Aphrodite, Supra*	Seden	Do
P.bellatulum	x	*P.niveum*	=	*P.Astarte*	Not Known	Do
P.bellatulum	x	*P.Blendia*	=	*P.Denura*	Do	Do
P.bellatulum	x	*P.Drayton*	=	*P.Verena*	Do	Do
P.bellatulum	x	*P.Atlantis*	=	*P.Belisaire*	Do	Do

Contd.

Parents				Hybrids	Hybridisers	Year
P.Belisaire	x	*P.Winston Churchill*	=	*P.Red Cloud*	Not known	Not known
P.fairieanum	x	*P.Alma Gavaert*	=	*P.Friedrich Mellin*	Do	Do
P.insigne	x	*P.actaeus*	=	*P.san-actaeus*	Do	Do
P.san-actaeus	x	*P.Chilton*	=	*P.Bernstein*	Do	Do
P.spicerianum	x	*P.villosum*	=	*P.Lathamianum*	Do	Do
P.Lathamianum	x	*P.Evanhurst*	=	*P.Lathahurst*	Do	Do
P.spicerianum	x	*P.Bruno*	=	*P.the Gurka*	Do	Do
P.the Gurka	x	*P.Banchory*	=	*P.Kukri*	Do	Do
P.venustum	x	*P.ciliolare*	=	*P.Marie Hey*	Do	Do
P.fairieanum	x	*P.venustum*	=	*P.Pradhanii*	Do	Do
P.insigne	x	*P.venustum*	=	*P.venusto-insigne*	Do	Do
P.spicerianum	x	*P.venustum*	=	*P.spicero-venustum*	Do	Do

Sources: Hooker (1894), Veitch & Sons (1894), Brians & Wilma (1984), Cribb (1986).

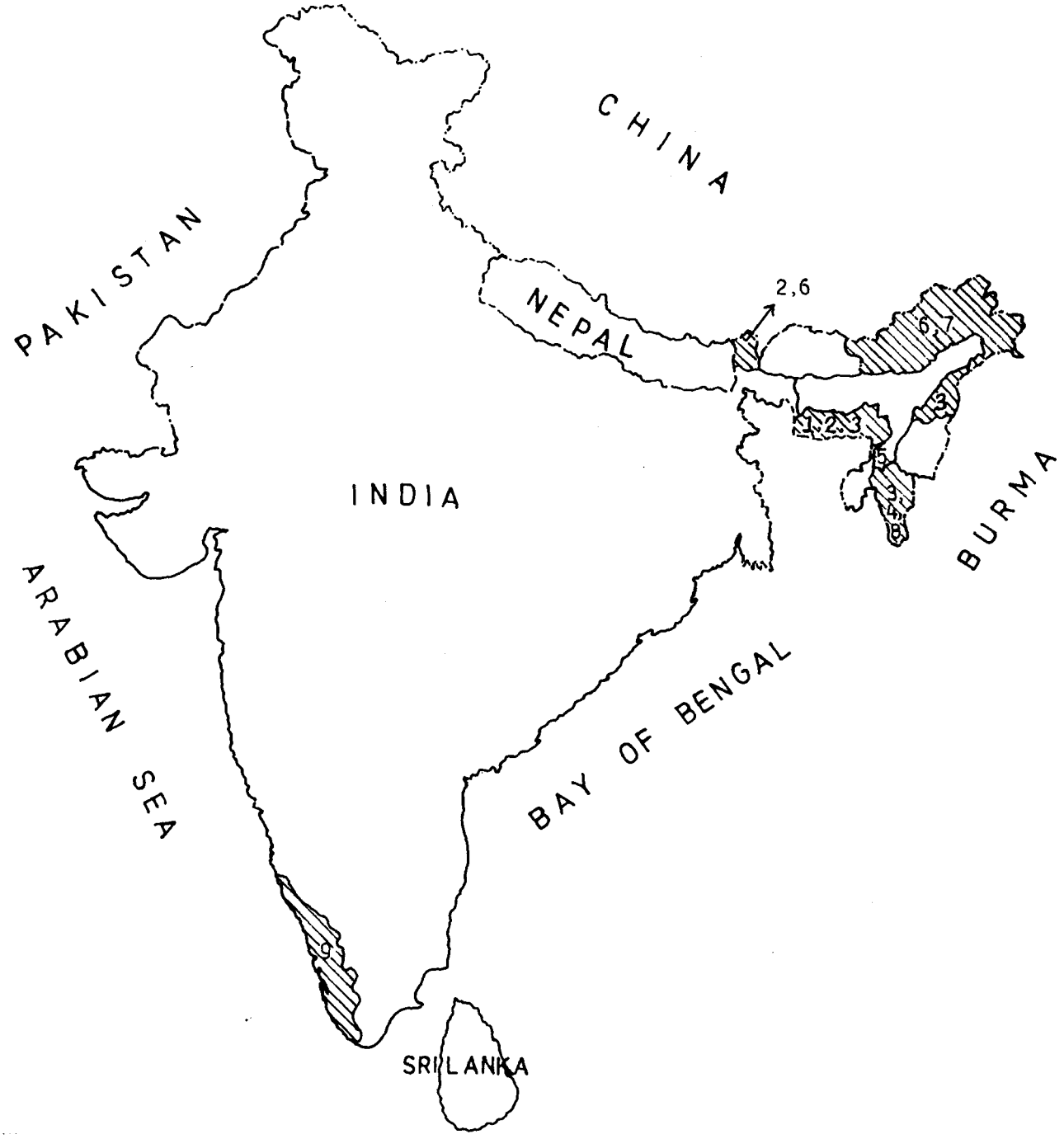


Fig. 4.1. Distribution of *Paphiopedilum* species in India. 1 - *Paphiopedilum insigne* (Wall. ex. Lindl.) Pfitz. (Meghalaya); 2 - *P. venustum* (Wall. ex Sims) Pfitz. (Meghalaya, Sikkim); 3 - *P. hirsutissimum* (Lindl.) Stein. (Meghalaya, Mizoram, Nagaland); 4 -*P. villosum* (Lindl.) Stein. (Mizoram); 5 -*P. spicerianum* (Reichb. f.) Pfitz. (Cachar); 6 - *P. fairieanum* (Lindl.) Stein. (Arunachal, Sikkim); 7 - *P. wardii* Summerh. (Arunachal) 8 - *P. charlesworthii* (Royle.) Pfitz. (Mizoram); 9 - *P. druryi* (Bedd.) Stein. (Kerala).

time in autumn of 1820. Subsequently it was rediscovered by Griffith on Khasi Hills between 1200m and 2000m altitude (Hooker 1894).

Paphiopedilum villosum was first discovered by Thomas Lobb (1853) near Moulmein (Burma) and subsequently by Rev. C. Parish. This species is found in Tenasserim (Mulmein, Burma) but is more abundant further north near Tongu (Burma) where they grow amongst mosses and decaying organic matter high on the stem and branches of the trees. In India this species is found in Mizoram (Kataki 1984).

Chapter 5

MORPHOLOGY, PHENOLOGY AND ANATOMY OF PAPHIOPEDILUM

General morphological characters of orchids

Orchids whether epiphytes or terrestrial, exhibit two types of habit, the monopodial type in which the main stem continues to grow and the flowers are produced from axils of leaves and sympodial type where growth of the main stem is arrested by a terminal flower or inflorescence during flowering season and new growth takes place every season from the bud eyes at the base. The roots that arise from the base of the stem are called basal roots and those which arise from the nodes are called aerial roots. The aerial roots are generally green and perform photosynthesis. The stem varies from an underground tuber and rhizome to pseudobulbs and simple, reed like, and elongated ones, with sympodial or monopodial growth. The leaf may be plicate, conduplicate, terete or cylindrical with acute apex, they are either fleshy or membranous.

Orchids are monocotyledonous plants having leaves with prominent ribs running the whole length of the leaf in a more or less parallel fashion and joining at the acute tip. Some orchids are saprophytes. These are entirely devoid of leaves and thus are entirely dependent for their food on dead and decaying matter of the forest floor.

In orchid flowers, character of perianth member is of special significance. The perianth differ considerably from one another, one of them being most complicated in structure. This has been termed as `lip' or `labellum' and the presence of this

curious petal is a characteristic feature of the flowers of all orchids. The inequalities in the front and back perianth members, although the side ones are identical, imparts irregularity or zygomorphic nature to the flower. Stamens and pistils are joined together to form a special structure called the 'column' which is another important identifying character of the orchid family. Ovary is inferior and it consists of innumerable very minute ovules which develop into seeds after fertilization. All the sepals may be almost alike, or the single one opposite the lip may be different in shape or colour from the two lateral sepals, which are alike. The two lateral petals are also alike and often show a marked resemblance in colour, if not in shape to the lip or third petal.

In orchids with the exception of lady's slipper, the pollen grains are joined together forming a solid mass termed as 'pollinia'. Pollinium has a special attachment known as 'viscidium'. In lady's slipper, 2 stamens placed one on each side of the column look more or less like stamens of other flowers except that they are stalkless. The pollen grains also do not form distinct pollinia, and they lie in a sticky paste like substance. The lady's slippers are therefore intermediate between the rest of the orchids and families like Liliaceae, possessing the lip and column of the former and pollen of the latter.

Morphology of *Paphiopedilum*

The genus *Paphiopedilum* Pfitz., commonly called as "Slipper Orchid", belongs to the family Orchidaceae, sub-family Cypripediodeae tribe Cypripedieae and sub-tribe Cypripedilinae of

the Order Orchideae (Rao 1979). Dressler and Dodson (1960) and Caray (1960) classified the slipper orchids into a seperate family Apostasioideae. Most authorities believe that the Apostasiods and Cypripedioids are more primitive than any other orchid sub-families (Rosso 1966).

All "slipper orchids" belong to the sub-tribe Cypripedilinae comprising four terrestrial genera : (i) *Cypripedium* Linn., of North American origin, (ii) *Paphiopedilum* Pfitz., the lady's slipper of Asia which is popular in horticulture (iii) *Phragmipedium* Rolfe., and (iv) *Selenipedium* Rchb.f., of South American origin.

In horticulture, the genus *Paphiopedilum* is erroneously put under *Cypripedium*, in reality *Cypripedium* is completely distinct from *Paphiopedilum*. The genus *Paphiopedilum* is distinct from its allied genus *Cypripedium* and other genera in having trilocular ovary (Kataki 1986). Infact this condition is attained because of excessive ingrowth of the placentae which do not fuse but form a three chambered ovary condition.

The morphology of *Cypripedium*, *Paphiopedilum*, and *Phragmipedium* has been described by Irmish (1853), Pfitzer (1882, 1903), Faber (1904), Camus (1908), Holm (1908) and Solereder and Meyer (1930).

The plant is a terrestrial perennial herb of dwarf to moderate size, with a leafy stem and distichous, radical, coreaceous often tessellated leaves and terminal flower (Fig. 5.1). The flower is large, showy and solitary arising from each offshoot. In a single plant, one to many flowering scapes may arise. The underground rhizome bears fibrous root system. The

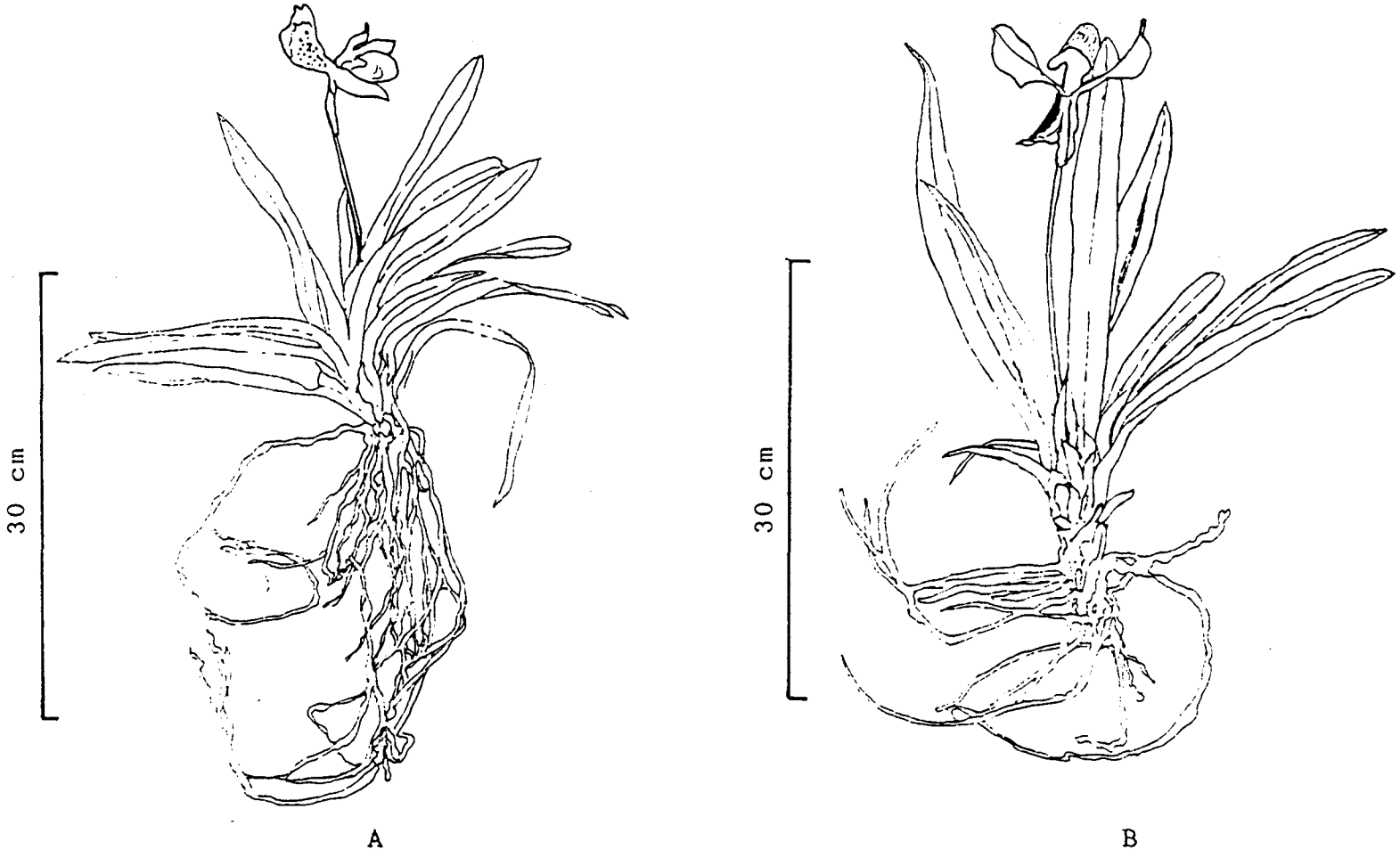


Fig.5.1. Habit of *Paphiopedilum*. A - *Paphiopedilum insigne*, B - *Paphiopedilum villosum*.

leaves arise from a leafy stem, five to eight in each season, pointing two ways alternately. The leaves are smooth, fleshy and waxy. They are long, keeled below and tessellated, glossy green to mottled green in colour. Leaves with a prominent midrib, are sessile and generally grow horizontally and bear cutinous coating on both the surfaces, the layer on the upper surface being thicker than that on the lower surface. The stomata are present only on the lower surface. Trichomes are absent on both the surfaces.

Paphiopedilum Pfitz., belongs to the sympodial group with three types of shoot organization. Since *Paphiopedilum* belongs to a conduplicate genus, it shows a condensed axis. There is no clear demarcation of the transition between the leafy stem and the rhizome as well as there is no clear demarcation between the nodes and the internodes. The leaves seemed to emerge from the same point. The stem of *Paphiopedilum* is one of the most primitive type. The term "stem" in *Paphiopedilum* species includes both rhizome as well as the leafy stem. Thus in this genus there are two types of stem, a short, underground rhizome and a short leafy stem continuing from the rhizome. The rhizome includes the lower subterranean part of the stem axis with indistinct nodes and internodes. Holttum (1955) reported that at a certain stage of development the subterranean monocotyledonous stem turns upward and produce leafy stem. The rhizome is slightly hard and gives rise to adventitious roots and very small and usually inconspicuous scales. The leafy stem is á continuation of the rhizome and is covered with laterally emerging leaves which during blooming season terminates into a long inflorescence axis.

New offshoot grows mostly annually from the base of the old offshoot. Both old as well as young roots arise from the underground rhizome. Sometimes young roots arise from the axil of the older leaves on the leafy stem. Therefore, it appears that the leafy stem in the later stage develops into rhizome. Roots bear root hairs.

During flowering season, the flowering scape arises between the imbricate bases of the leaves. Most of the species of *Paphiopedilum* bear solitary flowers except in a few species like *P. glaucophyllum*, *P. lowii*, *P. parishii*, *P. phillipinese*, *P. rosthschildianum* and *P. stonei* which produce five to six flowers at a time (Rao 1979). The flowering scape can be distinguished from the leafy stem by the presence of bracts and the flowering parts. This is the most conspicous part of the leafy stem. The flowers are beautiful and big. It is difficult to define *Paphiopedilum* by a particular colour as can be done with other orchids. The flowers are about 5 - 13 cm in width, having a combination of colours from yellow, green, brown, red and purple to white with beautiful purple and brown spots and lines. The flowering scape is about 28 - 34 cm long depending on the species. There are two sepals and three petals. Both sepals and petals are free. The two sepals vary in size. The dorsal or upper one is larger and broader than the ventral or lower one. The dorsal sepal resembles the petals in having blotches. The three petals consist of two side lobes which are spreading and a sessile lip or pouch called "slipper". The staminal column is short with two anthers on the underside of staminal disc and the stigma lies on the upper side of it. The ovary is about 6 cm long

and style is short. The elongated ovary is enclosed within a bract of more or less of the same length.

The genus *Paphiopedilum* blooms once in a year. The offshoot produces only one flower during its life and is said to be monocarpic. It is similar to the century plant (*Agave americana*) and talipot palm (*Corypha umbraculifera*) where a much longer time is passed in the vegetative phase (Summerhayes 1968). Therefore, the plants rely mostly on the vegetative propagation for reproduction. Modern hybrids bears flower twice or more in a year. The flowers last for about 3 months. The cut flowers when kept in plain water remain fresh for about six weeks. Blooming takes place between September to March. Thus, due to extraordinary intricate colouration of flowers and other unigue characters which attract and fascinate people, the *Paphiopedilum* has always stood high on the list of popular orchids, while other varieties have gained and lost favours among growers the world over.

Paphiopedilum insigne Pfitz.

Paphiopedilum insigne is a terrestrial herbaceous plant with small underground stem bearing roots below and a highly compressed leafy stem above.

Fibrous roots are numerous and bear innumerable root hairs.

Leaves arise from the highly compressed leafy stem. Leaves are smooth, linear, ligulate, sessile, acute, alternate and exstipulate. They are about 35-40cm long and pale green in colour.

Flower is big and showy, zygomorphic, about 10cm in length

and 12cm in width (Plate-5A). The flowering scape is about 30cm long. About 5cm long bract covers the young ovary. Sepals are two in number and lie opposite to each other. The lower sepal lies below the pouch or lip. The upper sepal is broad and oval, it bends forward forming a hood-shaped structure or helmet. It is about 5.5cm long and 3.5cm broad. The central and basal portion of the hood is apple green with numerous purple spots. The purple spots are concentrated towards the base while the apical portion is white. The lower sepal which lies below the pouch is also broad and oval. It is about 5.5cm in length and 3cm in breadth. It is apple green with purple spots distributed in lines. The spots are numerous towards the base while the apex is devoid of it. Both sepals are covered with numerous small hairs, concentrated mainly on the under side. The purple spots are present only on the upper surface of both the sepals. Aestivation is valvate.

There are three petals. Two lateral petals are spreading, oblong, linear, about 6cm in length and 1.5cm in width with undulated margin. They are pale green with purple longitudinal veins and are covered with small purple hairs which are numerous towards the base and the apex, the middle region is somewhat hairless. The lower petal forming a pouch, is called lip or labellum. The outer surface of the pouch is smooth whereas the inner side is covered with purple veins and hairs. The purple hairs are concentrated towards middle and base of the pouch. The yellowish green pouch resembles a slipper.

Staminode subquadrate, anthers two only and filament is absent. Anthers lie on either side below a staminal disc. The

Plate - 5A. *Paphiopedilum insigne* in flowering stage.

disc acts as a barrier for the pollen to reach the stigma and prevents self pollination.

Ovary is inferior, long, about 5.5cm in length and enclosed within the bract when young. The ovary is covered with numerous hairs. Style is short, stigma is only one lying above the staminal disc. Stigma secretes sticky fluid. Ovary is unilocular with marginal placentation. Ovules are numerous with bifurcated stalks. Fruit is a pod and ribbed. Seeds are numerous and very minute.

Paphiopedilum villosum (Lindl) Stein.

P. villosum is a terrestrial herbaceous plant which sometimes grows on the tree trunk where dead leaves and mosses accumulate and provide a suitable substratum.

The fibrous roots arise from the underground stem. They are less in number as compared to *P. insigne*. Roots bear numerous root hairs.

Stem is distinguished into rhizome and aerial shoot, the latter bears leaves. The leafy stem is highly compressed so the leaves appear to arise from one point only, as in *P. insigne*.

Leaves are alternate, smooth, linear, ligulate, sessile and acute. They are exstipulate and loriform, 40-45 cm in length and equitant at the base. Leaf margin is smooth and the tip is acute or obscurely bilobed. Colour of the leaves is deep green on the upper surface and pale green on the lower. At the base there are numerous purple spots.

Flowers are big and showy (Plate-5B). They are larger than *P. insigne*. The flower is zygomorphic, about 15cm in length and

Plate - 5B. *Paphiopedilum villosum* in flowering stage.

width. The peduncle is shorter than *P. insigne*.

The bract covers the entire ovary during the early stage of development. Sepals are two in number, polysepalous and hairy. One sepal is present on the lower side below the slipper or lip and another is on the dorsal or apical region, opposite to the lower one. The lower sepal is slightly elongated compared to *P. insigne*. It is pale green with green veins running parallel from the base to the apex. The lower sepal is about 6.5cm in length and 2.5cm in breadth. Numerous hairs cover the sepal. The hairyness is more towards the underside compared to the upper side. It is broad and oval, slightly bends forward to form a hood-like structure as in *P. insigne*. It is about 7cm in length and 3.5cm in width. The underside or the back side of the hood is immensely covered with hairs while the upperside contains hairs only in the periphery. The basal and central portions are devoid of hairs, instead, these portions are covered with purple spots starting from the base and extend upto the end of the mid-vein. The remaining part is pale green with a whitish band along the margin. The pale green region is also covered with hairs.

Petals are three in number. The two lateral petals are spreading, elongate, oval and slightly claw-shaped at the base. They are longer than the dorsal sepal. The upper half of the lateral petal is yellowish brown while the lower half is paler. The base is covered with brownish purple hairs. The hairs are concentrated mainly towards the base and margin whereas the middle region is hairless. Purple mid and side veins run along the lobes. The lateral petals are about 7.5cm in length and 1.2 cm in width. The lower petal is modified into a slipper like

structure. It is about 6.5cm long and 1.2 - 1.5cm wide. The upper surface of the slipper is smooth whereas the inner side is covered with brown purple hairs. The hairs are numerous towards the base and the centre of the slipper.

In the flower there is an oblong staminate with a staminal disc. Stamens only two in number lying on the under surface on either side of the staminal disc. The disc forms a barrier between the pollen and the stigma.

Ovary is inferior and about 6.5cm long. During the early stage of development it is completely enclosed within the bract and covered with numerous hairs. Style is short and stigma is one. The stigma lies on the staminal disc. It produces sticky fluid. Ovary is unilocular, ovules numerous and the placentation is marginal. Fruit is a ribbed pod. Seeds are very minute and numerous.

Similarities and dissimilarities between *P. insigne* and *P. villosum*

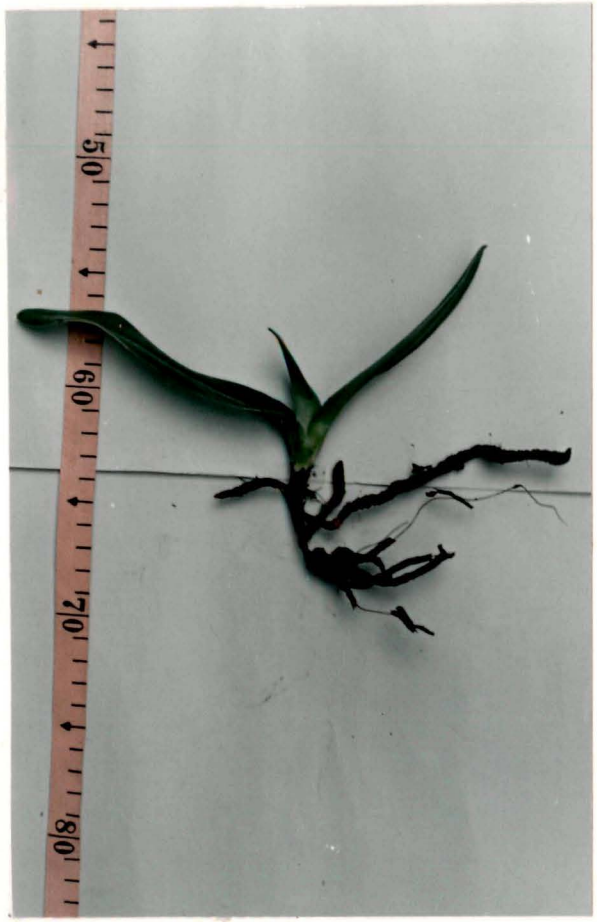
The two species are quite similar to each other with respect to their overall morphological characters. Both *P. insigne* and *P. villosum* are terrestrial orchids having two types of stem, the underground root bearing rhizome and a leafy stem. Nevertheless, the major differences between the two are mainly related to the size of the plant, root system and number of leaves. A comparative account of certain important morphological features are given in Table 5.1.

Table: 5.1. Similarities and dissimilarities between *P. insigne* and *P. villosum*.

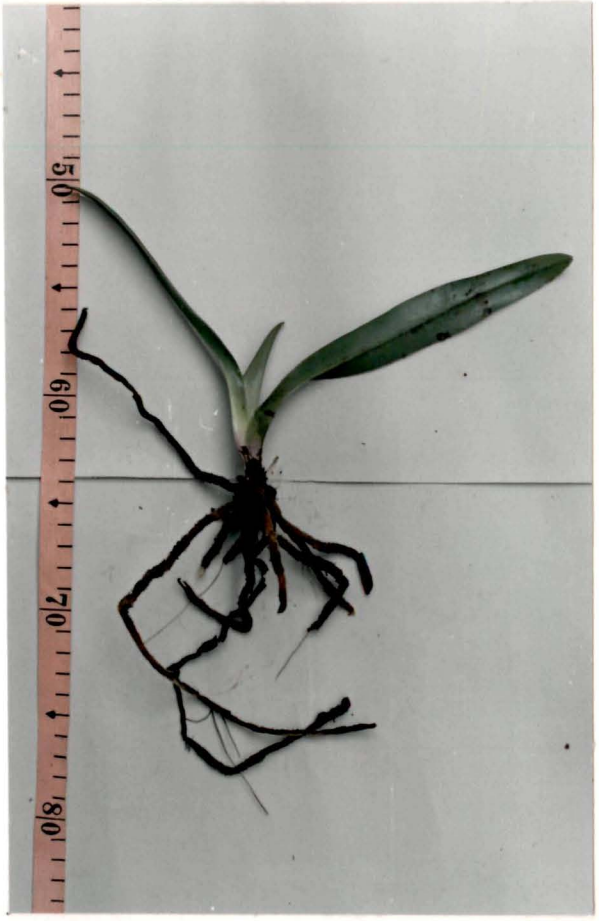
Characters	*P. insigne*	*P. villosum*
ROOT		
(a) number	Root number is more.	Root number is less.
(b) length	Total root length is more.	Total root length is less.
(c) hairs	Present.	Present.
STEM		
(a) Rhizome	Present.	Present.
(b) Aerial stem	Present.	Present.
LEAF		
(a) Morphology	Ligulate, linear, sessile with no spots at the base.	Same but having purple spots at the base.
(b) size	Small (about 35-40 cm in length).	Big (about 40-45 cm in length).
FLOWER		
(a) Floral axis	Solitary, longer in length, purple.	Solitary, shorter in length, colourless.
(b) Size	Small.	Big.
(c) Sepals	Two, apical sepal fringed at the tip with white margin.	Two, apical sepal with smooth margin and ends with purple mid vein.
(d) Petals	Three, lateral petals linear with undulated margin. Third petal is slipper shaped and smaller.	Three, lateral petals oval with smooth margin. Third petal is slipper shaped and larger.
(e) Stigma	One.	One.
(f) Anther	Nonfilamentous and 2 in number.	Nonfilamentous and 2 in number.
(g) Ovary	Unilocular.	Unilocular.
(h) Seed	Innumerable and very minute.	Innumerable and very minute.

Phenology

Paphiopedilum is a slow growing plant propagating both by sexual and vegetative means. Development of new plants from seeds is a very slow process. The viable dormant seeds germinate in soil and new seedlings generally appear during the rainy season. Seedlings take many years to become fully matured plants (Plate-5C1 & Plate-5C2). The mature plant bears a main shoot and a few young lateral offshoots emerging from the base of the main shoot. These offshoots serve as the means of vegetative propagation of adult plants. The new offshoot generally appears in the month of February and March. They grow for two to three years and then bear flowers. The adult plant produces one floral bud in the beginning of August. The growth of floral stalk is very rapid in the beginning for about a month and then it slows down. Flowering continues for three months extending from September to November. With the onset of winter in December, distortion of flower starts and it continues till the end of February. By the end of March all the flowers become dry. The capsule development occurs during December to March and maturation of the pod takes about a year. One, two or more new offshoots arise during February and March after the flowering is over, from the base of the flowering offshoot which subsequently withers away. These new offshoots, later on, contribute to the vegetative and reproductive growth of the plant. The offshoot flowers only once in its life cycle, whether it has reproduced vegetatively or not. After the dehiscence of the capsule from May onwards, the floral axis starts gradually drying downwards till the whole plant dries (Fig. 5.2).



A



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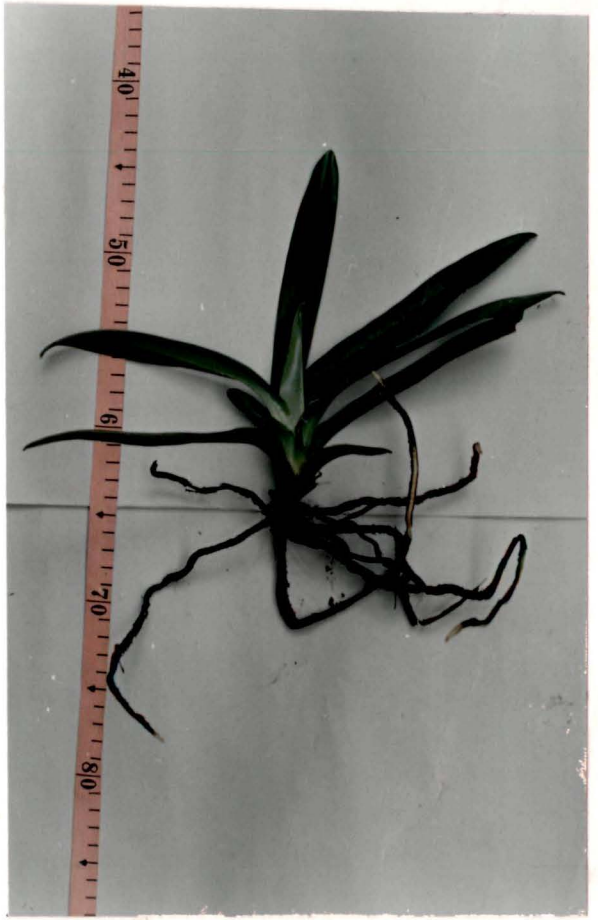


C

D

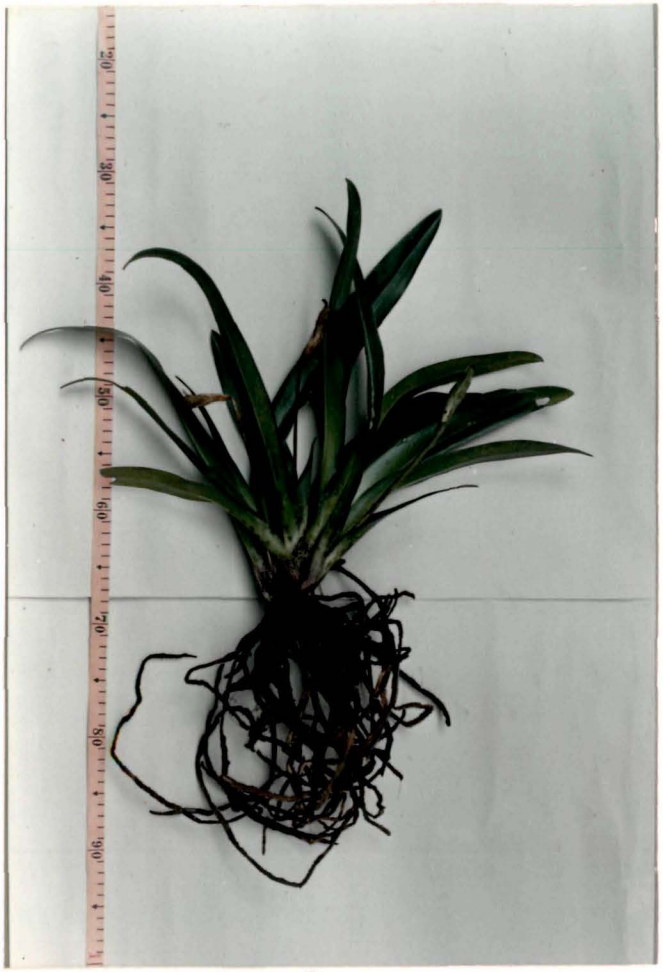
E

Plate - 5C1. Different stages of growth of *Paphiopedilum insigne*. A & B: Young offshoot, C: Adult plant bearing young offshoot, D: Flowering plant, E: Formation of pod.

C

B

A



D

E

Plate - 5C2. Different stages of growth of *Paphiopedilum villosum*. A: Young offshoot, B: Adult plant bearing young offshoot, C: Flowering plant, D: Formation of pod, E: Death of flowering plant.

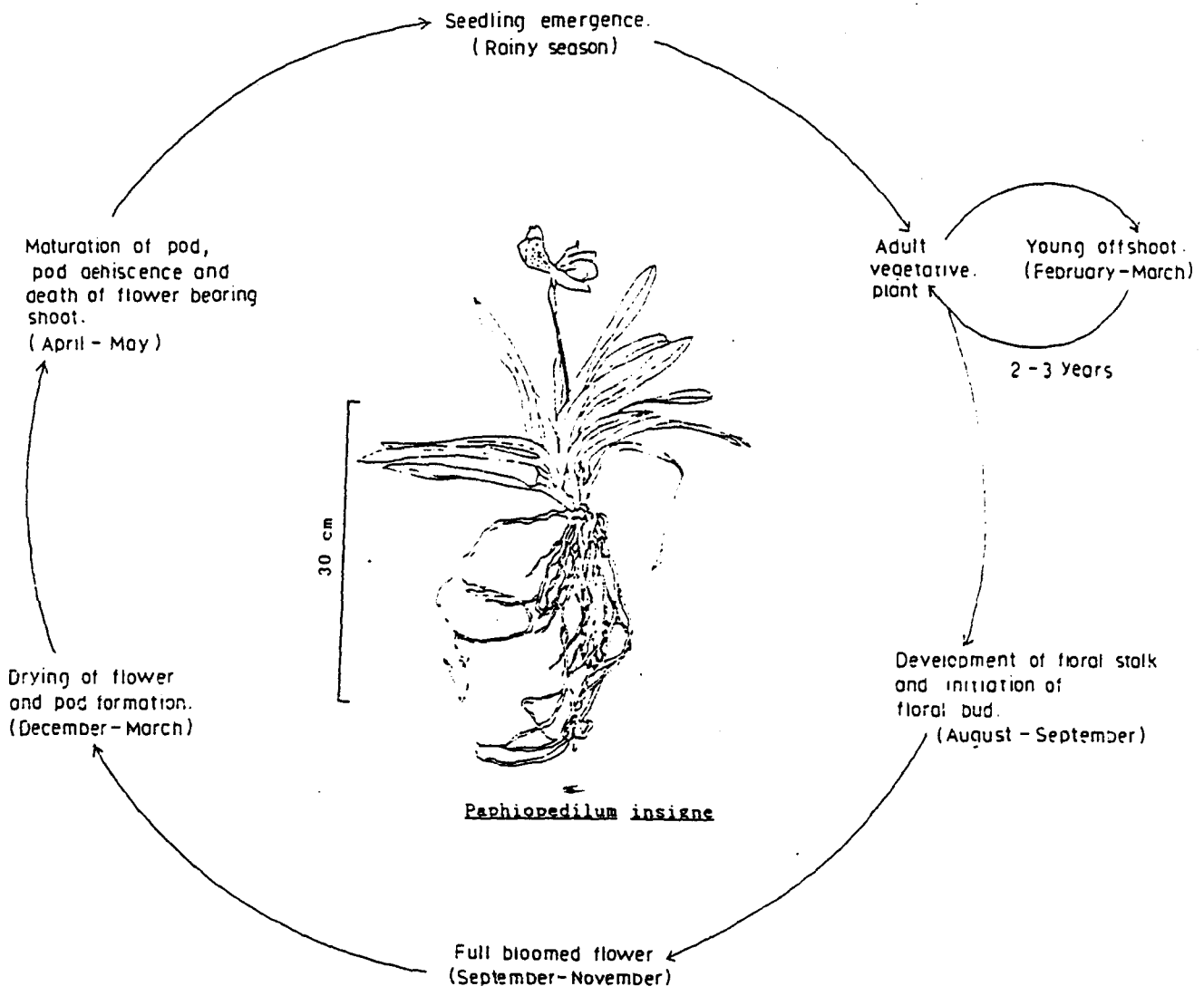


Fig. 5·2. Ecological life history and phenology of Paphiopedilum

Anatomy

Anatomy of various plant parts in the members of subfamily Cypripediodeae has been investigated by Irmirsh (1853), Menecke (1894), Holm (1904, 1908), Camus (1908), Fuchs & Ziegenspeck (1925) Solereder and Meyer (1930) and Cheadle (1942).

Root: The multilayered epidermis known as velamen in *Paphiopedilum* is similar to epiphytic orchids. It is made up of compactly arranged unequal, polygonal, parenchymatous cells. In older roots, the cells of the velamen lack protoplasts. The outermost layer of velamen bears unicellular root hairs which are much longer in *P. insigne* than in *P. villosum*. The length of root hair varies from 700μ in *Phragmipedium caudatum* to 2300μ in *Cypripedium calceolus var. pubescens*. In *P. insigne*, mean length of root hairs is 2030μ.

A uniseriate exodermis is present between the velamen and the cortex proper. It is made of alternate long dead and small living cells arranged in longitudinal rows. The small living cells are called *passage cells*. The long cells are sometimes thickened on all sides of the walls or only on the radial and tangential walls. On the basis of thickening these cells are called either `O' or `U' type exodermis. `U' type exodermis was reported by Menecke (1894) and `O' type was reported by Rosso (1966). In *P. villosum* the long exodermal cells retain protoplast.

The cortex proper is composed of large parenchymatous cells of more or less equal size and acts as a storage place for starch.

Uniseriate endodermis lies below the cortex. Depending on

the cell wall thickening, Solereder and Meyer (1930) classified the endodermis into (i) `P' type (ii) `O' type and (iii) `U' type. These cells alternate with groups of thin walled passage cells.

The xylem and phloem strands are radially arranged alternating with each other in the vascular cylinder. The phloem strands are more or less circular in outline while the xylem strands are arranged radially in a linear fashion. The number of xylem strands varies between 8 - 10, depending on the age of the root. Although Rosso (1966) reported that the root of *P. insigne* maintained 10 xylem strands throughout 18 cm root length, but only 8 xylem strands were present in *P. insigne* as is the case with *P. villosum* (Fig. 5.3a & Fig. 5.3b).

Pith is well developed and is made up of parenchymatous cells.

Thus, the root anatomy of these two species is similar except for longer root hairs in *P. insigne*.

Not mentioned in reference

Stem: The stem anatomy of *Cypripedium* and *Phragmipedium* has been described by Irmisch (1853), Pfitzer (1882, 1903), Faber (1904), Camus (1908), Holm (1908) and Solereder & Meyer (1930).

In the older rhizome the epidermis is hardly found. In the young rhizome it is present as a single layer. Trichomes and stomates are absent. A reduced cortex is made up of parenchymatous cells with intercellular spaces. The cells of the outer layer of the cortex contain brownish or yellowish substances. The endodermis lying below the cortex is composed of three types of cells viz., `P', `O' and `U' types (Rosso, 1966). The sclerenchyma band is present in the endodermis.

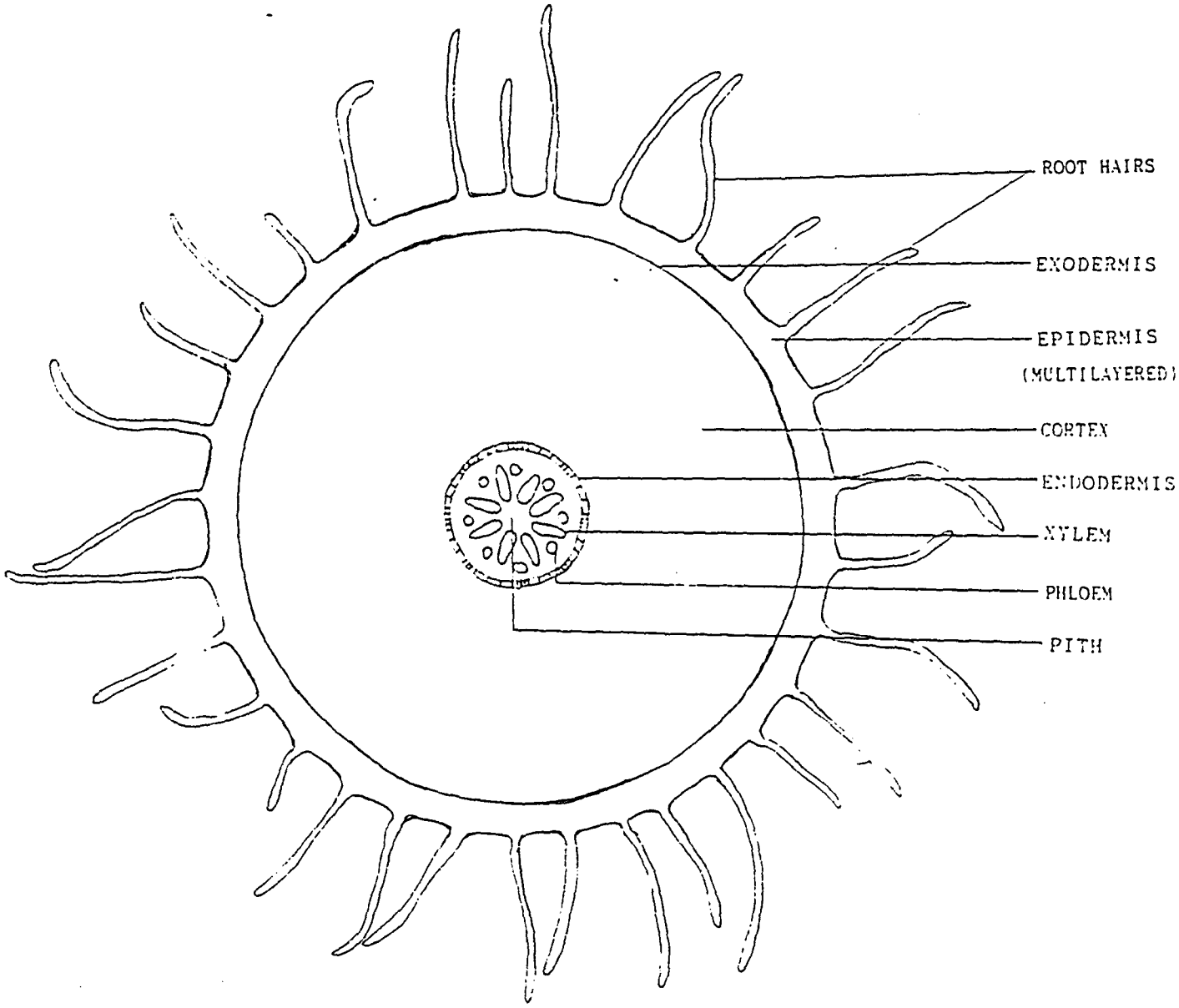


Fig.5.3a. TRANSVERSE SECTION THROUGH THE ROOT OF *PAPHIOPEDILUM*

(outline sketch)

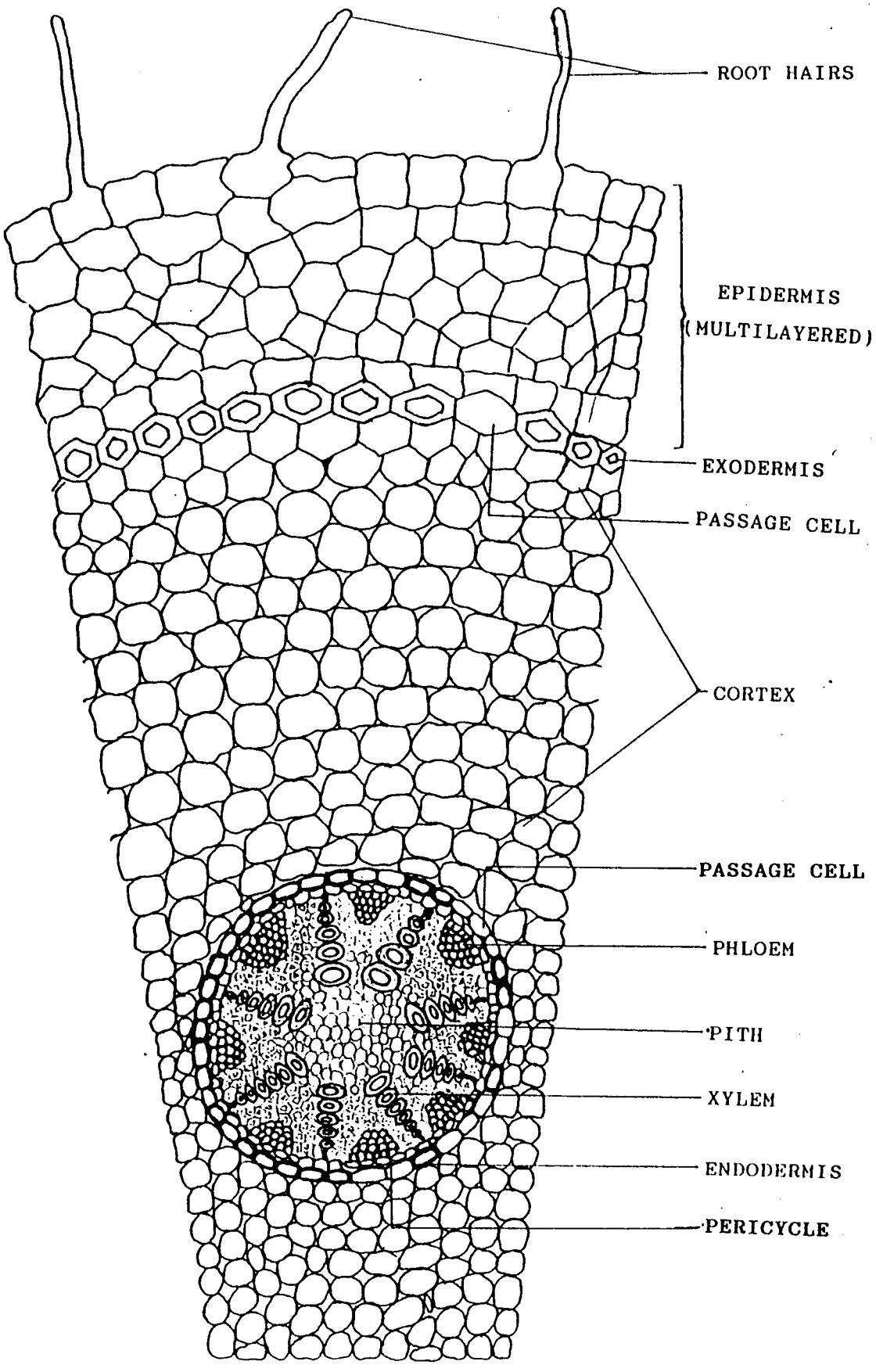


Fig.5.3b. TRANSVERSE SECTION THROUGH THE ROOT OF *PAPHIOPEDILUM*

Scattered amphivasal vascular bundles are found within the central ground tissue. According to Cheadle (1942), the phloem consists of sieve tube element with simple transverse end plates and a companion cell. Xylem is composed of only tracheids.

The anatomy of aerial stem of *Paphiopedilum* is similar to that of rhizome. In the epidermal cells of the aerial stem, chloroplasts are more abundantly found near the shoot apex than in the adjacent cortical cells. The cortex is thicker than in the rhizome. Offshoot traces arise from the axil of a leaf.

The prominent pericycle fibres surround the vascular cylinder and form a sclerotic sheath. Since the stem is highly compressed, the nodes can be traced only by the presence of the leaf and branch gaps which interrupt the sclerenchyma sheath. Root traces are larger in size than the leaf or branch traces and are found mostly in the rhizome.

The amphivasal vascular bundles of different sizes are found intermingled with each other in the ground tissue. Xylem consists of tracheids and the phloem is made up of sieve tubes and companion cells. The cells of the ground tissue show different amount of thickening. The cell walls are sclerified and contain coarse reticulate pits.

Floral axis: The anatomical structures of the inflorescence axis are similar to that of the leafy stem, the only difference being the quantity and arrangement of the tissues. Diffuse pigments are present in both epidermal cells as well as cuticle, which impart a distinctive colour to the rachis. Epidermis consists long, multicellular pigmented trichomes. Two rows of vascular bundles are concentrated towards the periphery, so the

pith is highly developed as in most dicot stems (Fig. 5.4a & Fig. 5.4b). The structure of vascular bundle is similar to that of the stem. Thus, the major difference between the stem and the inflorescence axis lies in the presence of the multicellular hairs and a well defined pith in the latter.

Leaf: The leaf anatomy of *Paphiopedilum* was studied by Mac Farlane (1892) and those of *Cypripedium*, *Paphiopedilum* and *Phragmipedium* by Moebius (1887), Faber (1904) and Solereder and Meyer (1930).

Leaf of *Paphiopedilum* shows a single layer epidermis with stomatal apparatuses and trichomes in the young leaves. The outer layer of both the epidermis are cutinised, but the abaxial layer is more thickened. The stomatal apparatus is present only on the abaxial surface in both *P. insigne* and *P. villosum* (Fig. 5.5a & Fig. 5.5b). Subsidiary cells are present in the stomata. Hairs are present only on the abaxial surface of the young leaves on the the apex of aerial stem. They are absent in older leaves.

Mesophyll cells are composed mostly of spongy tissue. The chloroplast in the mesophyll cells are more abundant towards the abaxial surface. There is a prominent mid vein, which represents the mid-rib region and a few small veinlets running more or less parallel to the main vein. The vascular bundles are amphivasal and are similar to those of the stem or floral axis.

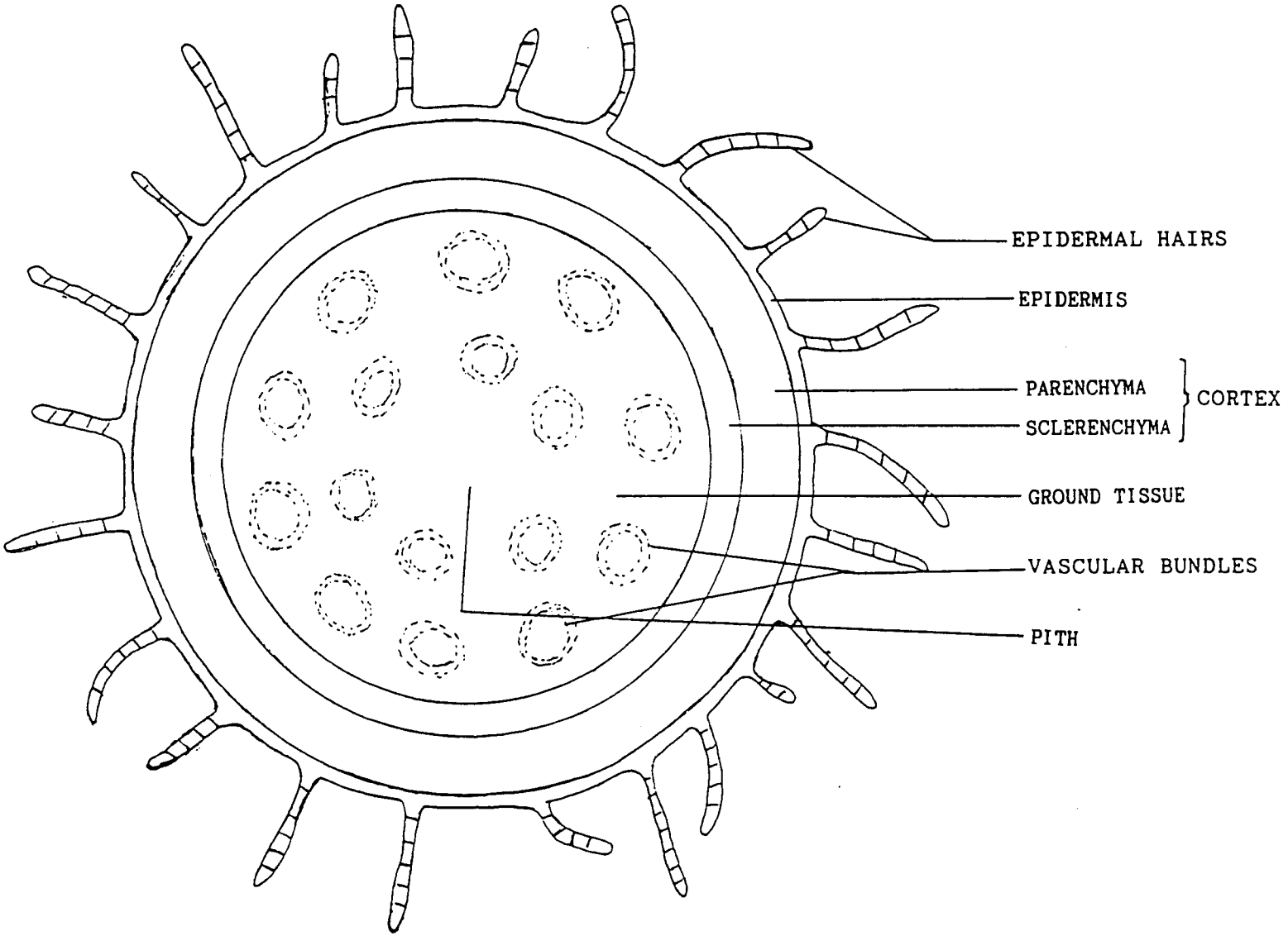


Fig.5.4a. TRANSVERSE SECTION THROUGH THE FLORAL AXIS OF *PAPHIOPEDILUM*

(outline sketch)

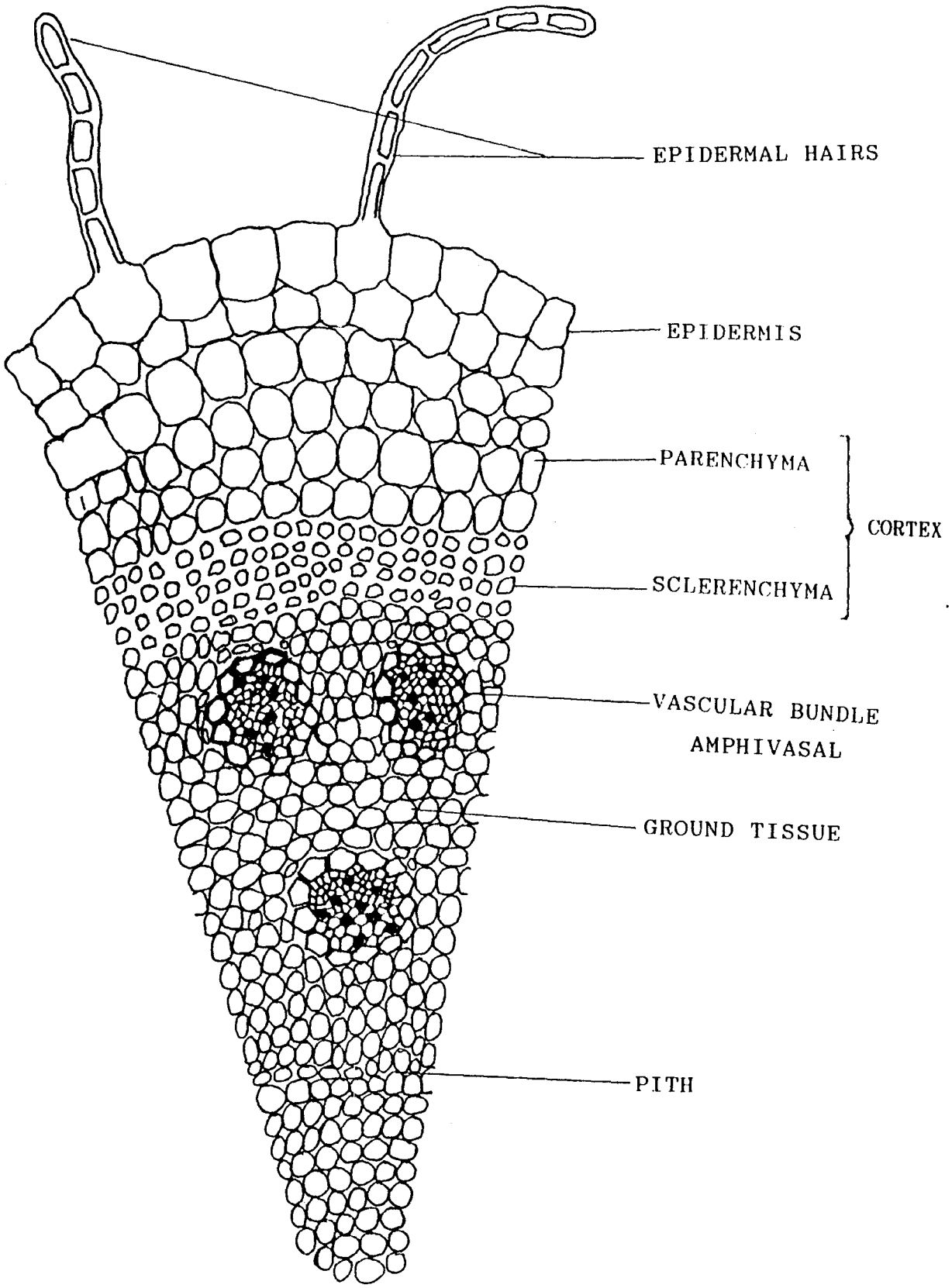


Fig.5.4b. TRANSVERSE SECTION THROUGH THE FLORAL AXIS OF *PAPHIOPEDILUM*

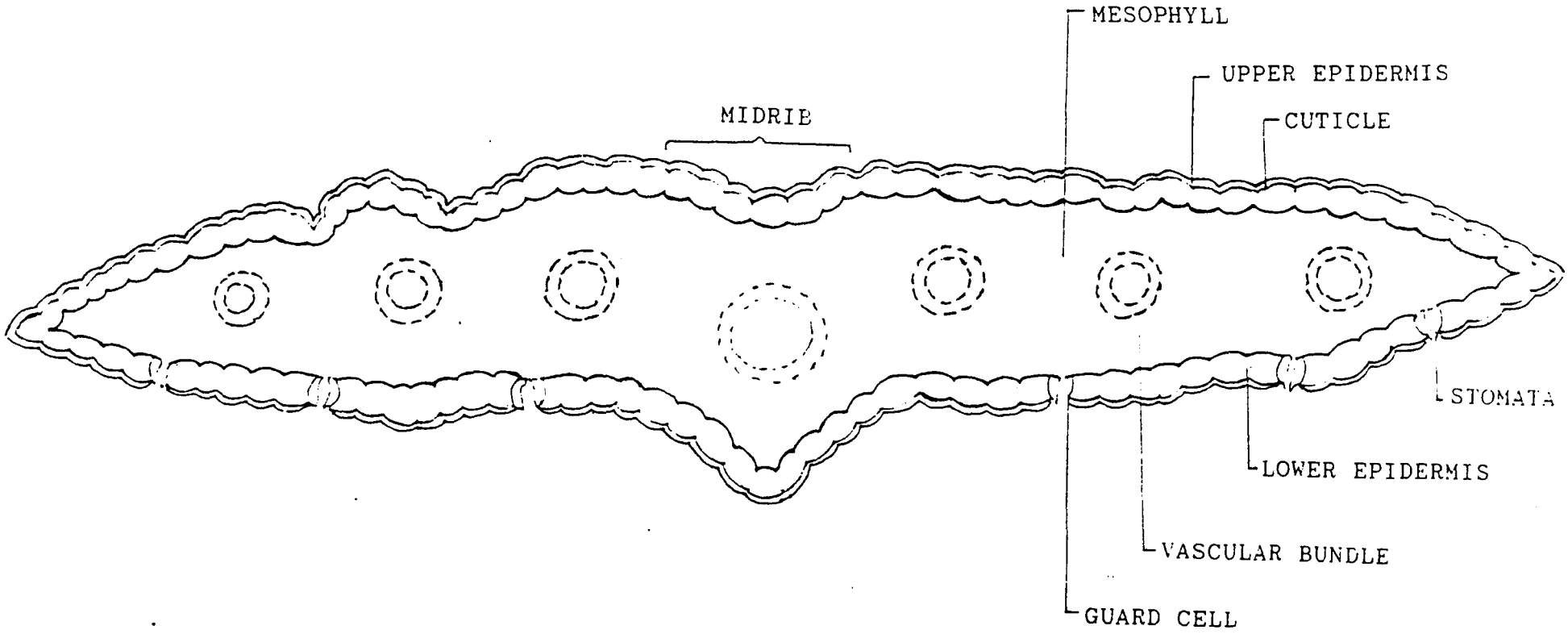


Fig.5.5a. TRANSVERSE SECTION THROUGH THE LEAF OF *PAPHIOPEDILUM*

(outline sketch)

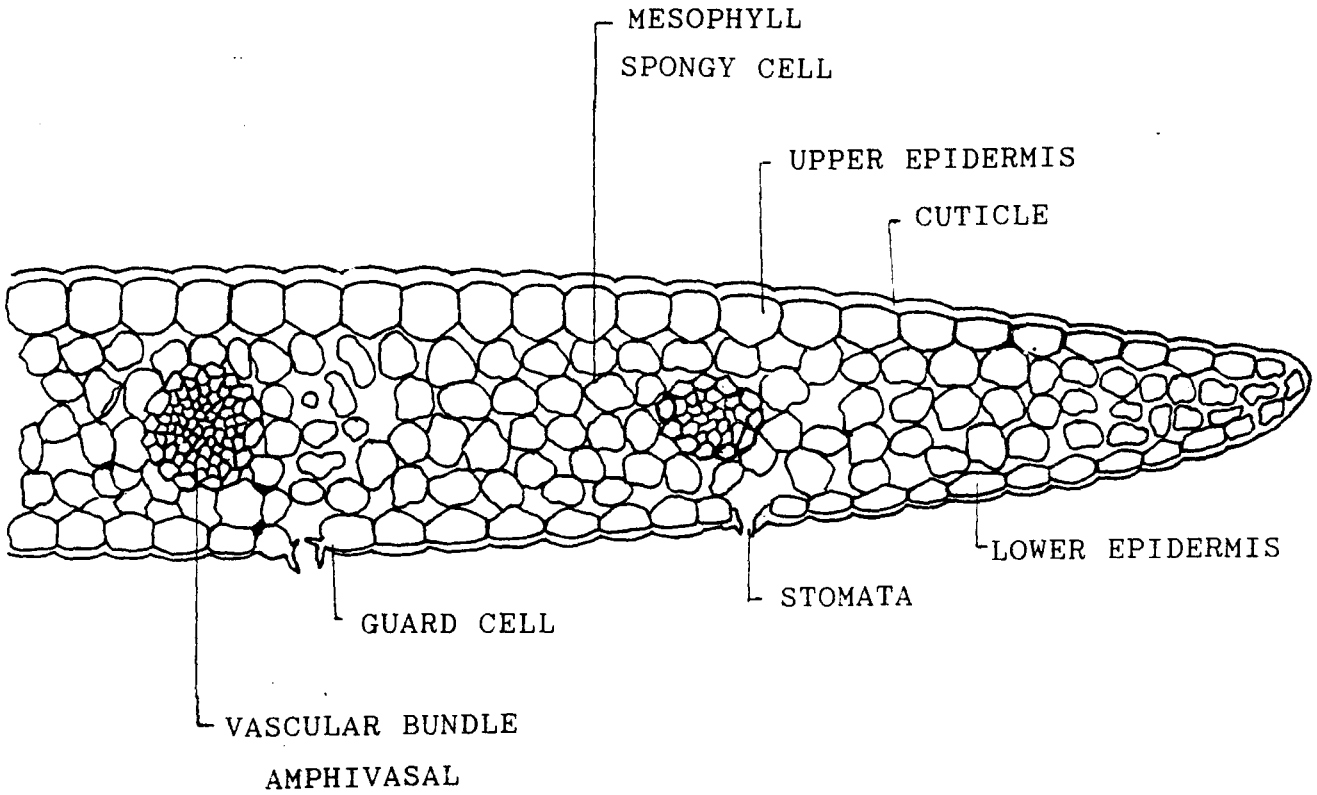


Fig.5.5b.TRANSVERSE SECTION THROUGH THE LEAF OF *PAPHIOPEDILUM*

Chapter 6

EFFECT OF WATERING

Water is one of the most important environmental factor which determines the growth of plant. Water supply affects directly and indirectly every plant process; it maintains the turgor pressure, acts as a solvent for gases and mineral nutrients and helps in many hydrolytic reactions that occur in the plant body.

The study of importance of water in plant growth has attracted the attention of a large number of workers. These studies show that the amount of moisture present in soil determines growth, reproduction allocation and mortality (Foulds 1978, Cunningham *et al.* 1979, Seliskar 1987, Hester and Irvin 1989); nutrient concentration and uptake (Misra and Singh 1982); and phenology and seed yield in plants (Muchow 1985). Mueller-Dombois and Sims (1966) studied the effect of different water depths on three grasses; *Calamogrostis canadensis*, *Andropogon gerardi* and *Koeleria cristata*, grown on two types of soil.

The combined effect of nutrient and different water tables on shoot biomass and species composition of *Cirsio-Molinietum* community was investigated by Vermeer (1986). Weerakoon and Lovett (1986) worked on the effect of watering frequency, drought and nutrient supply on growth and development of *Salvia reflexa* Hornem. Rahman and Rutter (1980) investigated the comparative ecology of *Deschamsia cespitosa* and *Dactylis glomerata* in relation to water factor.

Experiments of Chaghtai *et al.* (1987) and Schulze *et al.* (1987) furnished evidence that water requirement and water balance are important for growth and development of plants. Increased soil moisture affects water potential (ψ p) and transpiration rates in ericoid shrub - *Phillipia evansii* (Everson and Breen 1985) and water logging affects population growth, reproduction and distribution in plants (Davies 1984, Etherington 1984, Vandersman *et al.* 1988). Soil texture along with soil moisture influence reproductive strategies of *Spergula arvensis* and *Plantago major* (Trivedi and Tripathi 1982b) and population growth of *Galinsoga ciliata* and *G. parviflora* (Rai and Tripathi 1983).

Water stress affects growth, nitrogen fixing tissue, nodule growth and adventitious root development in *Trifolium repens* (Engin and Sprent 1973, Stevenson and Laidlaw 1985). It also affects seed germination (Heather and Hegarty 1979) and seed dormancy (Peters 1982) in plants. The effect of moisture stress and drought on biomass allocation in plants was studied by Ike (1986) and Roziyn and Vander Werf (1986). Role of water stress on soil reaction and plant distribution has been emphasised by Omaligo and Ene-Obong (1987) and Bauder (1989). Water deficit reduced dry matter allocation in sun flower (Sobrado and Turner 1986) and affected abundance and distribution of many plant species (Schulze *et al.* 1987).

Studies on the effect of soil water condition on the terrestrial orchids are almost completely lacking and no published literature is probably available on *Paphiopedilum insigne* and *Paphiopedilum villosum*.

This chapter discusses the results of an experiment set in the net house to study the growth response of these two orchid species under different soil moisture regimes.

MATERIALS AND METHODS

The experimental plant materials were obtained from the nurseries at Upper Shillong situated at 5.6 Km west of the Shillong city.

The young plants of *P. insigne* and *P. villosum* of approximately equal age were used for the experiment. Before setting the experiment, growth parameters of the plant such as length of the plant, length of the roots, length of the leaves, leaf area, leaf number and offshoot number etc. were measured and/or counted. The plants were planted in plastic pots (22 cm diameter and 22 cm depth), filled with mixed humus and soil in equal proportion. The base of the pot was punctured to provide a drainage hole. One plant was planted in each pot. The pots were kept in a net house whose roof and the four sides up to 1m height were covered with a thick transparent polythene sheet to stop the entry of rain water.

The experimental plan consisted of 4 watering treatments x 2 species x 3 replicates x 3 four monthly observations. The watering treatment were - weekly watering, fortnightly watering and monthly watering. One set of the pots kept in open without any watering treatment, served as control (Fig 6.1). In each watering treatment, 250 ml of tap water per pot was poured at weekly, fortnightly and monthly intervals, respectively. The

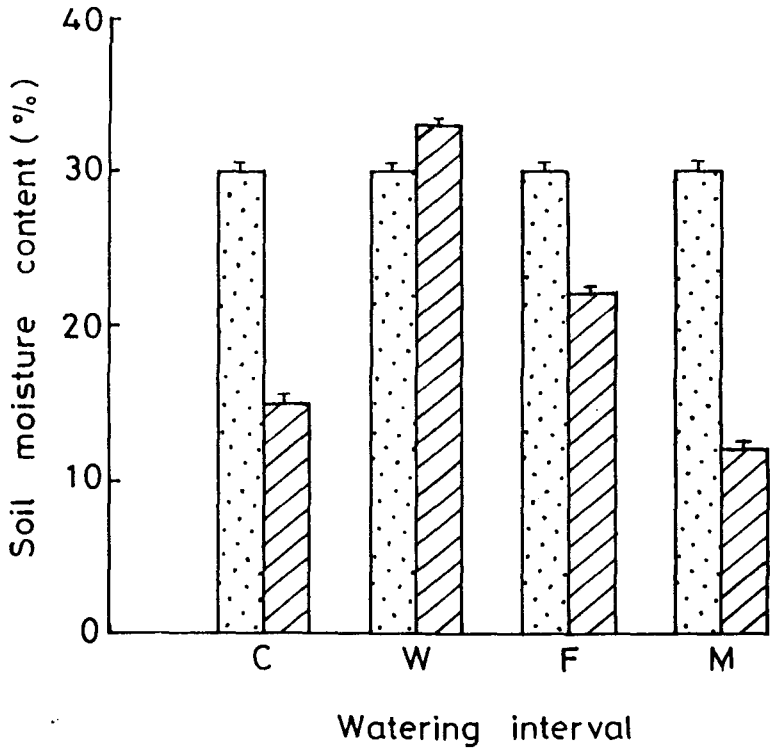


Fig. 6.1 Variation in soil moisture content in different watering treatments (⊡ ; Initial; ▨ ; Final). C - control; W - weekly watering; F - fortnightly watering; M - monthly watering.

control set received only rain water.

Morphological growth parameters such as number of offshoot, leaf number and leaf length were recorded at monthly interval. Leaf area was determined by Licor-leaf area meter. Time of flower initiation and duration of flowering were recorded. Length of the peduncle and capsule was measured.

Plants were sampled at 120, 240 and 360 days and at each sampling day, growth parameters were again measured and oven dry weight of each plant was determined. Besides morphological growth parameters and dry weight, plant growth was analysed in terms of relative growth rate (RGR), net assimilation rate (NAR) and leaf area ratio (LAR). These were computed using the following formulae according to Hughes and Freeman (1967) and Radford (1967).

$$RGR = \frac{InW_2 - InW_1}{t_2 - t_1}$$

$$NAR = \frac{(W_2 - W_1)(InA_2 - InA_1)}{(A_2 - A_1)(t_2 - t_1)}$$

$$LAR = \frac{(A_2 - A_1)(InW_2 - InW_1)}{(InA_2 - InA_1)(t_2 - t_1)}$$

Where W_1 and A_1 represent the dry weight per plant and leaf area per plant at time t_1 and W_2 and A_2 are the dry weight and leaf area per plant at time t_2, respectively.

RESULTS

Plants length (longest leaf and longest root)

Watering treatment significantly ($P < 0.05$) affected the length of both *P. insigne* and *P. villosum*. Over a period of one year increase in plant length was significantly higher in fortnightly watering treatment with about 7.2 % increase in *P. insigne* and about 6.4 % in *P. villosum* than the control. Under weekly watering *P. insigne* showed about 2.7 % increase but *P. villosum* showed about 1.8 % decrease than the control. In monthly watering treatment, the length of plants of both the species showed minimum value; as compared to control it was about 3.6 % less in *P. insigne* and about 4.1 % less in *P. villosum*. (Table 6.1).

Root number

The root number of *P. insigne* and *P. villosum* increased significantly ($P < 0.05$) during the first four months after planting, then it declined during the next four months and again increased till the end of the study period in all treatments. During one year period maximum increase (*ca* 17.3 %) in the root number of both the species occurred under weekly watering followed by fortnightly watering (*ca* 10.4 % in *P. insigne* and *ca* 7 % in *P. villosum*) as compared to the control. Minimum increase in root number of both the species was observed under monthly watering which was less than the control by about 3.4 % in *P. insigne* and about 10.4 % in *P. villosum* (Table 6.2).

Root length

Since orchids are slow growing plants, increase in root

Table 6. 1. Length (longest leaf + longest root) of *P. insigne*(Pi) and *P. villosum*(Pv). (cm/plant ± SEM) grown under different watering treatments.

Treatments	Species	MONTHS			
		0	4	8	12
Control	Pi	32.44±2.80	34.00±4.08	36.00±2.51	37.33±2.60
	Pv	33.55±2.00	34.00±2.04	35.00±2.29	36.66±1.45
Weekly watering	Pi	33.66±2.00	35.00±2.29	37.33±2.60	38.33±1.66
	Pv	32.94±1.60	34.33±2.40	35.16±6.89	36.00±2.51
Fortnightly watering	Pi	33.62±2.80	34.83±7.21	38.66±1.76	40.00±1.73
	Pv	33.44±3.10	35.00±5.13	37.33±2.66	39.00±2.00
Monthly watering	Pi	33.55±3.00	34.50±3.88	35.83±1.16	36.00±1.15
	Pv	33.61±3.52	34.00±2.08	34.33±2.18	35.16±6.89

Table 6.2. Effect of watering on root formation (number/plant ± SEM) in *P. insigne*(Pi) and *P. villosum*(Pv).

Treatments	Species	MONTHS			
		0	4	8	12
Control	Pi	7.55±1.61	9.00±1.52	9.33±2.33	9.66±2.33
	Pv	8.00±1.50	9.00±1.63	9.33±1.45	9.66±1.45
Weekly watering	Pi	7.80±1.53	9.00±2.08	9.66±1.45	11.33±1.76
	Pv	7.86±1.60	8.66±1.33	9.66±2.33	11.33±1.66
Fortnightly watering	Pi	7.93±2.11	8.33±2.02	8.66±2.33	10.66±2.70
	Pv	7.55±1.16	8.66±0.66	9.66±1.45	10.33±0.66
Monthly watering	Pi	7.55±2.43	8.00±1.73	8.66±1.33	9.33±0.66
	Pv	7.80±1.30	8.66±0.66	9.00±1.52	10.66±0.66

length within one year was less. Weekly watering significantly ($P < 0.05$) increased the root length in both *P. insigne* and *P. villosum* with an increase of about 6.5 % in *P. insigne* and about 3.7 % in *P. villosum* followed by fortnightly watering treatment (*ca* 2.2 % in *P. insigne* and *ca* 1.9 % in *P. villosum*) than the control. The effect of monthly watering was similar to that of the control (Table 6.3).

Offshoot number

During one year of observation from April 1987 to April 1988, new offshoots appeared after three months of planting in all the treatments. The offshoots were produced mainly during July to November. Both the species showed significant increase ($P < 0.05$) in offshoot production under fortnightly watering than the control and the other treatments. The effect of weekly watering on offshoot production was better than the control and monthly watering treatments. Water stress (monthly watering) significantly reduced ($P < 0.05$) offshoot production in *P. insigne* but such a significant reduction was not observed in case of *P. villosum* (Table 6.4).

Leaf number

In both *P. insigne* and *P. villosum*, leaf number was significantly higher ($P < 0.05$) in weekly watering than the control and other treatments. Fortnightly watering and monthly watering which had similar effect, caused a decline in the leaf number as compared to the control. Leaf formation was higher in *P. insigne* than *P. villosum* in all the treatments. Formation of new leaves occurred throughout the year without any seasonal pattern. New leaves appeared in the second month i.e. June after

Table 6.3. Effect of watering on root length (cm/plant ± SEM) in *P. insigne*(Pi) and *P. villosum*(Pv).

Treatments	Species	MONTHS			
		0	4	8	12
Control	Pi	43.33±0.88	44.00±1.00	45.30±0.88	46.00±0.58
	Pv	41.33±1.76	42.66±1.45	43.83±1.48	44.66±1.45
Weekly watering	Pi	43.00±1.53	45.00±1.15	47.33±1.45	49.00±1.73
	Pv	41.00±1.00	43.33±1.76	45.00±1.53	46.33±1.20
Fortnightly watering	Pi	43.33±1.20	44.66±0.88	45.66±1.00	47.00±1.00
	Pv	41.33±0.88	43.00±1.00	44.66±0.88	45.50±0.87
Monthly watering	Pi	43.00±0.88	44.83±0.93	45.33±0.66	46.00±1.15
	Pv	41.33±0.88	42.66±0.88	43.66±0.88	44.66±0.88

Table 6.4. Effect of watering on offshoot formation (number/plant ± SEM) in *P. insigne*(Pi) and *P. villosum*(Pv).

Treatments	Species	MONTHS											
		M	J	J	A	S	O	N	D	J	F	M	A
Control	Pi	1.33±0.19	1.33±0.19	1.88±0.22	1.99±0.19	2.16±0.20	2.16±0.20	2.33±0.33	2.33±0.33	2.66±0.33	2.66±0.33	2.66±0.33	2.66±0.33
	Pv	1.44±0.29	1.44±0.29	1.77±0.11	1.88±0.11	2.00±0.00	2.00±0.00	2.00±0.00	2.33±0.33	2.66±0.33	2.66±0.33	2.66±0.33	2.66±0.33
Weekly watering	Pi	1.88±0.29	1.88±0.29	2.10±0.40	2.21±0.44	2.66±0.33	3.00±0.00	3.00±0.00	3.00±0.00	3.00±0.00	3.00±0.00	3.00±0.00	3.00±0.00
	Pv	1.55±0.40	1.55±0.40	2.11±0.11	2.55±0.22	2.83±0.50	3.49±0.16	3.49±0.16	3.49±0.16	3.66±0.33	3.66±0.33	3.66±0.33	3.66±0.33
Fortnightly watering	Pi	1.55±0.40	1.55±0.40	1.99±0.50	2.44±0.72	3.16±0.16	3.66±0.33	3.66±0.33	3.66±0.33	3.66±0.33	3.66±0.33	3.66±0.33	3.66±0.33
	Pv	1.77±0.40	1.77±0.40	2.55±0.11	2.99±0.19	3.16±0.50	3.66±0.33	3.83±0.50	3.83±0.50	4.33±0.33	4.33±0.33	4.33±0.33	4.33±0.33
Monthly watering	Pi	1.66±0.19	1.66±0.19	2.05±0.22	2.10±0.29	2.33±0.33	2.33±0.33	2.33±0.33	2.33±0.33	2.66±0.33	2.66±0.33	2.66±0.33	2.66±0.33
	Pv	1.44±0.11	1.44±0.11	1.66±0.19	1.88±0.11	2.33±0.33	2.33±0.33	2.33±0.33	2.44±0.16	2.66±0.33	2.66±0.33	2.66±0.33	2.66±0.33

Table 6.5. Effect of watering on leaf formation (number/plant ± SEM) in *P. insigne*(Pi) and *P. villosum*(Pv).

Treatments	Species	MONTHS											
		M	J	J	A	S	O	N	D	J	F	M	A
Control	Pi	6.66 ±0.83	7.77 ±1.28	8.10 ±1.23	8.55 ±1.28	10.46 ±0.11	10.46 ±0.11	10.99 ±0.27	10.99 ±0.27	12.00 ±0.00	12.00 ±0.00	12.00 ±0.00	12.00 ±0.00
	Pv	6.22 ±0.11	6.97 ±0.34	7.11 ±0.29	7.22 ±0.22	7.83 ±0.50	7.83 ±0.50	7.83 ±0.50	7.83 ±0.50	7.83 ±0.50	8.00 ±0.58	9.00 ±1.00	9.67 ±0.33
Weekly watering	Pi	6.88 ±1.49	7.66 ±1.38	8.11 ±1.60	8.61 ±1.47	10.66 ±0.00	11.50 ±0.40	11.50 ±0.40	12.00 ±1.00	13.33 ±1.20	13.33 ±1.20	14.33 ±1.20	15.33 ±1.77
	Pv	6.89 ±0.48	7.33 ±0.51	7.66 ±0.58	8.00 ±0.38	8.66 ±0.66	9.16 ±0.16	9.66 ±0.33	9.66 ±0.33	10.00 ±0.57	11.00 ±1.53	11.00 ±1.53	12.33 ±1.86
Fortnightly watering	Pi	6.11 ±0.51	6.55 ±0.40	6.77 ±0.29	7.33 ±0.38	8.33 ±0.33	8.66 ±0.33	8.66 ±0.33	9.33 ±0.67	10.33 ±1.20	10.33 ±1.20	11.33 ±1.43	11.33 ±1.45
	Pv	5.22 ±0.11	6.11 ±0.11	6.44 ±0.29	6.88 ±0.40	7.16 ±0.50	7.66 ±0.33	7.66 ±0.33	7.66 ±0.33	8.33 ±0.88	8.33 ±0.88	8.33 ±0.88	8.33 ±0.88
Monthly watering	Pi	5.88 ±0.80	6.44 0.91	6.88 ±0.94	7.10 ±1.09	8.49 ±0.13	8.49 ±0.13	8.49 ±0.13	8.49 ±0.13	9.67 ±1.45	9.67 ±1.45	10.33 ±2.03	10.33 ±2.03
	Pv	6.11 ±0.48	6.55 ±0.58	6.66 ±0.50	6.99 ±0.69	7.49 ±0.68	7.49 ±0.68	7.83 ±1.17	7.83 ±1.17	9.00 ±0.58	9.00 ±0.58	9.67 ±0.88	9.67 ±0.88

Table 6.6. Effect of watering on leaf length (cm/plant ± SEM) in *P. insigne* (Pi) and *P. villosum* (Pv).

Treatments	Species	MONTHS											
		M	J	J	A	S	O	N	D	J	F	M	A
Control	Pi	131.00 ±4.93	132.00 ±4.73	132.33 ±4.67	133.00 ±4.16	134.00 ±4.36	134.66 ±4.41	135.33 ±5.05	136.00 ±4.73	136.33 ±5.05	137.00 ±4.73	137.66 ±4.81	139.33 ±4.48
	Pv	132.33 ±4.33	133.66 ±4.91	135.00 ±4.62	135.33 ±4.63	137.33 ±4.67	138.00 ±4.62	139.00 ±4.93	139.66 ±4.91	140.33 ±4.91	141.33 ±5.81	143.00 ±6.03	144.66 ±5.78
Weekly watering	Pi	132.00 ±12.01	134.00 ±11.51	135.00 ±11.02	136.00 ±11.01	137.66 ±11.21	138.66 ±11.69	139.00 ±11.07	140.00 ±11.60	141.00 ±11.60	141.66 ±11.27	143.33 ±11.47	145.00 ±11.25
	Pv	133.33 ±13.34	135.00 ±14.02	136.83 ±14.34	137.00 ±13.51	138.33 ±12.87	139.66 ±12.79	140.33 ±12.40	141.66 ±12.79	143.00 ±12.13	145.00 ±12.67	147.33 ±12.40	148.66 ±12.34
Fortnightly watering	Pi	133.66 ±4.10	135.16 ±4.38	135.91 ±2.97	138.50 ±3.75	141.83 ±3.81	143.83 ±4.11	145.50 ±3.75	146.83 ±4.15	148.50 ±4.19	149.83 ±4.19	151.83 ±4.51	154.66 ±4.85
	Pv	131.33 ±2.40	133.66 ±2.18	136.00 ±1.00	139.00 ±1.00	141.00 ±2.08	144.33 ±1.45	146.33 ±1.20	148.00 ±1.33	151.00 ±1.00	152.66 ±1.76	155.66 ±1.66	158.33 ±1.85
Monthly watering	Pi	131.00 ±9.72	133.00 ±10.16	135.00 ±2.51	136.66 ±9.95	137.33 ±9.78	138.66 ±9.71	139.66 ±9.71	140.00 ±9.46	140.33 ±9.39	141.00 ±9.65	141.66 ±9.91	143.66 ±9.81
	Pv	132.66 ±2.02	133.66 ±1.85	135.00 ±2.51	137.33 ±2.18	138.00 ±2.64	140.00 ±2.00	140.66 ±2.40	141.33 ±2.18	142.33 ±2.73	143.00 ±2.51	144.00 ±3.05	144.66 ±2.85

Table 6.7. Effect of watering on leaf area (cm^2/plant ± SEM) in *P. insigne* (Pi) and *P. villosum* (Pv).

Treatment	Species	MONTHS											
		M	J	J	A	S	O	N	D	J	F	M	A
Control	Pi	323.54 ±12.39	326.05 ±11.87	326.88 ±11.72	328.56 ±10.46	331.07 ±10.95	332.74 ±11.08	334.41 ±12.67	336.09 ±11.87	336.92 ±10.28	337.76 ±11.08	340.27 ±12.08	344.44 ±11.87
	Pv	417.42 ±14.05	421.74 ±15.92	426.06 ±14.98	427.14 ±15.02	433.62 ±15.13	435.78 ±14.98	439.02 ±16.00	441.18 ±15.92	443.34 ±15.92	446.58 ±18.85	451.98 ±19.73	457.38 ±18.75
Weekly watering	Pi	326.05 ±30.15	331.07 ±28.90	333.58 ±27.68	336.09 ±27.64	340.27 ±28.14	342.78 ±29.35	345.29 ±29.46	347.80 ±30.78	350.31 ±30.78	351.98 ±29.95	356.17 ±30.46	360.77 ±30.29
	Pv	420.66 ±43.25	426.06 ±45.45	428.22 ±44.37	432.54 ±43.80	436.86 ±41.72	441.18 ±41.47	443.34 ±40.18	447.66 ±41.47	451.98 ±39.32	458.46 ±41.07	466.02 ±40.32	470.34 ±40.35
Fortnightly watering	Pi	330.23 ±10.29	334.83 ±11.67	339.01 ±11.61	343.20 ±10.16	346.13 ±11.20	351.15 ±10.46	358.26 ±10.31	360.77 ±11.52	366.62 ±10.62	371.64 ±11.24	376.66 ±12.01	383.77 ±12.83
	Pv	414.18 ±7.79	421.74 ±7.09	429.30 ±3.24	439.02 ±3.02	445.50 ±6.75	456.30 ±4.71	462.78 ±3.89	469.26 ±3.89	477.90 ±3.24	483.30 ±5.72	493.02 ±5.40	501.66 ±6.02
Monthly watering	Pi	323.54 ±24.40	328.56 ±25.50	332.74 ±26.36	337.76 ±24.97	339.43 ±24.55	342.78 ±24.37	345.29 ±24.37	346.13 ±23.75	346.96 ±23.58	348.64 ±24.23	350.31 ±24.89	355.33 ±24.62
	Pv	418.50 ±6.57	421.74 ±6.02	426.06 ±8.16	433.62 ±7.09	435.78 ±8.58	442.26 ±6.48	444.42 ±7.79	446.58 ±7.09	449.82 ±8.85	451.98 ±8.16	453.06 ±8.65	457.38 ±9.23

Table 6.8. Effect of watering on the length of floral stalk (cm/plant ± SEM) of *P. insigne* (Pi) and *P. villosum* (Pv).

Treatments	Species	MONTHS					
		A	S	O	N	D	J
Control	Pi	13.62±0.37	20.75±0.25	25.75±0.50	27.12±0.37	27.12±0.37	27.12±0.37
	Pv	14.25±1.75	21.50±1.25	26.00±1.00	26.87±0.87	26.87±0.87	26.87±0.87
Weekly watering	Pi	14.87±0.62	23.50±1.00	26.87±0.87	29.62±0.12	29.62±0.12	29.62±0.12
	Pv	15.12±1.37	21.37±0.62	25.12±0.62	26.12±0.87	26.12±0.87	26.12±0.87
Fortnightly watering	Pi	16.87±1.88	23.62±1.37	28.12±0.87	29.50±1.25	29.50±1.25	29.50±1.25
	Pv	16.75±0.75	22.37±0.12	26.83±0.17	27.75±0.25	27.75±0.25	27.75±0.25
Monthly watering	Pi	15.50±0.50	19.75±1.25	21.62±1.62	22.75±2.75	22.75±2.75	22.75±2.75
	Pv	14.37±0.87	19.00±0.25	22.75±1.00	23.87±0.87	23.87±0.87	23.87±0.87

planting and it kept on increasing till the end of the experiment (Table 6.5).

Leaf length

Increase in total length of the leaves per plant in both the species was significantly higher ($P < 0.05$) in fortnightly watering (*ca* 11.00 % increase in *P. insigne* and *ca* 9.4 % in *P. villosum* than the control), followed by weekly watering (*ca* 4.1 % increase in *P. insigne* and *ca* 2.8 % in *P. villosum*). Growth in length occurred throughout the year, though it was slow during the first four months. In monthly watering the response of *P. villosum* was similar to that of the control, while in *P. insigne* it was better under monthly watering as compared to the control (Table 6.6).

Leaf area

In both the species leaf area increased significantly ($P < 0.05$) in fortnightly watering as compared to control. It also varied significantly ($P < 0.05$) between *P. insigne* and *P. villosum* being higher in the latter than the former. Monthly watering severely arrested the growth of leaf area in both the species (Table 6.7).

Flower

Water stress significantly reduced ($P < 0.05$) the growth of the floral stalks of both *P. insigne* and *P. villosum*. During August 1987 each plant which was having either one or more offshoots, produced one flower bud. All watering treatments except monthly treatment had little effect on the growth of floral stalk in both the species. Normally, *P. insigne* possessed longer stalk than *P. villosum*, but under monthly watering, length

of the floral stalks of both the species was significantly reduced to about the same length (Table 6.8). Size of the flower was not affected by watering in both *P. insigne* and *P. villosum*.

Root/shoot ratio (total root length/total shoot length)

Watering treatments affected root/shoot ratio (Table 6.9). The values showed that weekly watering enhanced root length while fortnightly watering enhanced leaf length thereby causing higher ratio in the former and lower ratio in the latter. Monthly watering adversely affected both the above and belowground parts. Root/shoot ratio in this treatment after 12 months was similar to control.

Dry weight

Total plant dry weight attained a peak under fortnightly watering in both the species while the minimum value was observed under monthly watering. During the study period, dry weight registered an increase in all the treatments, except under monthly watering where increase was negligible (Fig. 6.2). Total dry weight was significantly higher in *P. villosum* than *P. insigne* in all the treatments.

Growth analysis

Watering treatments significantly affected the relative growth rate (RGR) of *P. insigne* and *P. villosum*. RGR was higher under fortnightly watering in both the species as compared to the rest of the treatments including control. Between the two species RGR was higher in *P. villosum*. In all the treatment RGR increased linearly with time until four months after which the increase was slowed down and became almost constant till the end of the experiment, with an exception in *P. villosum* under monthly

Table 6.9. Root/Shoot Length Ratio of *P. insigne*(Pi) and *P. villosum*(Pv).

Treatments	Species	MONTHS		
		4	8	12
Control	Pi	0.33	0.33	0.33
	Pv	0.32	0.32	0.32
Weekly watering	Pi	0.33	0.34	0.34
	Pv	0.32	0.32	0.31
Fortnightly watering	Pi	0.32	0.31	0.30
	Pv	0.30	0.30	0.28
Monthly watering	Pi	0.32	0.32	0.32
	Pv	0.31	0.30	0.32

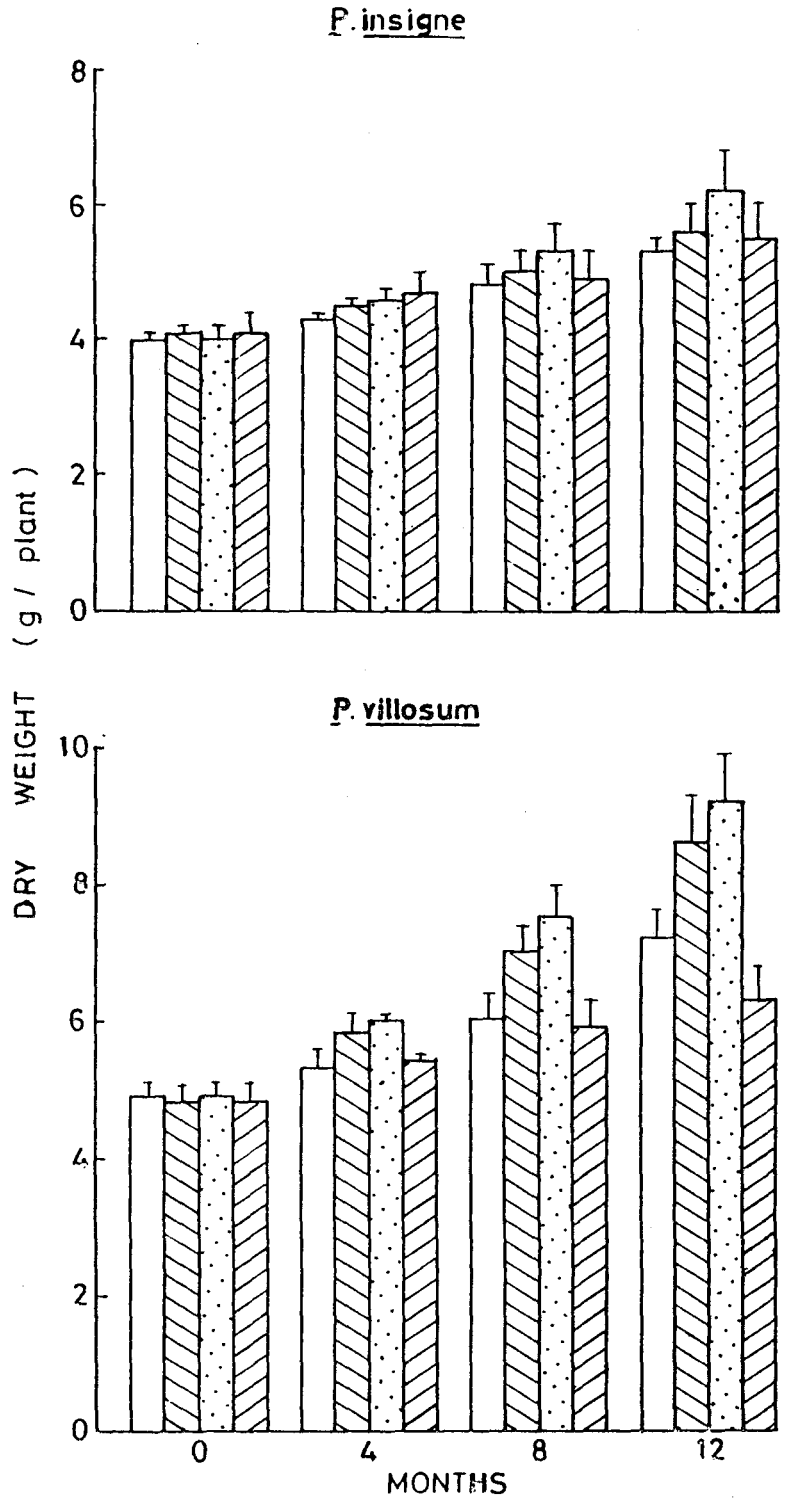


Fig. 6.2 Dry weight of *P. insigne* and *P. villosum* grown under different watering treatments. control ☐ ; weekly watering ▨ ; fortnightly watering ⁘ ; monthly watering ▩

watering (Fig.6.3).

The trend of NAR and LAR was similar to RGR in both the species (Fig 6.4, 6.5).

DISCUSSION

The growth and development of *P. insigne* and *P. villosum* was greatly affected by watering, although both the species could survive under varying soil water regimes. Root and offshoot formation in both *P. insigne* and *P. villosum* showed a distinct seasonal pattern in control as well as under different watering treatments. Root system showed good growth during rainy season (May-August) after which it declined during September-December. The growth resumed again during January-April. The period between July and November was favourable for the offshoot production, this was followed by a period of dormant stage from January to the end of the experiment in April.

Unlike offshoot, number of leaves showed a continuous increase through out the year without any marked seasonality. Both these species required relatively higher soil moisture (*ca* 32%) for the formation of larger number of leaves than the offshoots which showed better growth when soil moisture was about 22%.

A marked increase in root number and root length under weekly watering indicated that high water content in the soil (*ca* 32%) enhanced root formation which eventually contributed to the increase in root length of the plant.

Greater offshoot production and higher leaf length and area under fortnightly watering in both the species suggest that for

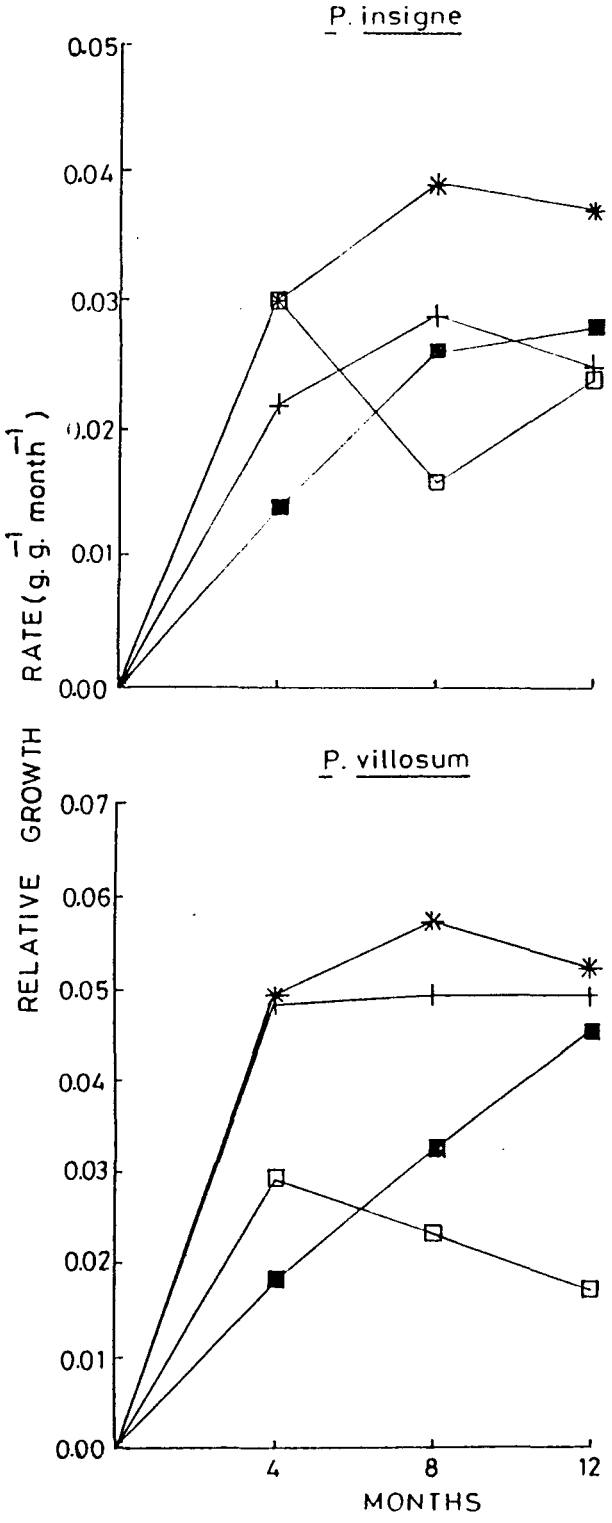


Fig. 6.3 Relative growth rate (g. g^{-1}. month $^{-1}$.) of *P. insigne* and *P. villosum* under different watering treatments. (—■—), control; (—┼—) weekly watering; (—✳—) fortnightly watering; (—□—) monthly watering.

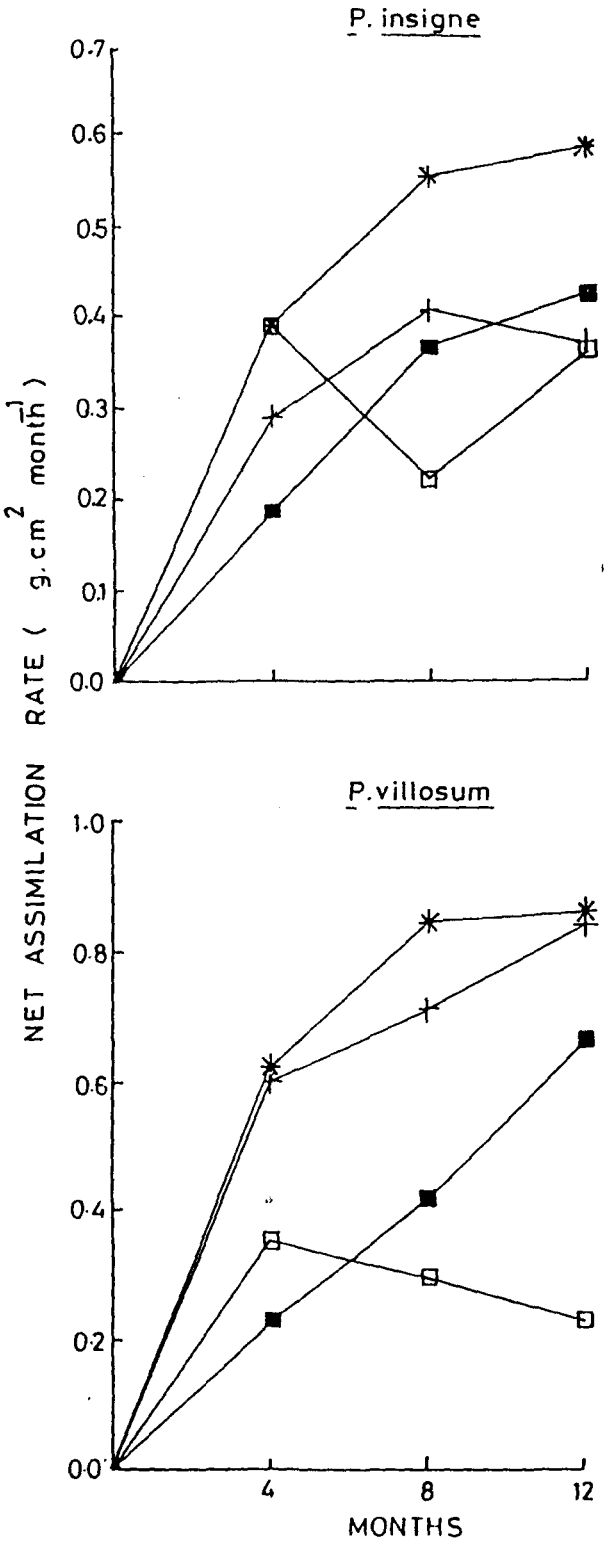


Fig. 6.4 Net assimilation rate (mg. cm^{-2} $month^{-1}$) of *P. insigne* and *P. villosum* under different watering treatments. (—■—) control; (—┼—) weekly watering; (—✳—) fortnightly watering; (—□—) monthly watering.

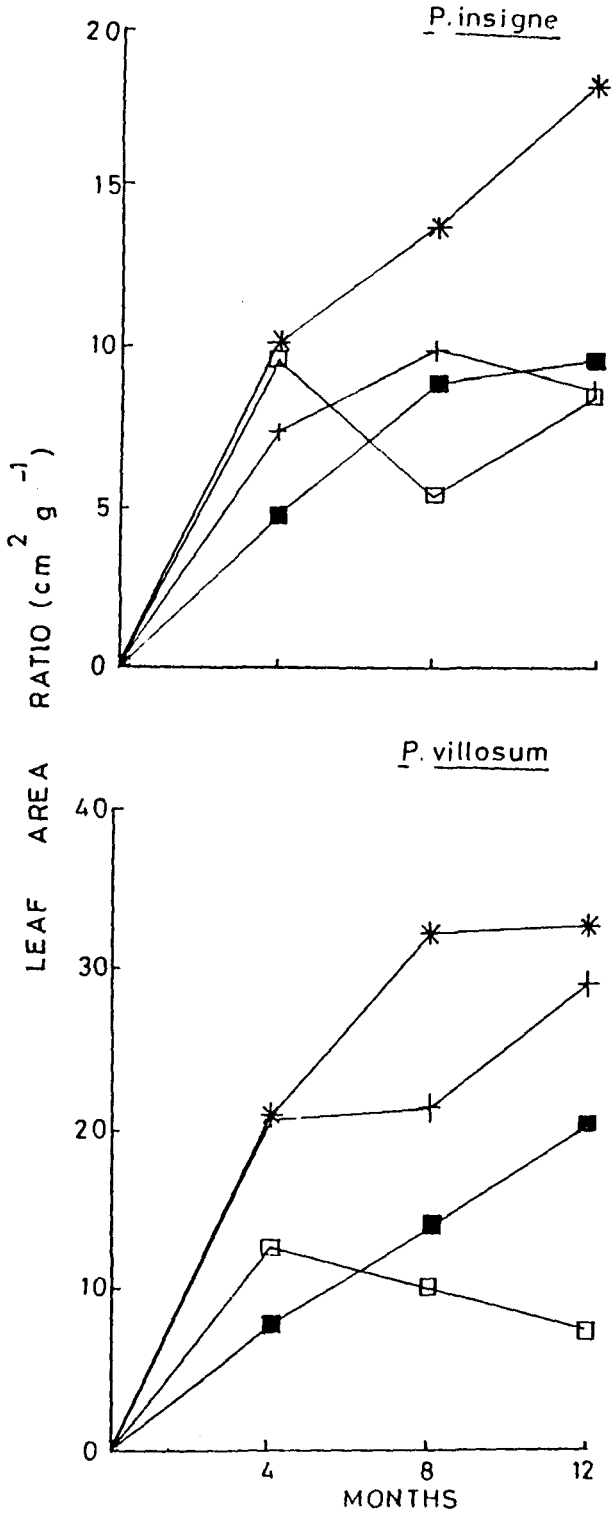


Fig. 6.5 Leaf area ratio (cm^2 g^{-1}) of *P. insigne* and *P. villosum* under different watering treatments (—■—) control; (—+—) weekly watering; (—✳—) fortnightly watering; (—□—) monthly watering.

these growth parameters, relatively less amount of water in soil (*ca* 22%) favoured their growth.

Decline in soil moisture level suppressed the length of leaves as well as root in both the species in a similar fashion. Heather and Hegarty (1979) observed that moisture stress affected the growth of radicles in seedlings of some vegetable crops. Sobrado and Turner (1986) reported that water deficit reduces whole plant components beginning from the root to the reproductive parts. The results also conforms the finding of Stevenson and Laidlaw (1985) in *Trifolium repens* where root growth was highly affected by drought stress. Minimum offshoot production under monthly watering may be due to suppression of bud formation as reported by McIntyre (1976) in the rhizome of *Agropyron repens*.

Growth of reproductive organs such as floral stalk was markedly suppressed in *P. insigne* under monthly watering than *P. villosum* indicating thereby that in the former it was more adversely affected by water stress than in the latter. Flower initiation and timing of flowering did not vary from the control but the duration of flowering varied markedly between control and watering treatments. In control, flowers faded early (November) than in monthly watering treatment. In fortnightly watering flowers lasted till the end of December and in weekly watering, till the first week of January.

Dry weight of both the species was highest in fortnightly watering whereas the lowest value was recorded in monthly watering. This is in agreement with the findings of Omaligo and Ene-Oblong (1987) who reported that water stress reduced the

total biomass production in *Anthephora ampulacea*. Similar findings have been reported by Yadav and Tripathi (1985) in case of *Eupatorium adenophorum* and *E. riparium* under low soil moisture.

Although root formation was more in *P. insigne*, total dry weight was higher in *P. villosum* probably due to greater leaf area.

RGR in plants depends on NAR and LAR (Briggs, Kidd and West 1920). Thus higher NAR and LAR in fortnightly watering was responsible for greater RGR under this treatment. Since both these growth analyses measures had higher value in *P. villosum*, its RGR was higher than *P. insigne* indicating that higher LAR, NAR and RGR were ultimately responsible for greater dry matter accumulation in *P. villosum*.

Monthly watering where soil moisture range between 14% and 16%, adversely affected all these growth analysis parameters resulting into a marked decline in the dry weight of the plant. The effect was however, more prominent in case of *P. villosum* whose dry weight decreased below the level of control plants in the last sampling.

Too much of watering leads to the loss of aeration in most orchid roots (Kataki 1974, Rao 1979, Rittershausen and Rittershausen 1984). Jones and Etherington (1970) reported that *Erica cinerea* and *Erica tetralix* were rapidly killed by water logging and *E. cinerea* was more severely affected than *E. tetralix*. This might be the reason for poor growth performance in weekly watering where soil moisture content varied between 31% and 33% during the study period.

Chapter 7

EFFECT OF SUBSTRATE QUALITY

Soil is one of the most important environmental factors which affects growth and development of plants. Plant characteristics are very much influenced by the soil properties. Germination, growth and distribution, size and vigour of the vegetative organs, stem woodiness, depth of the root system and date of appearance of flowers are influenced by the soil properties. The land plants are strongly influenced by soil qualities and they exhibit differences in their distribution pattern and growth behaviour (Arora 1964, Mishra 1966, Pandaya *et al.* 1968, Swarup *et al.* 1954, Saksena 1955, Sharma 1967, 1968, Kalpage 1974, Hume and Cavers 1983, Davies 1984). Mooney (1966) reported the influence of different soil types on the distribution pattern of two closely related species of *Erigeron*. Gulmon and Turner (1978) observed differences in growth performance of root and shoot of tomato (*Lycopersicum esculentum*) grown in different soil conditions. Studies on the effect of porosity and organic matter content of soil on the presence or absence of *Plantago* species were carried out by Noe and Blom (1981). Soil texture has been shown to affect reproductive efforts of the plant species (Trivedi and Tripathi 1982b, Rai and Tripathi 1983).

In case of orchids, importance of mycorrhizal association on their growth and development have been reported by many workers. Katiyar *et al.* (1986) reported that all the terrestrial and

epiphytic orchids, except those with hanging roots which are not in contact with the bark, are infected by mycorrhiza. Under natural condition, orchids may be infected by a fungus through out its life or may become independent at maturity (Bernard and Burgeff 1909, Summerhayes 1968, Arditti 1973). Fungi helps in absorption of organic matter and nutrients (Campbell 1963, Smith 1967).

Little work has been done to understand the growth behaviour of orchid species in relation to their habitat conditions (Bose and Bhattacharjee 1980, William *et al.* 1985). Hegde (1982) gave an account of habitat - distribution of both terrestrial and epiphytic orchids of Arunachal Pradesh. Gupta and Singh (1986) studied the growth of *P. villosum* and *Dendrobium moschatum* on different potting media.

In view of the little amount of work done on orchids in relation to soil conditions, an experiment was conducted to study the effect of different types of substrates on the growth performance of *P. insigne* and *P. villosum*. The findings of this experiment are discussed in this chapter.

MATERIALS AND METHODS

One young plant with 4 - 5 leaves and one small offshoot was planted in each experimental plastic pot in April 1988 (21cm diameter and 21cm depth) in the following six types of potting media.

Treatment 1. Mineral soil

Treatment 2. Mineral soil and humus - 3 : 1 proportion

Treatment 3. Mineral soil and humus - 1 : 1 proportion

Treatment 4. Mineral soil and humus - 1 : 3 proportion

Treatment 5. Humus

Treatment 6. Mixed litter (Pine & Broad leaved).

The mixtures were thoroughly mixed before filling in the experimental pots. The experimental lay out included 6 substrates, 2 species, 4 replicates and 1 harvest. Moisture content, pH and nutrient content (total nitrogen, phosphorus and potassium) of each potting media were analysed in the beginning and results are given in Table 7.1.

The experiment was conducted in an unheated net house of 5m x 3m size. The four sides of the net house were covered up to one meter height from the ground level with a thick transparent polythene sheet, in order to protect the pots from the splashing rain water but the pots received water from top during the rainy season (May-September). During dry season (October-February) each pot was watered with tap water at 10 days interval. Care was taken to protect the plants from weeds, insects, pests, small animals etc. Monthly observations were taken for the growth parameters of shoot and the experiment was conducted for one year period from April 1988 to April 1989. The plants were harvested in April 1989, their growth parameters were recorded and finally dry weight was determined after drying the sample in a hot air oven at 80°C for 24 hours. Growth analysis of the plants was also carried out by calculating LAR, NAR and RGR according to the formulae given in Chapter 6.

Table 7.1 . Physico-chemical characteristics of different potting media at the time of planting of *P. insigne* and *P. villosum*.

Treatment	Mineral soil% (v/v)	Humus % (v/v)	Moisture Content %	pH	Nitrogen Content mg g^{-1}	Phosphorus Content mg g^{-1}	Potassium Content mg g^{-1}
Mineral Soil	100	0	9.10	6.10	0.0172	0.020	0.268
MS+HU (3:1)	75	25	11.91	5.59	0.0162	0.015	0.206
MS+HU (1:1)	50	50	5.84	5.44	0.0107	0.020	0.255
MS+HU (1:3)	25	75	18.68	4.96	0.0335	0.016	0.157
Humus	0	100	36.02	5.61	0.0383	0.028	0.202
Litter	0	100	14.21	4.80	0.0291	0.019	0.206

MS - Mineral Soil, HU - Humus.

RESULTS

Plant length (longest root and longest leaf)

Both *P. insigne* and *P. villosum* showed maximum length in humus and minimum in mineral soil (Fig. 7.1a). Plants in the mineral soil plus humus (1:3) and litter did not show any significant difference. In the potting media containing mineral soil and humus in 3:1 and 1:1 proportions, the plant length was close to the minimum value. Although both the species showed highest increase in length under humus, growth of *P. insigne* in general was better than *P. villosum*, in all the treatments. (Fig. 7.1b).

Root number and root length

Humus favoured root growth of both *P. insigne* and *P. villosum*. Both root number as well as root length was significantly higher in this medium than the mineral soil where root number in both the species was minimum (Fig 7.2a and Fig. 7.3a). The root growth of *P. insigne* was better than *P. villosum* in all the treatments (Fig. 7.2b and Fig. 7.3b).

Offshoot production

New offshoots developed from the mother plants after two months of planting. *P. insigne* produced offshoot a little earlier than *P. villosum*. In litter also offshoot formation was delayed in *P. villosum*. Under 1:3 ratio of mineral soil and humus and under humus, offshoot production was very slow in both the species, where it started in September. After September, no new offshoot was produced till March, in any treatment. It again started after March in all the treatments (Table 7.2). ANOVA of

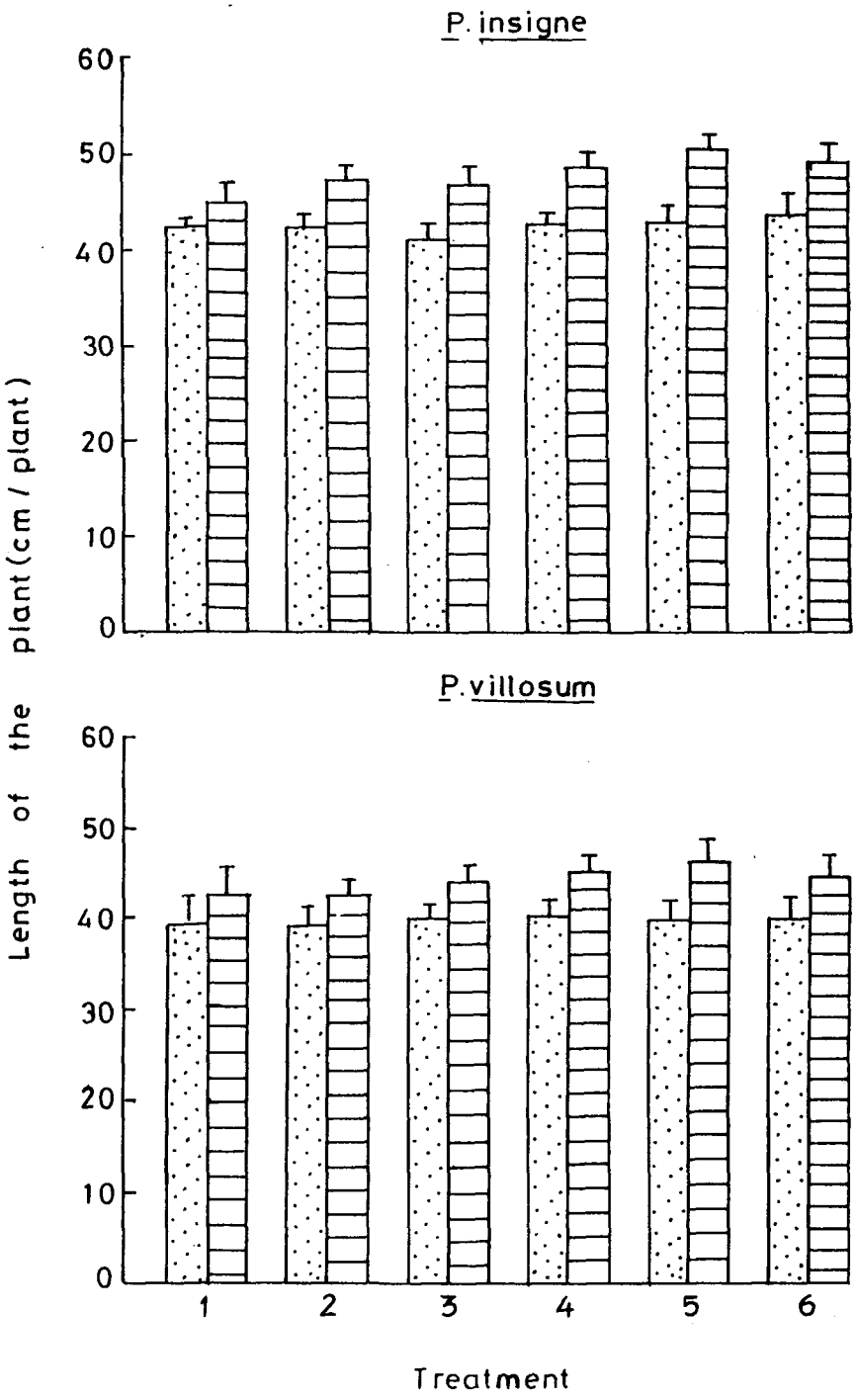


Fig. 7.1a Effect of substrate quality treatments on the length (longest root to longest leaf) of two species of *Paphiopedilum*. ⊡ Initial; ▤ Final.

1 - mineral soil; 2 - mineral soil and humus (3:1); 3 - mineral soil and humus (1:1); 4 - mineral soil and humus (1:3); 5 - humus; 6 - litter.

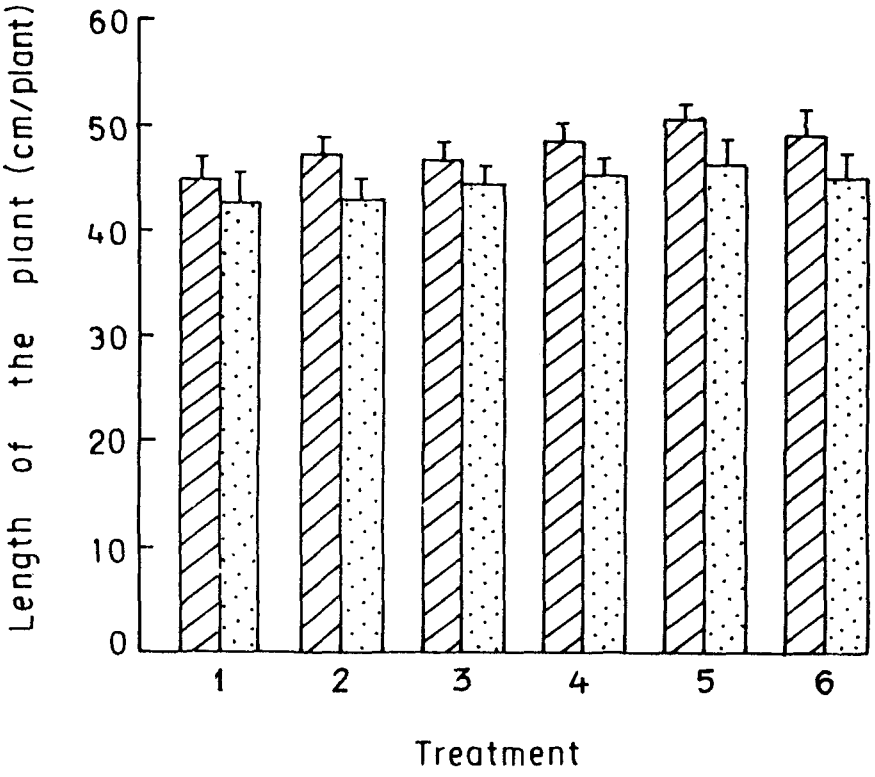


Fig. 7.1b Effect of substrate quality on the mean length of *P. insigne* (▨) and *P. villosum* (⁘) after 12 months of growth.

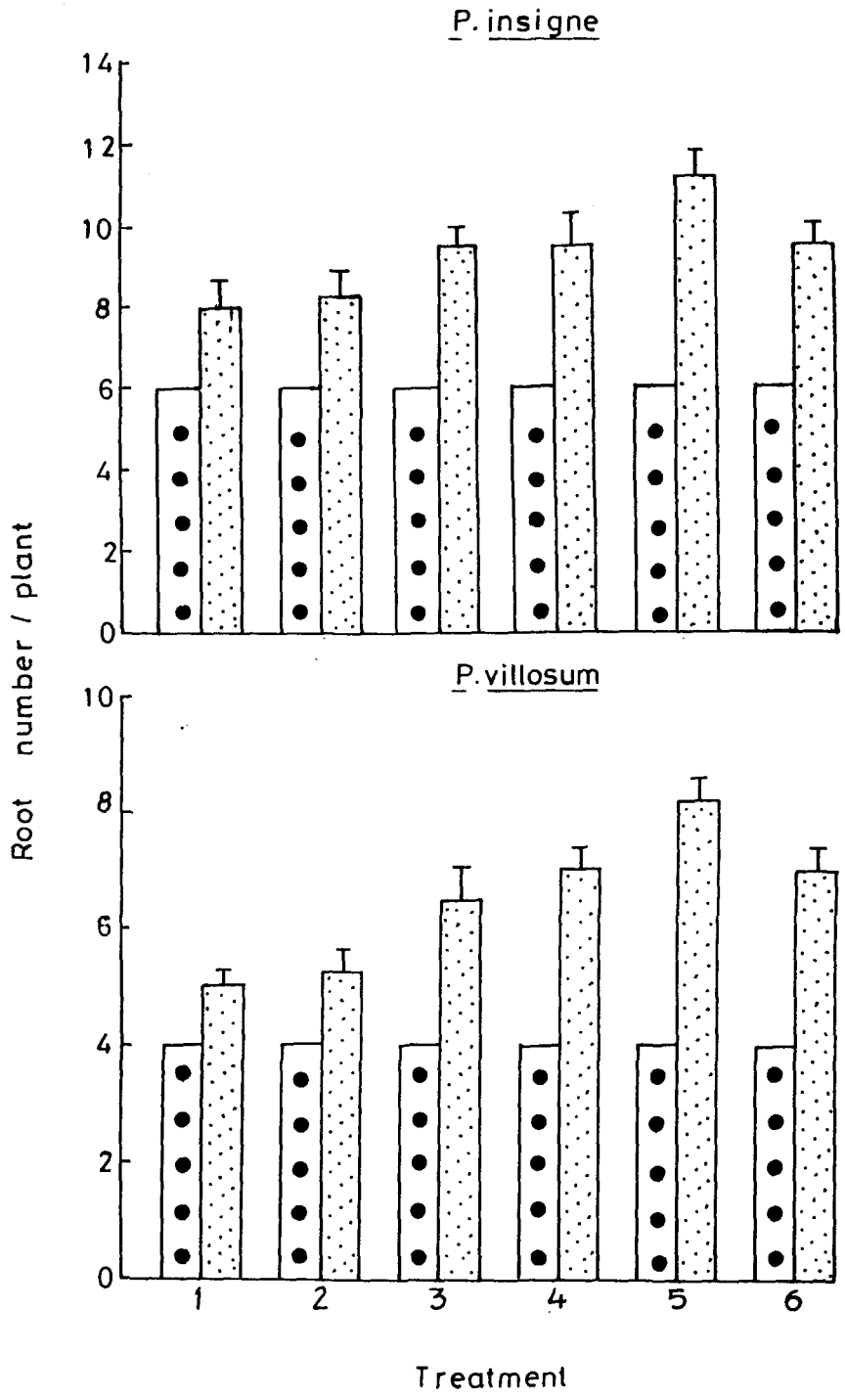


Fig. 7.2a Effect of different substrates on the root number of *P. insigne* and *P. villosum* after 12 months of growth (▣ , Initial; ⁘ , Final).

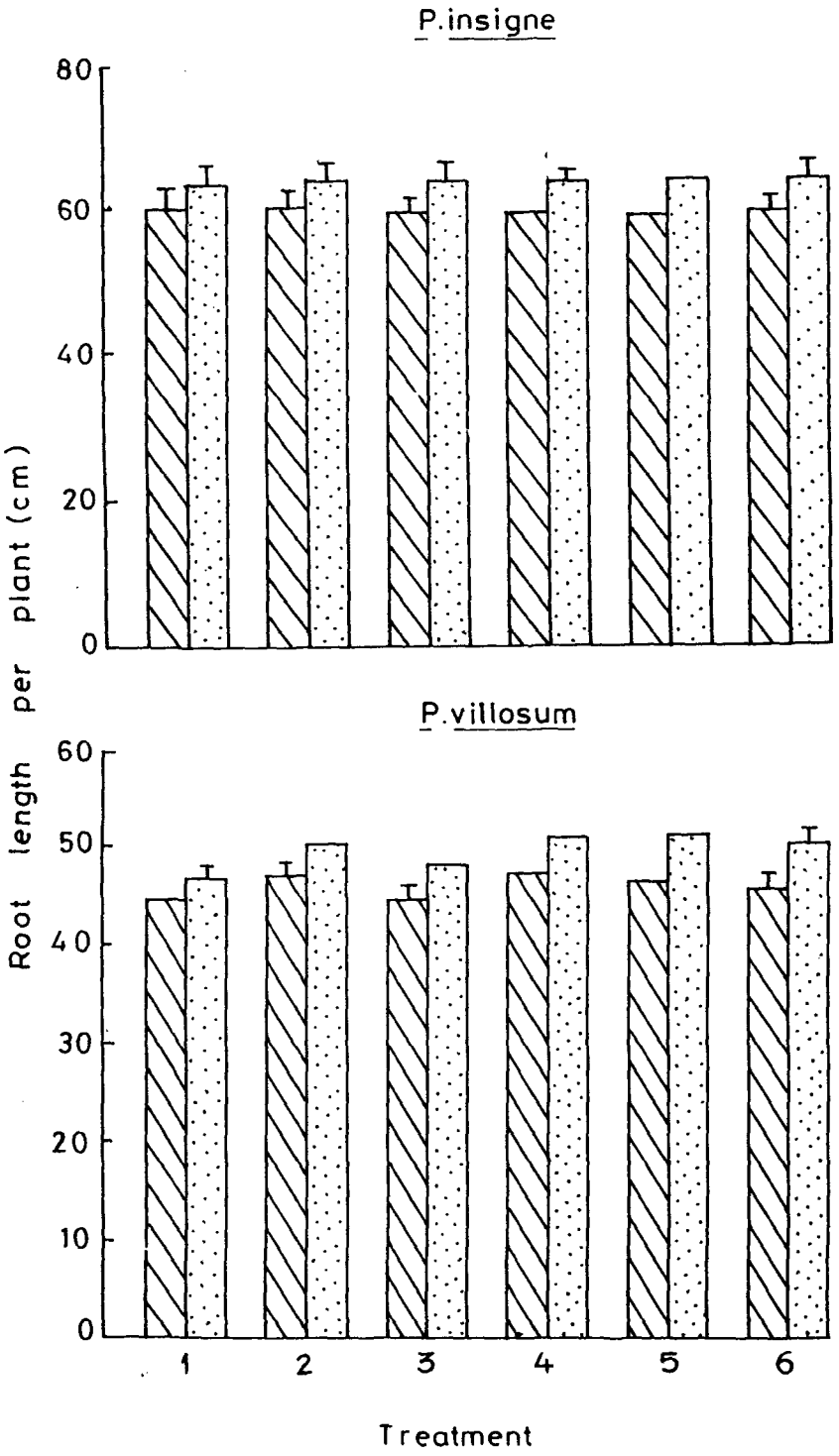


Fig. 7.3a Effect of different substrates on root length of *P. insigne* and *P. villosum* during 12 months of growth (▨ , Initial; ⁘ Final).

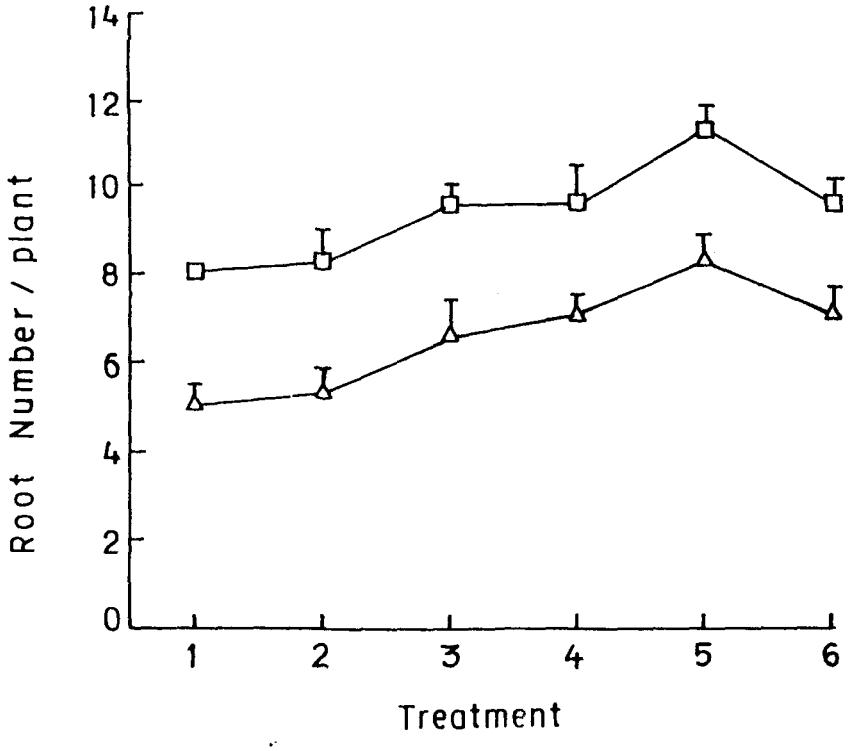


Fig. 7.2b Comparison between the root number of *P. insigne* (—□—) and *P. villosum* (—△—) during 12 months of planting when grown on different substrates.

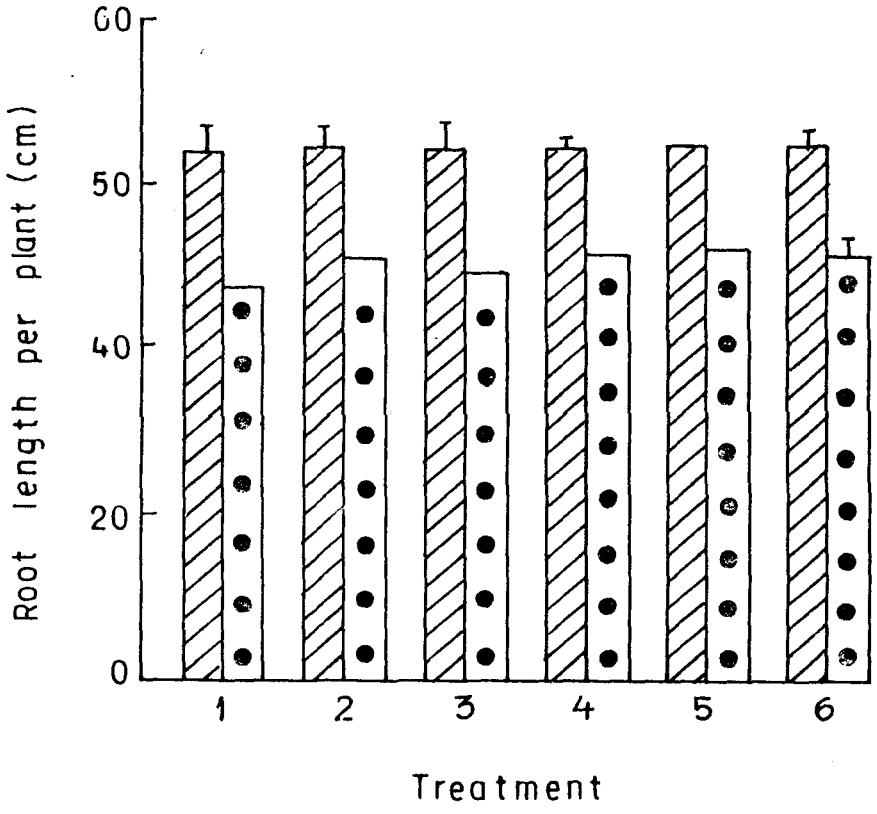


Fig. 7.3b Root length of *P. insigne* (▨) and *P. villosum* (◉) during twelve months of growth as affected by different substrates.

Table 7.2 . Effect of different substrates on offshoot production (number/plant ± SEM) in *P. insigne* and *P. villosum*

Treatment	Species	MONTHS											
		M	J	J	A	S	O	N	D	J	F	M	A
	Pi	1.25	1.25	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.75	2.00
MS		±0.25	±0.25	±0.28	±0.28	±0.28	±0.28	±0.28	±0.28	±0.28	±0.28	±0.25	±0.00
	Pv	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	2.00	2.00
		±0.25	±0.25	±0.28	±0.28	±0.28	±0.28	±0.28	±0.28	±0.28	±0.28	±0.00	±0.00
	Pi	2.00	2.00	2.25	2.25	2.75	2.75	3.25	3.25	3.25	3.25	3.50	4.00
MS+HU		±0.00	±0.00	±0.25	±0.25	±0.47	±0.47	±0.47	±0.47	±0.47	±0.47	±0.28	±0.00
(3:1)	Pv	1.50	1.50	1.75	1.75	2.25	2.25	2.25	2.25	2.25	2.25	2.75	3.00
		±0.28	±0.28	±0.25	±0.25	±0.25	±0.25	±0.25	±0.25	±0.25	±0.25	±0.25	±0.00
	Pi	1.75	1.75	2.00	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.75	3.00
MS+HU		±0.25	±0.25	±0.00	±0.25	±0.25	±0.25	±0.25	±0.25	±0.25	±0.25	±0.25	±0.00
(1:1)	Pv	2.00	2.00	2.25	2.25	3.00	3.00	3.00	3.00	3.00	3.00	3.50	4.00
		±0.00	±0.00	±0.25	±0.25	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00	±0.28	±0.00
	Pi	2.00	2.00	2.00	2.00	2.50	2.50	2.50	2.50	2.50	2.50	3.00	3.00
MS+HU		±0.00	±0.00	±0.00	±0.00	±0.28	±0.28	±0.28	±0.28	±0.28	±0.28	±0.00	±0.00
(1:3)	Pv	1.50	1.50	1.50	1.50	2.25	2.25	2.25	2.25	2.25	2.25	2.50	3.00
		±0.28	±0.28	±0.28	±0.28	±0.47	±0.47	±0.47	±0.47	±0.47	±0.47	±0.28	±0.00
	Pi	1.50	1.50	1.75	1.75	2.25	2.25	2.25	2.25	2.25	2.25	2.50	3.00
Humus		±0.28	±0.28	±0.47	±0.47	±0.25	±0.25	±0.25	±0.25	±0.25	±0.25	±0.28	±0.00
	Pv	1.50	1.50	1.50	1.50	2.50	2.50	2.50	2.50	2.50	2.50	2.75	3.00
		±0.28	±0.28	±0.28	±0.28	±0.28	±0.28	±0.28	±0.28	±0.28	±0.28	±0.28	±0.00
	Pi	2.00	2.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.25	3.25
Litter		±0.00	±0.00	±0.70	±0.70	±0.70	±0.70	±0.70	±0.70	±0.70	±0.70	±0.62	±0.62
	Pv	1.75	1.75	1.75	1.75	2.75	2.75	2.75	2.75	2.75	2.75	3.00	3.25
		±0.25	±0.25	±0.25	±0.25	±0.47	±0.47	±0.47	±0.47	±0.47	±0.47	±0.40	±0.25

Pi - *Paphiopedilum insigne*; Pv - *Paphiopedilum villosum*.

data showed that offshoot production was affected ($P < 0.05$) by soil conditions and it significantly varied ($P < 0.05$) between the two species.

Leaf number

Leaf number per plant was greater in humus in both the species. Although soil condition significantly affected ($P < 0.05$) leaf number of both the species, the difference between the two species in this regard was insignificant. For both the species, mineral soil provided most unfavourable medium for leaf production. Like offshoot, new leaves were observed two months after planting (July) and flushing continued till October, after which it stopped during winter season and revived again with the coming of spring (Table 7.3).

Leaf length and leaf area

Total leaf length per plant in both *P. insigne* and *P. villosum* was greater when humus was abundant in the medium (1 part mineral soil : 3 parts humus). Thus soil which significantly affected leaf length, obviously had a significant effect ($P < 0.05$) on leaf area as well. Leaf length and leaf area of both the species showed significant increase ($P < 0.05$) in mineral soil-humus (1:3) mixture than other media (Table 7.4). Leaf area among the two species varied significantly ($P < 0.05$) but its increase did not exhibit any seasonal trend, rather it continued from the beginning till the end of the experiment (Table 7.5). In all the treatments, *P. villosum* showed significantly higher ($P < 0.05$) leaf length as well as leaf area than *P. insigne*.

Table 7.3 . Effect of different substrates on leaf (number/plant ± SE) production in *P. insigne* (Pi) and *P. villosum.* (Pv).

Treatment	Species	MONTHS											
		M	J	J	A	S	O	N	D	J	F	M	A
	Pi	5.00	5.00	6.25	6.25	7.25	7.25	7.25	7.25	7.25	7.25	7.50	7.50
MS		±0.40	±0.40	±1.03	±1.03	±1.03	±1.03	±1.03	±1.03	±1.03	±1.03	±0.98	±0.98
	Pv	5.25	5.25	5.25	5.25	5.25	5.25	5.25	5.25	5.25	5.75	6.25	6.25
		±0.75	±0.75	±0.75	±0.75	±0.75	±0.75	±0.75	±0.75	±0.75	±0.25	±0.47	±0.47
	Pi	6.00	6.00	6.00	6.00	7.00	7.00	7.75	7.75	7.75	7.75	8.50	9.00
MS+HU		±0.91	±0.91	±0.40	±0.40	±1.22	±1.22	±1.31	±1.31	±1.31	±1.31	±0.86	±0.91
(3:1)	Pv	5.50	5.50	6.00	6.00	7.50	7.50	8.25	8.25	8.25	8.25	8.25	8.25
		±1.19	±1.19	±1.00	±1.00	±1.25	±1.25	±0.94	±0.94	±0.94	±0.94	±0.94	±0.94
	Pi	5.50	5.50	6.00	6.00	6.75	6.75	6.75	6.75	6.75	7.50	8.50	9.00
MS+HU		±1.04	±1.04	±0.91	±0.91	±0.75	±0.75	±0.75	±0.75	±0.75	±0.86	±0.86	±0.57
(1:1)	Pv	5.50	5.50	7.00	7.00	8.25	8.25	8.75	8.75	8.75	8.75	8.75	8.75
		±0.64	±0.64	±0.40	±0.40	±0.25	±0.25	±0.47	±0.47	±0.47	±0.47	±0.47	±0.47
	Pi	6.25	6.25	6.25	7.25	7.25	7.25	8.00	8.00	8.00	8.00	9.00	9.00
MS+HU		±0.55	±0.55	±0.55	±0.72	±0.72	±0.72	±1.08	±1.08	±1.08	±1.08	±1.08	±1.08
(3:1)	Pv	5.50	5.50	5.50	5.50	7.00	7.00	7.75	7.75	7.75	7.75	8.00	8.75
		±0.86	±0.86	±0.86	±0.86	±1.15	±1.1	±1.37	±1.37	±1.37	±1.37	±1.22	±0.85
	Pi	5.50	5.50	5.50	5.75	7.25	7.25	7.75	7.75	7.75	7.75	9.25	9.75
Humus		±0.74	±0.74	±0.74	±0.75	±0.75	±0.75	±0.62	±0.62	±0.62	±0.62	±0.47	±0.25
	Pv	5.25	5.25	6.00	6.00	8.00	8.00	8.00	8.00	8.00	8.00	8.75	8.75
		±0.85	±0.85	±0.70	±0.70	±0.70	±0.70	±0.70	±0.70	±0.70	±0.70	±1.10	±1.10
	Pi	5.50	5.50	6.00	6.00	6.75	6.75	7.00	7.00	7.00	8.00	8.75	8.75
Litter		±0.74	±0.74	±0.40	±0.40	±0.85	±0.85	±0.81	±0.81	±0.81	±0.40	±0.47	±0.47
	Pv	5.25	5.25	6.00	6.00	7.75	8.25	8.25	8.25	8.25	8.25	8.50	8.50
		±0.94	±0.94	±0.70	±0.70	±1.10	±1.10	±1.10	±1.10	±1.10	±1.10	±0.86	±0.86

Table 7.4 . Effect of different substrates on leaf length (cm/plan ± SEM) in *P. insigne* (Pi) and *P. villosum* (Pv).

Treatment	Species	MONTHS											
		M	J	J	A	S	O	N	D	J	F	M	A
	Pi	113.87	116.00	116.50	117.50	118.25	119.25	120.00	120.75	121.50	122.50	122.75	124.00
MS		±15.76	±15.88	±16.13	±15.94	±15.73	±15.55	±15.67	±15.32	±15.62	±15.08	±14.95	±14.35
	Pv	115.50	116.62	117.62	118.75	119.75	120.50	121.62	122.50	123.62	124.62	125.87	127.12
		±13.93	±19.26	±19.86	±19.69	±19.73	±19.57	±23.05	±18.16	±19.73	±18.22	±17.31	±16.45
	Pi	111.87	113.00	113.75	114.87	115.87	116.87	117.87	119.12	119.75	120.75	122.00	123.50
MS+HU		±28.39	±28.50	±28.25	±28.39	±28.21	±28.20	±28.04	±27.63	±27.44	±27.13	±26.73	±16.22
(3:1)	Pv	116.62	117.75	119.00	120.12	121.62	122.87	124.12	125.62	126.87	127.87	129.37	131.37
		±1.25	±1.29	±1.06	±1.10	±1.47	±1.39	±1.85	±2.09	±2.06	±2.60	±3.03	±3.79
	Pi	108.00	109.62	110.87	111.75	113.75	114.75	116.00	118.25	119.00	120.75	121.75	124.00
MS+HU		±8.34	±8.35	±8.35	±8.41	±8.15	±8.19	±7.88	±7.36	±7.25	±6.86	±6.84	±6.74
(1:1)	Pv	116.62	118.12	119.37	120.62	121.87	123.25	124.75	126.00	127.50	129.25	130.25	132.00
		±13.46	±13.33	±13.52	±13.61	±13.42	±13.49	±13.33	±13.15	±12.84	±12.05	±12.19	±12.32
	Pi	108.25	109.50	111.00	112.00	113.62	114.50	116.25	118.25	119.00	120.75	122.00	124.75
MS+HU		±12.54	±12.22	±12.17	±12.13	±12.49	±12.50	±11.93	±10.68	±10.31	±9.44	±9.28	±8.33
(1:3)	Pv	115.37	117.00	118.87	120.12	122.75	124.75	127.00	128.25	129.75	132.25	134.50	137.50
		±16.09	±16.31	±16.81	±17.39	±17.75	±17.77	±17.34	±16.60	±15.73	±14.29	±15.13	±13.44
	Pi	107.75	109.50	110.50	111.37	113.37	114.75	116.25	117.75	119.00	120.00	120.75	122.50
Humus		±14.82	±15.18	±14.61	±14.41	±14.38	±14.02	±13.60	±12.71	±12.04	±11.51	±11.47	±10.50
	Pv	116.12	118.00	119.50	121.50	123.50	124.25	126.50	127.50	129.50	131.00	133.50	135.00
		±11.31	±11.45	±12.66	±12.90	±12.50	±12.53	±11.77	±11.43	±10.82	±11.42	±11.10	±11.46
	Pi	110.25	112.00	113.25	114.50	116.00	117.00	119.00	120.00	120.75	121.50	122.50	124.00
Litter		±7.22	±6.77	±6.62	±7.70	±8.15	±8.11	±7.77	±8.19	±7.97	±8.18	±8.18	±9.01
	Pv	117.50	118.50	120.00	121.50	123.00	124.00	125.00	126.75	128.25	129.50	130.50	131.50
		±10.30	±9.98	±9.58	±9.92	±9.63	±9.38	±8.90	±8.77	±8.51	±8.60	±8.87	±9.04

Table 7.5 . Effect of substrates on leaf area (cm^2/plant ± SEM) in *P. insigne* (Pi) and *P. villosum* (Pv).

Treatment	Species	MONTHS											
		M	J	J	A	S	O	N	D	J	F	M	A
	Pi	280.54	285.89	287.14	289.02	290.91	294.04	295.93	297.81	299.69	302.20	302.83	305.97
MS		±41.84	±39.87	±40.50	±40.36	±39.85	±39.05	±39.35	±38.46	±39.21	±37.85	±37.52	±36.03
	Pv	363.63	366.52	369.71	373.41	376.65	379.08	382.72	385.56	389.20	392.44	396.49	400.54
		±61.46	±62.43	±64.37	±63.80	±63.93	±63.41	±62.46	±58.71	±60.69	±59.04	±56.10	±61.61
	Pi	275.53	278.35	280.24	283.06	285.47	288.08	290.59	293.73	295.30	297.81	300.93	304.71
MS+HU		±62.58	±71.55	±70.91	±71.26	±70.81	±70.80	±70.38	±69.37	±68.89	±68.10	±67.09	±65.81
(3:1)	Pv	366.52	269.76	374.22	377.86	382.72	386.77	390.82	395.68	399.72	402.97	407.83	414.31
		±4.02	±4.35	±3.43	±3.58	±4.78	±4.50	±6.00	±6.78	±6.69	±8.42	±9.84	±12.29
	Pi	265.80	269.57	272.71	275.22	280.24	282.75	285.89	291.53	293.42	297.81	300.32	305.97
MS+HU		±20.95	±21.13	±21.15	±21.13	±20.47	±20.58	±19.79	±18.48	±18.24	±17.21	±17.18	±16.93
(1:1)	Pv	366.52	371.38	375.43	379.48	383.53	387.99	392.85	396.89	401.76	407.43	410.67	416.34
		±43.63	±43.19	±43.83	±44.11	±43.49	±43.73	±43.19	±42.63	±41.62	±39.04	±39.51	±39.92
	Pi	266.43	269.57	273.33	275.84	279.92	282.12	286.51	291.53	293.42	297.81	300.95	307.85
MS+HU		±31.49	±30.69	±30.54	±30.45	±31.35	±31.50	±29.95	±26.81	±25.90	±23.70	±23.29	±20.90
(1:3)	Pv	362.45	367.74	373.81	377.86	386.37	392.85	400.14	404.19	409.05	417.15	424.44	434.16
		±52.16	±52.85	±54.48	±56.35	±57.52	±57.58	±56.19	±53.80	±50.99	±46.32	±49.03	±43.55
	Pi	265.18	269.57	272.73	274.26	279.30	282.75	286.51	290.28	293.42	295.93	297.81	302.20
Humus		±37.20	±38.11	±55.50	±36.18	±36.11	±35.19	±34.14	±31.92	±30.22	±28.91	±28.78	±26.43
	Pv	364.90	370.98	375.84	382.32	388.80	391.23	397.77	401.76	408.24	413.10	421.20	426.06
		±36.65	±37.10	±41.03	±41.79	±40.52	±40.60	±37.51	±37.04	±35.05	±37.01	±35.99	±37.15
	Pi	271.45	275.85	278.98	282.12	285.89	288.40	293.42	295.93	297.81	299.69	302.20	305.97
Litter		±18.13	±16.99	±16.62	±19.34	±20.46	±20.36	±19.52	±20.57	±20.01	±20.53	±20.53	±22.63
	Pv	369.36	372.60	377.46	382.32	387.18	390.42	393.66	399.33	404.19	408.24	411.48	414.72
		±33.39	±32.35	±31.04	±32.14	±31.21	±30.42	±28.85	±28.44	±27.59	±27.88	±28.75	±29.29

Flower

The main offshoot of each plant bore flower. The time of emergence of flower bud did not differ in all the treatments but the flower opened late in mineral soil in both the species. Mineral soil condition significantly reduced ($P < 0.05$) the length of the floral stalk of both *P. insigne* and *P. villosum*. The former was more severely affected than the latter. Other treatments did not show any significant affect on the growth of floral stalk of both the species (Table 7.6).

Root/Shoot ratio (total root length/total leaf length)

Root/shoot ratio of both the species was less than one (0.3-0.5); *P. insigne* had higher value than *P. villosum* in all the treatments (Fig 7.4).

Dry weight

Dry matter yield per plant was maximum, in mineral soil - humus (1:3) mixture and the minimum in the mineral soil. Dry weight of *P. villosum* was higher than *P. insigne* (Fig. 7.5).

Growth analysis

Relative growth rate (RGR) was highest in the mineral soil - (1:3) humus mixture for both the species and both of them showed lowest value in the mineral soil. In first four media *P. insigne* showed greater RGR than *P. villosum* then it declined sharply in humus and became equal to *P. insigne* in the litter. Net assimilation rate (NAR) was also higher in case of *P. insigne* than *P. villosum* and both the species showed highest value in the fourth medium, i.e., mineral - humus (1:3) mixture. *P. villosum* showed LAR peak in mineral soil - humus mixture (1:3) and declined sharply under humus and litter, while *P. insigne* showed

Table 7.6 . Effect of substrates on the length of floral stalk (cm/plant ± SEM) in *P. insigne* (Pi) and *P. villosum* (Pv)

Treatment	Species	MONTHS					
		A	S	O	N	D	J
MS	Pi	15.25 ±0.47	22.50 ±1.32	26.25 ±1.31	28.75 ±1.25	28.75 ±1.25	28.75 ±1.25
	Pv	15.25 ±0.85	23.25 ±1.49	27.75 ±1.03	28.75 ±0.47	28.75 ±0.47	28.75 ±0.47
MS+HU (3:1)	Pi	16.75 ±0.75	24.00 ±1.58	28.00 ±1.08	30.00 ±1.41	30.00 ±1.41	30.00 ±1.41
	Pv	15.00 ±0.91	24.75 ±1.37	28.75 ±0.47	29.00 ±0.40	29.00 ±0.40	29.00 ±0.40
MS+HU (1:1)	Pi	16.00 ±1.08	24.25 ±1.75	27.50 ±1.25	28.50 ±1.25	28.50 ±1.25	28.50 ±1.25
	Pv	17.00 ±1.58	24.75 ±1.31	28.75 ±0.47	29.00 ±0.40	29.00 ±0.40	29.00 ±0.40
MS+HU (1:3)	Pi	16.00 ±0.91	24.00 ±1.95	27.50 ±1.19	29.75 ±0.75	29.75 ±0.75	29.75 ±0.75
	Pv	15.25 ±1.10	25.75 ±2.01	28.25 ±1.10	28.50 ±1.19	28.50 ±1.19	28.50 ±1.19
Humus	Pi	15.75 ±0.85	24.00 ±1.47	28.25 ±0.85	30.75 ±1.10	30.75 ±1.10	30.75 ±1.10
	Pv	15.00 ±1.08	23.25 ±1.79	27.75 ±1.10	28.25 ±1.10	28.25 ±1.10	28.25 ±1.10
Litter	Pi	15.25 ±1.10	23.00 ±1.77	26.75 ±1.65	29.25 ±1.37	29.25 ±1.37	29.25 ±1.37
	Pv	15.50 ±1.84	24.25 ±1.93	28.00 ±1.08	28.25 ±1.10	28.25 ±1.10	28.25 ±1.10

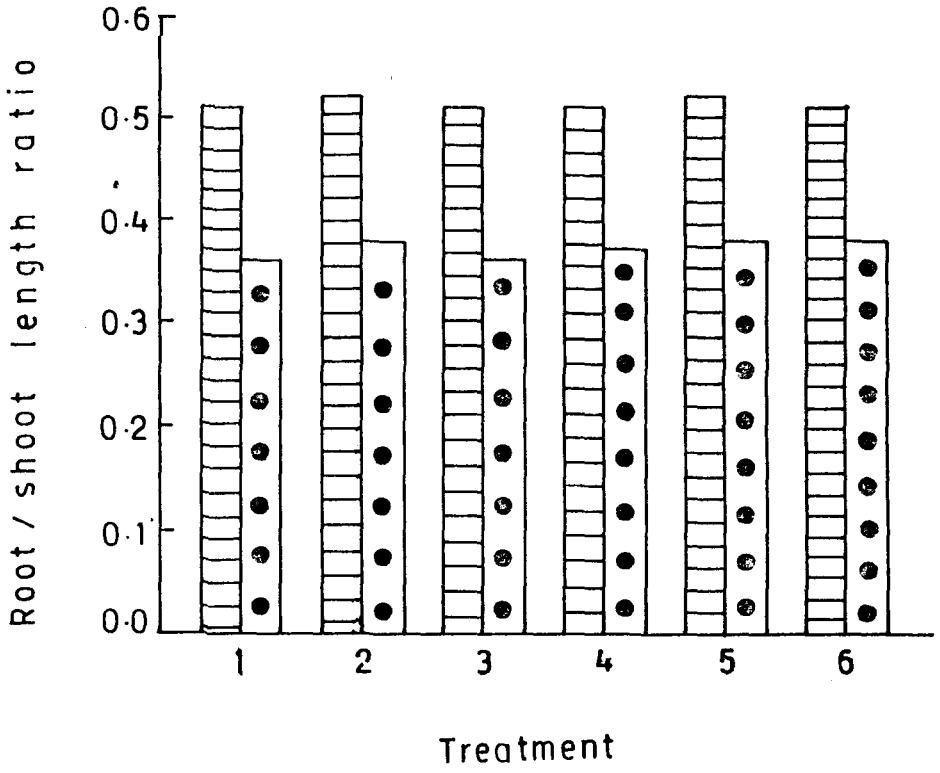


Fig. 7.4 Root/Shoot ratio of *P. insigne* (▭) and *P. villosum* (▭) under different substrate quality.

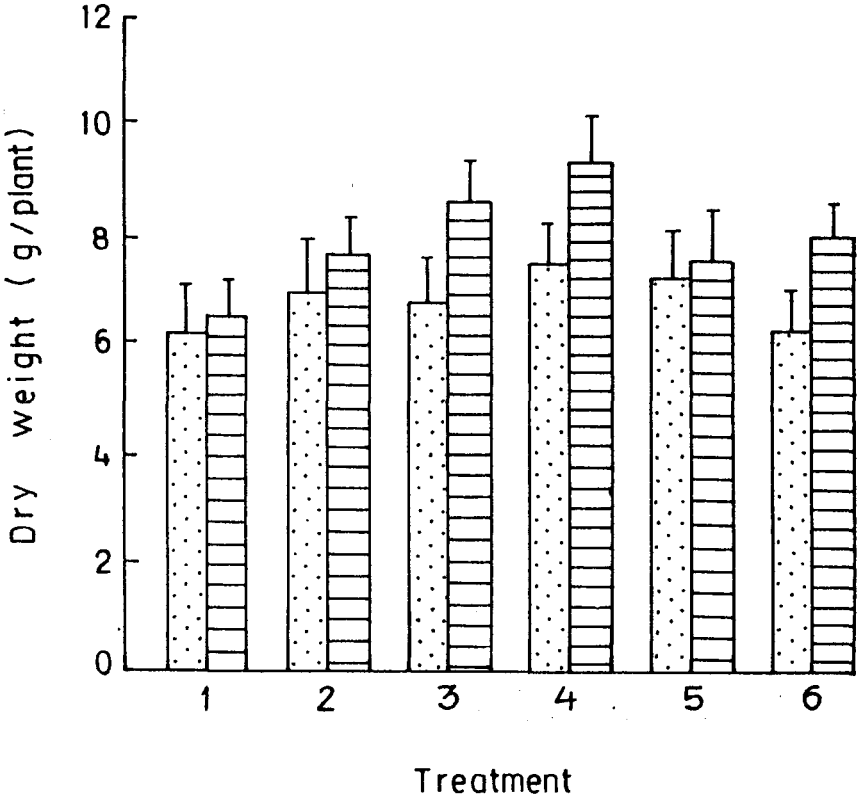


Fig. 7.5 Effect of different substrates on the biomass of *P. insigne* (⊡) and *P. villosum* (⊟) after 12 months of growth.

gradual increase from the mineral soil till it reached peak in the mineral soil - humus (1:3) mixture and then slowly declined in the litter (Fig. 7.6).

DISCUSSION

Both the species took time to get established after planting and grew relatively slowly. However, relatively earlier offshoot production in *P. insigne* indicates that this species may colonize new habitats more easily and quickly and is less susceptible to changes in soil conditions. Results showed that either humus or a mixture of humus with mineral soil in 3:1 proportion was less favourable for offshoot production. Humus was the most favourable medium for the root growth in both the species. This conforms Hegde's (1982) field observations on the orchids of Arunachal Pradesh where in he has concluded that types of soil, its properties, exposure, temperature and rainfall are important factors that determine the growth and abundance of terrestrial orchids under natural habitat. In this experiment soil organic matter was found to favour formation of new leaves as well as new roots in both the species. Formation of new leaves declined as the proportion of mineral soil increased in the potting media. Leaf length and leaf area per plant was also found to be greater when the proportion of organic matter was higher in the mixture. Better growth of leaf and root system in organic matter rich medium may be attributed to higher soil moisture content and nitrogen level and better soil aeration. Since fine textured soil does not favour root growth (Kalpage 1974) and soil having pore

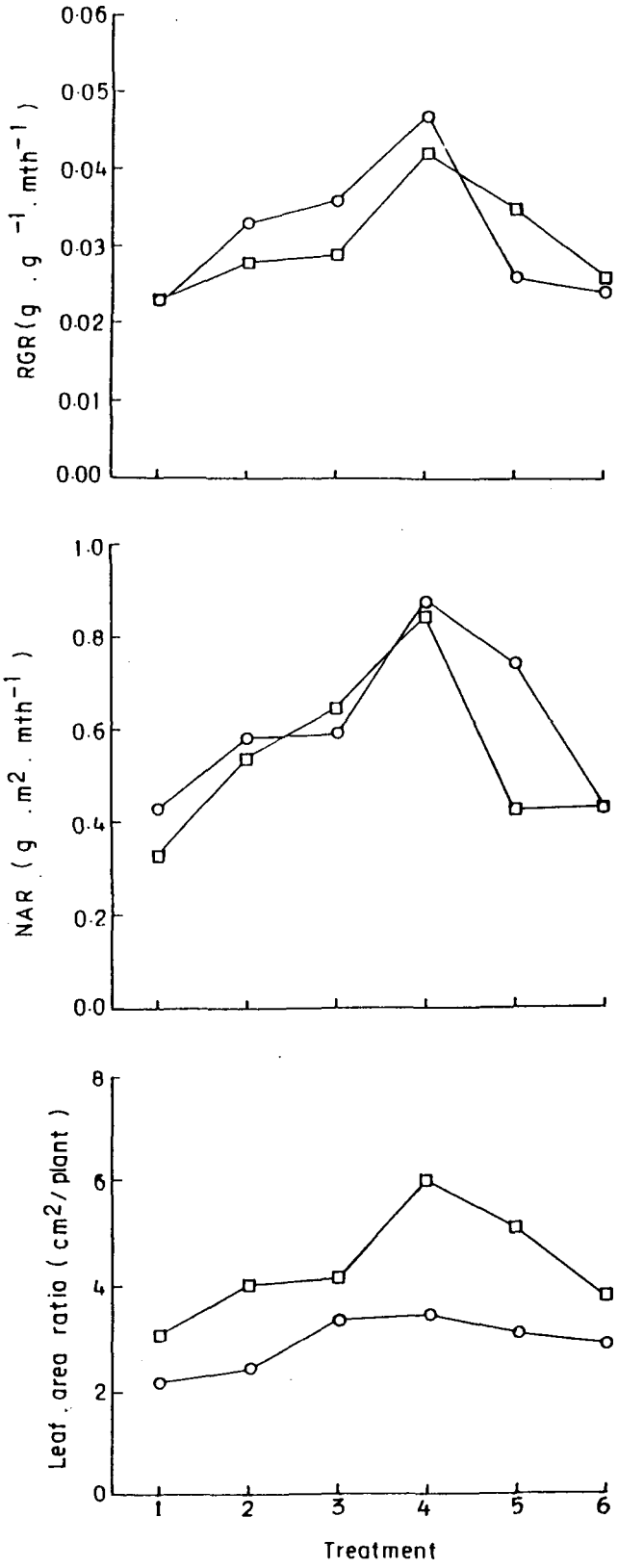


Fig. 7.6 Mean relative growth rate (RGR); net assimilation rate (NAR) and leaf area ratio (LAR) of *P. insigne* (—○—) and *P. villosum* (—□—) under different types of substrates.

space between 0.5 - 0.3 mm is favourable for root growth (Russel 1958), this might be one of the reasons for the increase in root number as well as root length of both the species in humus and poor growth under mineral soil.

Dry weight and leaf area followed the same trend attaining peak under mineral soil - humus (1:3) mixture and minimum in the mineral soil.

Only the main shoot of plant produced flower. This is because the newly formed offshoots take 2-3 years to flower. In both the species offshoots produced flowers, when the leaves attained an average length of 10cm.

Flowers developed in the litter medium lasted for a relatively shorter duration as compared to the rest of the treatments. Reduction in the length of floral stalk under mineral soil may be due to low organic content of the soil.

The absence of seed setting in any of the treatment may be attributed to the absence of pollinators as the plants are rarely self pollinated (Withner 1974, Keddy *et al* 1983).

Thus the nature of substrate played an important role in determining the growth and development of these two species of terrestrial orchids. Acidic (pH 5) potting medium containing a mixture of mineral soil and humus in 1:3 ratio (v/v), where soil moisture content was about 18 %, was the most favourable medium for vegetative and reproductive growth of both the species. Conversely, mineral soil which was characterised by low (*ca* 9 %) moisture content and pH 6 was unfavourable for their growth.

Chapter 8

EFFECT OF LIGHT INTENSITY

Plants differ in their response to environmental variables. Light being the most important climatic factor, large number of work has been done to analyse its effect on plants (Evans and Hughes 1960, Khaleafa *et al.* 1982, Skuterud 1984, Longstreth and Mason 1984, Read 1985). While considering the influence of light, two most significant variables - photoperiod and light intensity have been investigated in great detail. Many orchid species are known for their difference in sensitivity to the day length. Umstrom (1949) and Holdson and Laurie (1951) reported that even a slight change in day length may critically affect the growth and flowering of *Cattleya* (cited by Bhattacharjee 1979). In many other orchid species also, it has been found that change in day length may significantly alter their flowering characters (Rotor 1952, Lin and Molnar 1983).

Corré (1983) gave an account of the effect of shading on plant growth. Studies of Fitter and Ashmore (1974) showed that shade caused a large decrease in dry matter production in *Veronica persica* and a moderate decrease in *Veronica montana*, when both the species were grown under the same light intensity. *Achillea species* which is a light tolerant plant was highly affected by reduced light intensity and the plant failed to produce seeds and they seldom flowered when shaded (Clausen *et al.* 1940). Bourdot *et al.* (1984) explained that if shading is increased beyond 0.40 relative level of irradiance the dry matter

production of *Achillea millefolium* is greatly reduced.

Light is of great importance for the production of food reserves in orchids as well as it has a formative effect on stem and leaves where strong and healthy tissues are produced.

P. insigne and *P. villosum* both are found mostly in shady places, on the forest floor, on decaying organic matter in rock crevices and sometimes by the side of the rocks. Therefore, an experiment was set up to investigate the effect of light intensity on the growth behaviour of these two species. The experiments were conducted over a period of one year, under controlled conditions and results are discussed in this chapter.

MATERIALS AND METHODS

The experiment was carried out in two unheated and uncovered net houses of 3m height and 3m x 5m area. The net houses were constructed under the shade of trees where mean annual light intensity was about 15800 lux in one net house and in the other it was about 8300 lux at midday sun. The former was considered as lighted habitat and the latter as the shaded condition. Since neither of the two species grow in open, in their natural habitats, experiment was not conducted in direct or full sunlight, where annual mean light intensity was about 20,000 lux (Fig. 8.1). The experimental design was 2 light regimes x 2 species x 4 replicates and 1 harvest. The experimental pots were filled with garden soil and the plant with at least one offshoot was planted in each pot during December 1988. During dry season, watering was done in all the pots at fortnightly intervals.

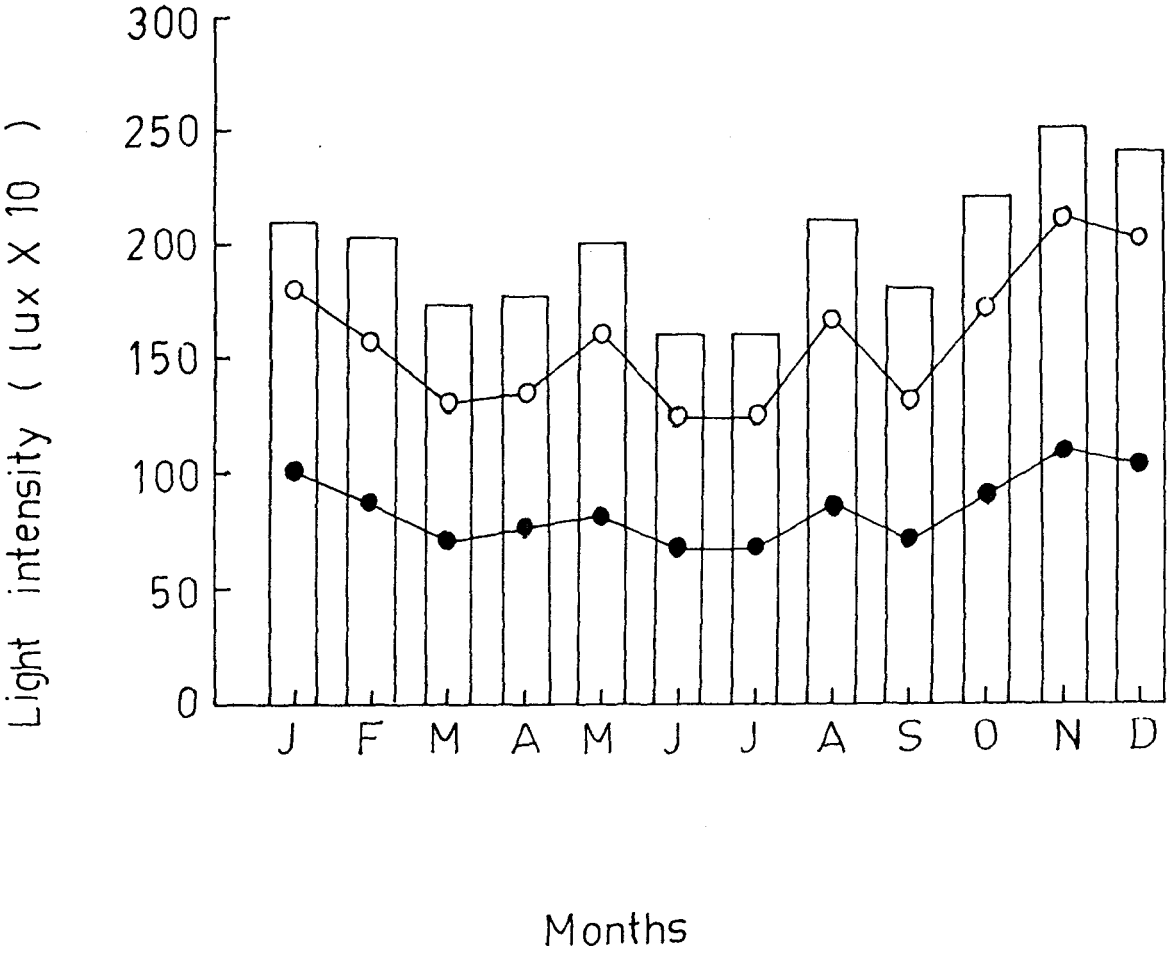


Fig. 8.1 Light intensity data during the study period (Jan-Dec 1988). □ open; —o— lighted condition; —●— shaded condition.

All possible morphological growth parameters, e.g. length of the plant, leaf number, offshoot number, leaf length and leaf area etc. were measured. Later on, monthly measurements were taken for all morphological growth parameter of shoot for a period of one year. Time of flower initiation, flowering period, length of the floral stalk and duration of flower were recorded.

RESULTS

Plant length

Both the species of *Paphiopedilum* showed higher plant length under lighted environment as compared to the shaded condition. Annual increase in length under lighted condition was greater in *P. insigne* than in *P. villosum* (Fig. 8.2).

Root number

Number of roots in both the species was found to be more under high light intensity than under low light. In both light regimes, *P. insigne* showed better growth than *P. villosum*. However, in lighted condition, the increase in root number in case of *P. insigne* was almost twice that in the shaded condition. The increase in root number in *P. villosum* from low to high light regime was only marginal (Fig. 8.3).

Root length

Like root number, growth in root length was also favoured by lighted condition in both the species. However, *P. insigne* showed better growth than *P. villosum* (Fig. 8.4).

Offshoot number

Low light intensity markedly reduced offshoot production

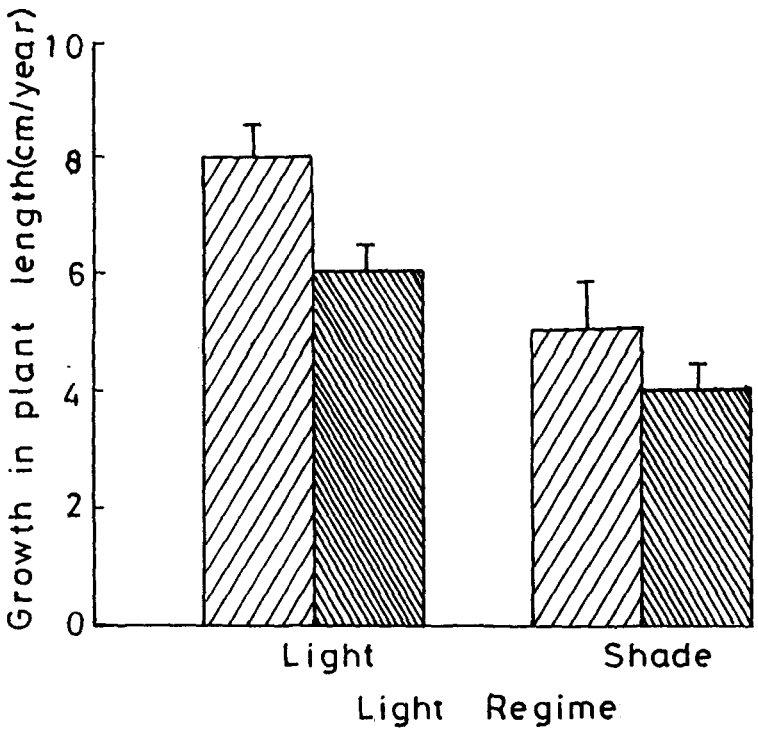


Fig. 8.2. Effect of light regime on the growth of two species of *Paphiopedilum* during one year period, ▨ *P. insigne*; ▨ *P. villosum*.

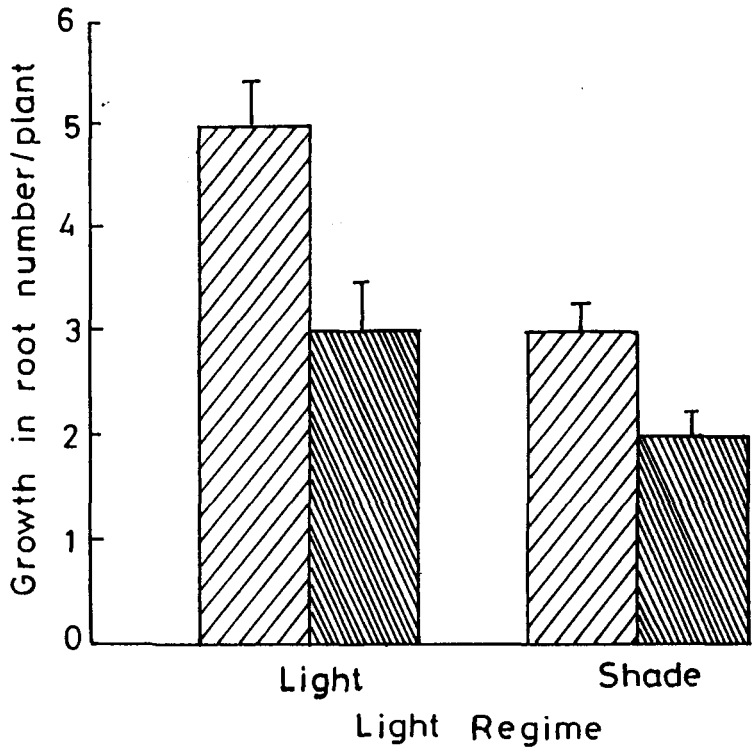


Fig. 8.3. Effect of light regime on root number of *P. insigne* and *P. villosum*. ▨ *P. insigne*; ▩ *P. villosum*.

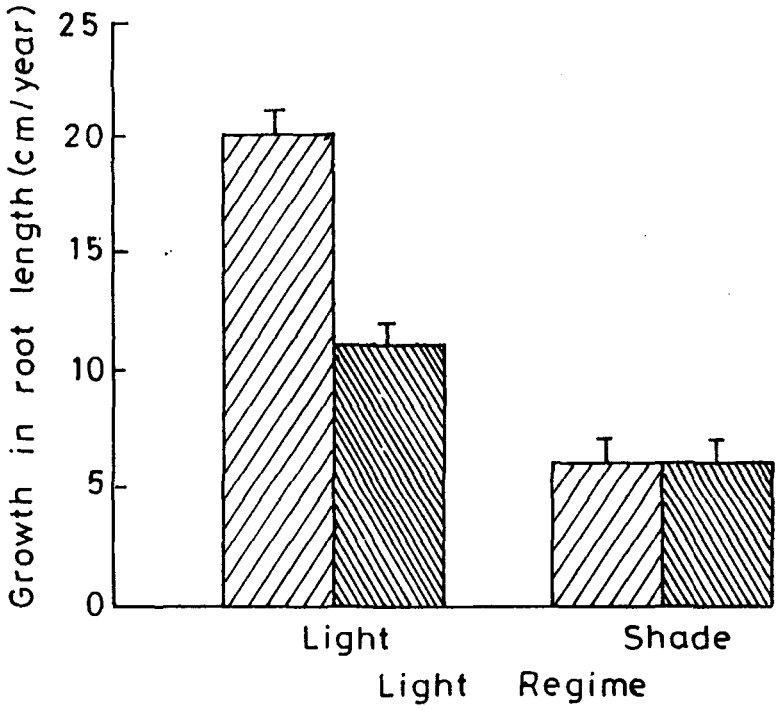


Fig. 8.4 Effect of light regime on the root length of *Paphiopedilum* species. ▨ *P. insigne*; ▩ *P. villosum*.

which was completely inhibited in case of *P. villosum*. Increase in light intensity had a marked positive effect on offshoot production in both the species (Table 8.1).

Leaf number

Leaf production significantly increased ($P<0.01$) in lighted condition as compared to shaded one in both the species. In both the species it was equally suppressed under shaded condition (Table 8.2).

Leaf length

Under relatively high light intensity leaf length increased almost linearly upto 210 days in both the species. Beyond this it stabilized in case of *P. insigne* but it continued to increase till the end of experiment in *P. villosum*. Both the species showed a slow increase in leaf length in shade as compared to lighted condition, but the trend was similar in both the species. The peak value in shade was significantly lower than the corresponding value under lighted condition (Fig. 8.5).

Leaf area

Effect of light intensity on leaf area was more prominent than leaf length. In light it increased almost in linear fashion till the end of the experiment in *P. villosum*. In *P. insigne* the increase was relatively slow and after 210 days of planting, it remained almost unchanged. In shade the trend in temporal variation in leaf area was similar to that of the light condition but the values were significantly lower than the lighted habitat (Fig. 8.6).

Flower

Flower production was strongly affected by low light

Table 8.1 . Effect of light intensity on the growth of offshoot (number/plant ± SEM) in *P. insigne* (Pi) and *P. villosum* (Pv).

Month	Species	Light condition	
		Light	Shade
January	Pi	1.33±0.27	1.00±0.00
	Pv	1.00±0.00	1.00±0.00
February	Pi	1.33±0.27	1.00±0.00
	Pv	1.00±0.00	1.00±0.00
March	Pi	1.33±0.27	1.00±0.00
	Pv	1.33±0.27	1.00±0.00
April	Pi	1.33±0.27	1.00±0.00
	Pv	1.33±0.27	1.00±0.00
May	Pi	1.66±0.30	1.33±0.30
	Pv	1.66±0.30	1.00±0.00
June	Pi	2.00±0.00	1.33±0.30
	Pv	2.00±0.00	1.00±0.00
July	Pi	2.00±0.00	1.33±0.30
	Pv	2.00±0.00	1.00±0.00
August	Pi	2.00±0.00	1.33±0.30
	Pv	2.00±0.00	1.00±0.00
September	Pi	3.00±0.47	1.33±0.30
	Pv	2.66±0.27	1.00±0.00
October	Pi	3.00±0.47	1.33±0.30
	Pv	2.66±0.27	1.00±0.00

Table 8.1 (contd.)

Month	Species	Light condition	
		Light	Shade
November	Pi	3.00±0.47	1.33±0.30
	Pv	2.66±0.27	1.00±0.00
December	Pi	3.00±0.47	1.33±0.30
	Pv	2.66±0.27	1.00±0.00

Analysis of variance

Source of Variation	Significance level
Light	P <0.01
Time	P <0.01
Species	NS
Light x Time	P <0.01
Light x Species	NS
Time x Species	NS

Table 8.2 . Effect of light intensity on the leaf growth (leaf number/plant ± SEM) in *P. insigne* (Pi) and *P. villosum* (Pv).

Month	Species	Light condition	
		Light	Shade
January	Pi	5.33±0.30	4.33±0.30
	Pv	4.33±0.30	4.66±0.30
February	Pi	5.33±0.30	4.33±0.30
	Pv	4.33±0.30	4.66±0.30
March	Pi	6.33±0.12	4.33±0.30
	Pv	5.33±0.30	4.66±0.30
April	Pi	7.00±0.50	4.33±0.30
	Pv	6.00±0.94	4.66±0.30
May	Pi	7.66±0.72	4.33±0.30
	Pv	7.33±0.98	5.00±0.00
June	Pi	8.33±0.30	4.66±0.30
	Pv	8.00±1.24	5.00±0.00
July	Pi	8.33±0.30	4.66±0.30
	Pv	8.00±1.24	5.00±0.00
August	Pi	8.33±0.30	5.00±0.00
	Pv	8.00±1.24	5.66±0.13
September	Pi	10.66±1.08	5.00±0.00
	Pv	10.33±1.80	5.66±0.13
October	Pi	10.66±1.08	5.33±0.33
	Pv	10.33±1.80	5.66±0.13

Table 8.2 (contd).

Month	Species	Light condition	
		Light	Shade
November	Pi	10.66±1.08	5.33±0.33
	Pv	10.33±1.80	5.33±0.33
December	Pi	10.66±1.08	5.33±0.33
	Pv	10.33±1.80	5.66±0.13

Analysis of variance

Source of Variation	Significance level
Light	P <0.01
Time	P <0.01
Species	P <0.05
Light x Time	P <0.01
Light x Species	P <0.01
Time x Species	NS

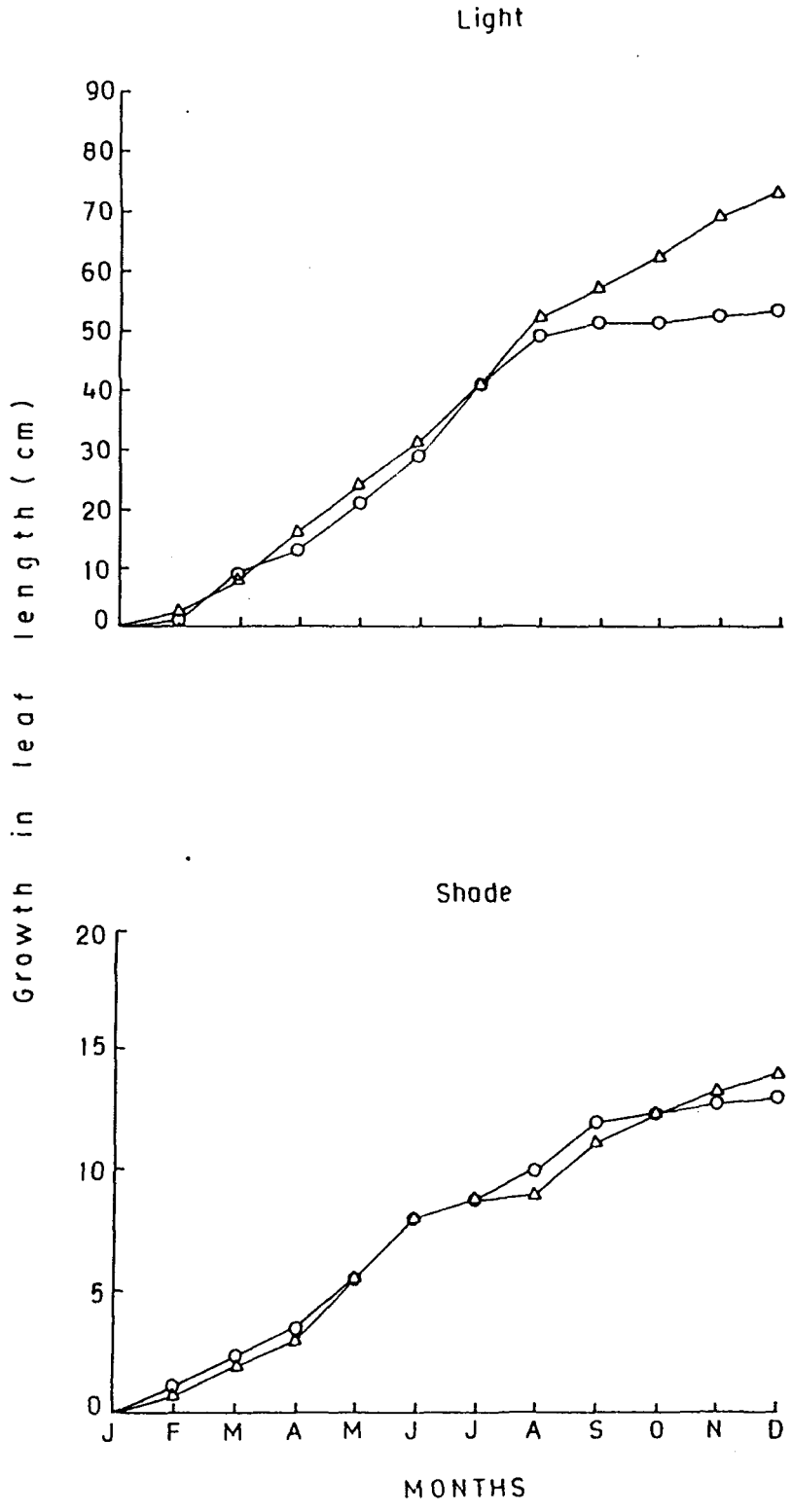


Fig. 8.5 Effect of light regime on the growth of leaf length of *P. insigne* and *P. villosum* under lighted and shaded conditions.—○— *P. insigne*;—△— *P. villosum*.

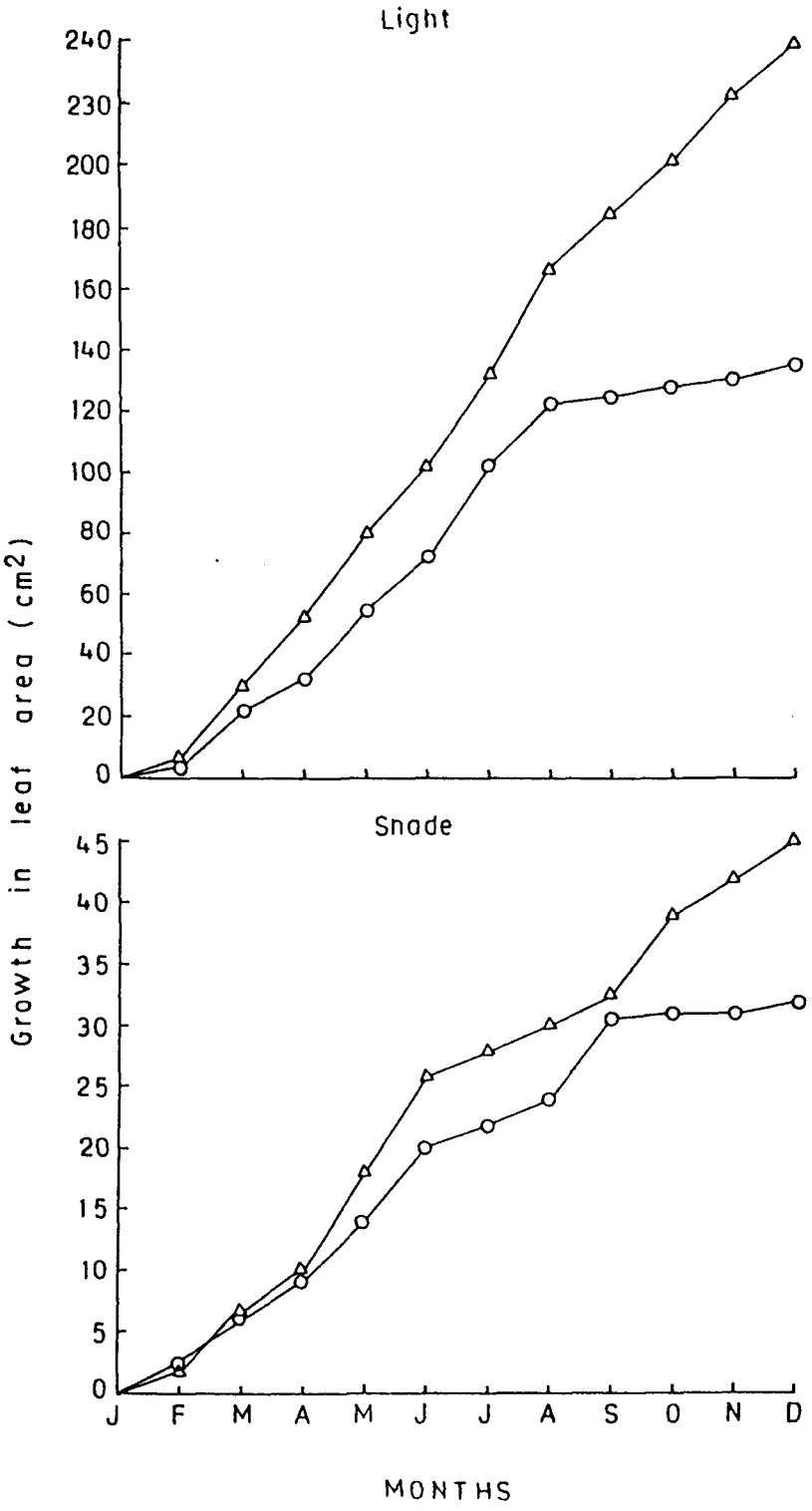


Fig. 8.6 Effect of light intensity on leaf area of *P. insigne* and *P. villosum* under lighted and shaded condition.—o— *P. insigne*. —Δ— *P. villosum*.

intensity where in both the species it was completely inhibited. However, the flower and floral stalk development was normal in the lighted condition (Table 8.3).

Root/Shoot ratio (total root length/total leaf length)

Root/shoot ratio of *P. insigne* was more than *P. villosum* in both the light regimes. Higher ratio in both the species was observed under shaded condition, indicating relatively better root development under low light intensity. This was true particularly in case of *P. insigne* (Fig. 8.7).

DISCUSSSION

The growth and development of *P. insigne* and *P. villosum* was strongly influenced by light intensity although both of them were able to grow and survive under varying light regimes. Better growth of both the species under lighted condition is in agreement with Solangaarachchi and Harper's observation (1987) on clover growth which showed significant difference between open and shaded treatment.

Despite the fact that the plant of both the species are found growing in shady places, results show that their growth is hampered when light intensity is reduced to the level of approximately 8300 lux. This finding conforms the observation of Skuterud (1984) on *Elymus repens*. He reported that a 50 % reduction in full day light intensity caused a decline in the weight of new rhizomes, and 12.5% decline caused complete absence of rhizome production. A decrease in the light intensity below 50% of full day light caused reduction in the weight of aerial

Table 8.3 . Effect of light intensity on the growth of floral stalk of *P. insigne* (Pi) and *P. villosum* (Pv).

Month	Species	Light condition	
		Light	Shade
August	Pi	12.50±0.65	-
	Pv	9.25±0.47	-
September	Pi	20.50±0.64	-
	Pv	18.25±0.63	-
October	Pi	24.00±0.40	-
	Pv	20.75±0.85	-
November	Pi	28.00±0.41	-
	Pv	26.25±0.75	-
December	Pi	28.00±0.41	-
	Pv	26.25±0.45	-

- Did not develop flower.

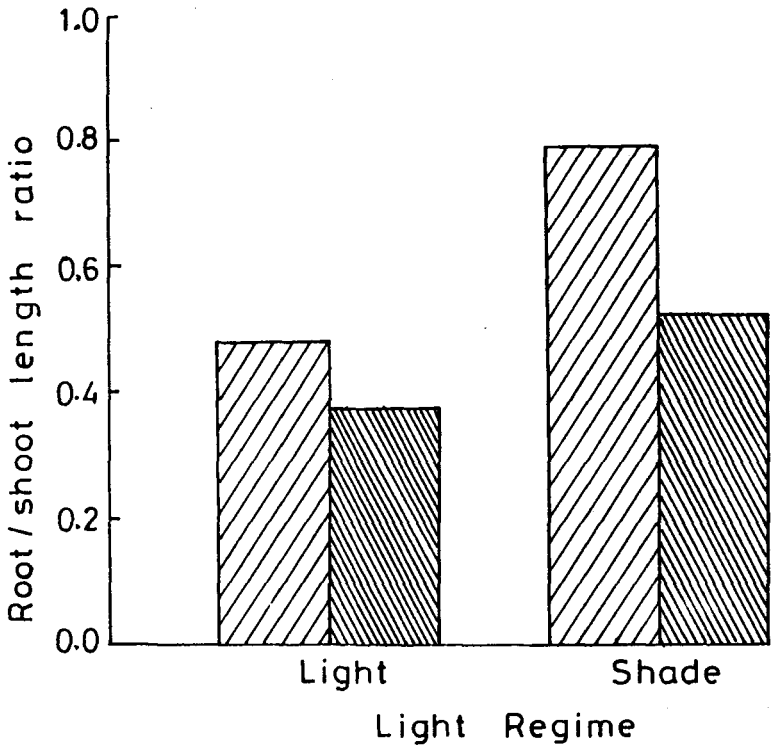


Fig. 8.7 Root/Shoot ratio (Total root length/Total leaf length) of *P. insigne* (▨) and *P. villosum* (▩) as affected by two light regimes.

parts of *E. repens*. Shading is also found to reduce the dry weight of *Crotalaria juncea* L. and *Crotalaria sericea* Retz. and a reduction in light intensity from 100% to 80% showed a 2/3 reduction in leaf area of *C. juncea* as compared to *C. sericea* (Pandey and Sinha 1977). Increased light intensity caused an increase in leaf thickness and the amount of mesophyll tissues, whereas in low light, leaves were very thin in *Fragaria vesca* (Chabot and Chabot 1977). Greater offshoot and leaf production and higher leaf area in *P. insigne* compared to *P. villosum* in both light regimes show a relatively broad range of tolerance for light intensity of the former species than the latter. However, for both of them relatively higher light intensity was more favourable for shoot growth. It is evident from higher root/shoot ratio in shade that plants allocated more photosynthate towards below ground parts under low light intensity. White clover when grown under dense shade showed a decline in photosynthetic capacity and even shortening of life span (Woledge 1986). Evans and Hughes (1960), Packham and Willis (1982), Westoby and Howell (1982), Bourdot *et al.* (1984) and Zeiger *et al.* (1985), also showed that shading leads to the reduction in total dry weight.

The absence of flower production under low light, was notable feature of both the species. This conforms the findings of Clausen *et al.* (1940), Ashmun and Pitelka (1984) and Pitelka *et al.* (1985) on the ramets of *Aster acuminatus*, which produced more flowers under high light than under low light intensity. Though both the species are capable of reproducing vegetatively, there was a complete absence of offshoot production in *P.*

villosum in low light condition. Therefore in habitats where light intensity is about 15800 lux, these plants responded by better vegetative and sexual reproduction. This is supported by the work of Healy *et al.* (1982) on *Regina*. Thus the difference in growth behaviour of two species of *Paphiopedilum* under the two light regimes reflects the plastic response of plant to the varying light environment (Bradshaw 1965, Hickman 1975, Rice and Bazzaz 1989).

The study showed that the two *Paphiopedilum* species are better adapted to grow in lighted condition and their growth markedly reduced under low light condition. Of the two species, *P. insigne* seemed to be better adapted to varied light intensities than *P. villosum*.

Chapter 9

EFFECTS OF SOIL NUTRIENT LEVEL AND LIGHT INTENSITY

Nutrients availability in the soil that is required for the growth of plants, varies over time and space. The fluctuation in nutrient availability interfere with the growth and development of plants particularly on infertile soil, where growth rate is generally slow (Jones and Etherington 1970). A number of experiments have been carried out in which species from infertile soil were grown at different levels of nutrients, especially phosphorus and nitrogen. Findings of these studies show that low nutrient availability may affect plant growth in various ways (Bradshaw *et al.* 1960,1964, Hackett 1965, Clarkson 1967, Rorrison 1968, Veerkamp and Kuiper 1982b). The growth response of plants to nutrient concentration differ from one another depending on the nutrient requirements (Erdei *et al.* 1986). Davy and Bishops (1984), McGraw (1985), Heil and Bruggink (1987) reported that growth and reproduction of plants are strongly affected by nutrient level in their growth medium. Addition of phosphorus alone seemed to have no effect on the forbs, but in combination with nitrogen, it enhanced their aboveground production (McMaster *et al.* 1982). Addition of nitrogen alone may overcome apical dominance in *Agropyron repens* (McIntyre 1976), while potassium stress may lead to the death of *Carex acutiformis* (Veerkamp and Kuiper 1982b). Studies on the effect of nitrogen, phosphorus and potassium fertilizers on the growth and development of plants have been carried out by a large number of workers (Inam *et al.*

1982, Rao *et al.* 1983, Daniels 1986, Gupta and Govind 1986, Bornkamm and Raghi-atri 1986, Omaliko *et al.* 1987. Lamb and Klaussner 1988). Use efficiency of nitrogen and other nutrient elements has been studied by Elaine and Vitousek (1986), Patel and Singh (1986), Seemann *et al.* (1987) and Pandey and Dubey (1991).

Studies have been done on the combined effect of light intensity and nutrients on the growth performance of plants (Gulmon and Chu 1981, Peace and Grubb 1982, Jurik *et al.* 1982, Larsson *et al.* 1986, Daniels 1986, Nuemaier *et al.* 1987). Findings of Diepenbrock (1981) and Fernandes *et al.* (1985) suggested that light intensity along with temperature and nitrogen application affect plant metabolism. Combined effects of soil nitrogen and plant density on the growth and reproduction of *Spergula arvensis* and *Plantago major* were studied by Trivedi and Tripathi (1982a) whereas the effects of soil nitrogen, light intensity and plant density on *Eupatorium adenophorum* and *E. riparium* were discussed by Tripathi and Yadav (1982). Another study dealing with the combined effects of watering frequency, drought and supply of nutrients is that of Weerakoon and Lovett (1986). The effect of mineral nutrients other than nitrogen, phosphorus and potassium was studied by Heil *et al.* (1988) and Ashraf *et al.* (1989).

Works on the mineral nutrition of orchids are negligible. Nonetheless, some studies dealing with the effect of nitrogen, phosphorus and potassium on growth and flowering of orchid species have been carried out by Bhattacharjee (1981) and Yadav and Bose (1986). The effect of fertilizer on the growth of some

orchid species has been carried out by Katiyar *et al.* (1987) and Yoneda (1989). Analysis of plant parts of *Laelia* and *Cattleya* has been done by Carlucci *et al.* (1980).

Phaphiopedilum insigne and *Paphiopedilum villosum* are found growing mainly on the soil rich in organic matter under the shade of tree on the forest floor and sometimes in the rock crevices. Therefore, an experiment was designed to investigate the growth response of these species to the variable soil nutrient level and light regime under controlled conditions.

MATERIALS AND METHODS

The experiment was conducted in a transparent polythene roofed net house, whose four sides were covered upto 1m height with the polythene sheet to protect the potted plants from splashing rain water. The net house was partitioned into two parts with the help of bamboo sticks. The roof and all four sides of one part of the net house was covered with a white muslin cloth up to a height of 1.5m from the ground level. In the other part, the top was covered with black muslin cloth and the sides with white muslin cloth. In the compartment covered with black cloth mean annual light intensity was 9600 lux at midday sun. This was about 50% less than that portion of the net house which was covered with white cloth (Fig.9.1). The experimental design consisted of 5 nutrient treatments X 2 light regimes X 2 species X 4 replicates X 1 harvest. The plastic pots (21 cm diameter and 19cm depth containing garden soil and having a basal drainage hole) were used for the experiment. In each of

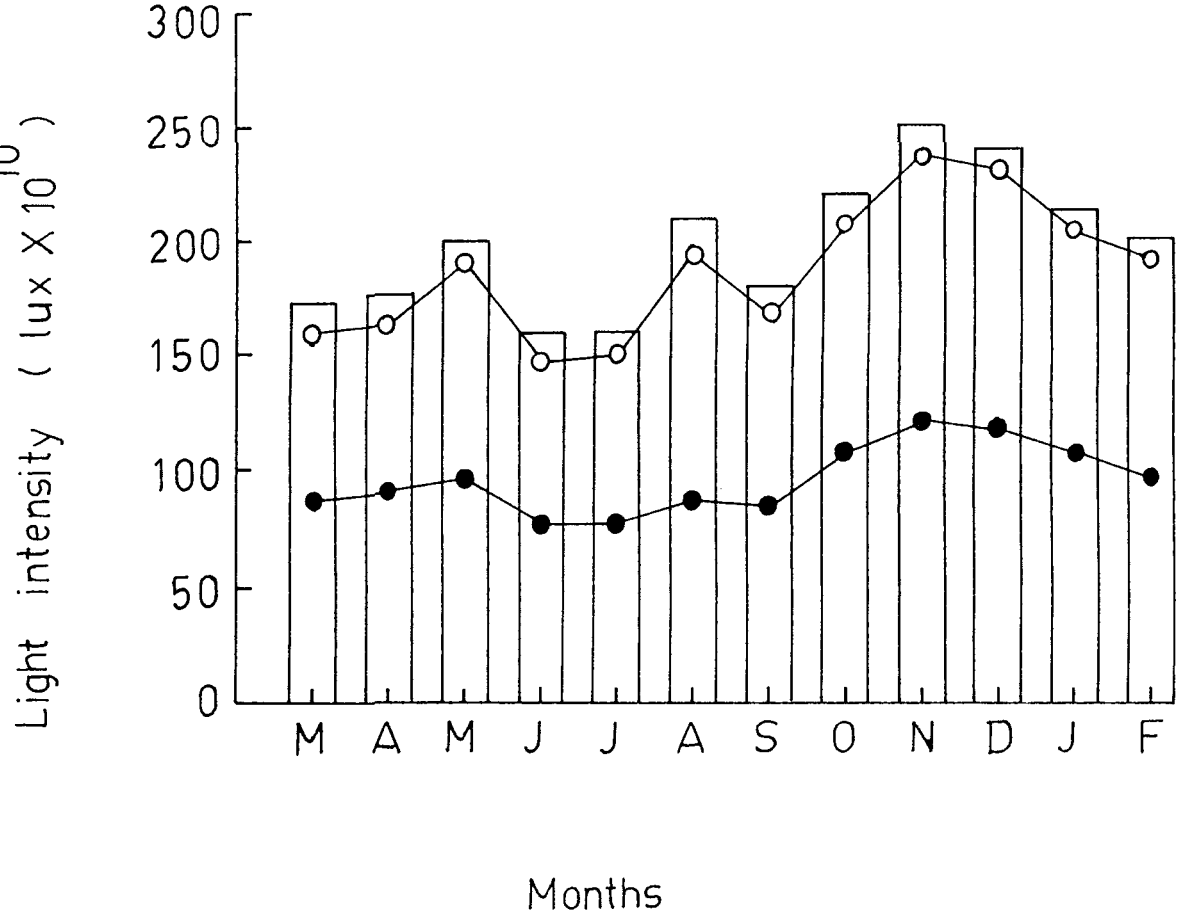


Fig. 9.1 light intensity data during the study period (March 1988- February 1989). □ open,—o— lighted,—●— shaded condition.

the two light regimes, the following five nutrient levels were maintained:

Treatment 1. Control (C) - No nutrient was added.
Treatment 2. (+ N) - 0.2g per pot Ammoniun Nitrate was added.
Treatment 3. (+ P) - 0.2g per pot Super Phosphate was added.
Treatment 4. (+ K) - 0.2g per pot Potassium Chloride was added.
Treatment 5. (N+P+K) - 0.2g each of the above mentioned nutrients per pot were added together.

Each fertilizer was added as surface dressing (Daniels 1986)

The details of planting materials and growth parameters studied are similar to those described in the previous chapters.

RESULTS

Addition of nutrient and light intensity both influenced the growth performance of *P. insigne* and *P. villosum*.

Plant length

Addition of nitrogen to the potting medium had a marked effect on plant length both in light and shade condition as compared to the addition of phosphorus and potassium alone or nitrogen, phosphorus and potassium together and control (Fig. 9.2a). The values were higher in the former than in the latter (Fig. 9.2b).

Root number

Relatively higher light intensity favoured root growth in terms of number, both in. *P. insigne*, and *P. villosum*. Addition

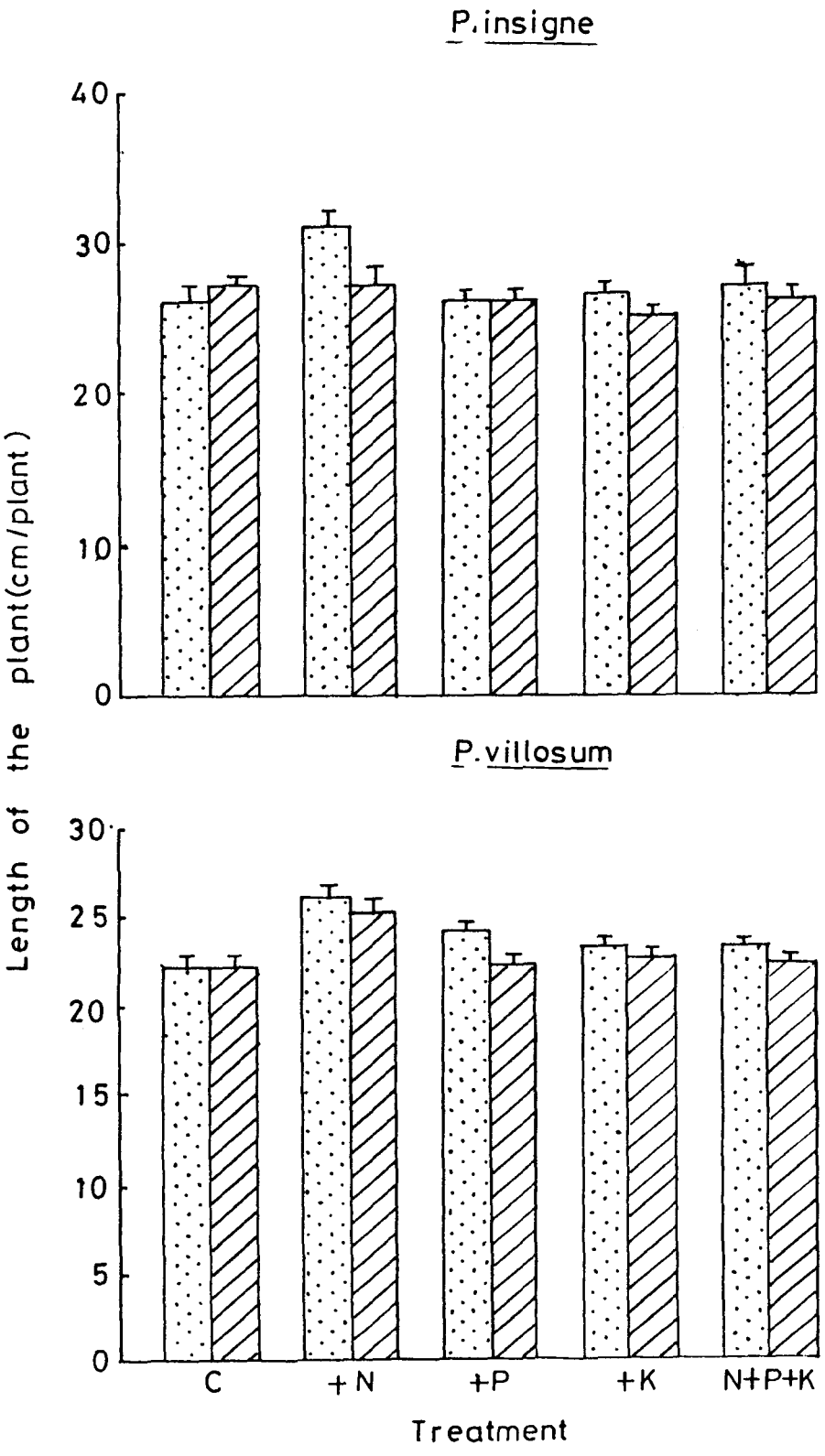


Fig. 9.2a Effect of soil amendment (addition of nutrient) and light conditions (light; shade) on the increase in plant length. C - Control

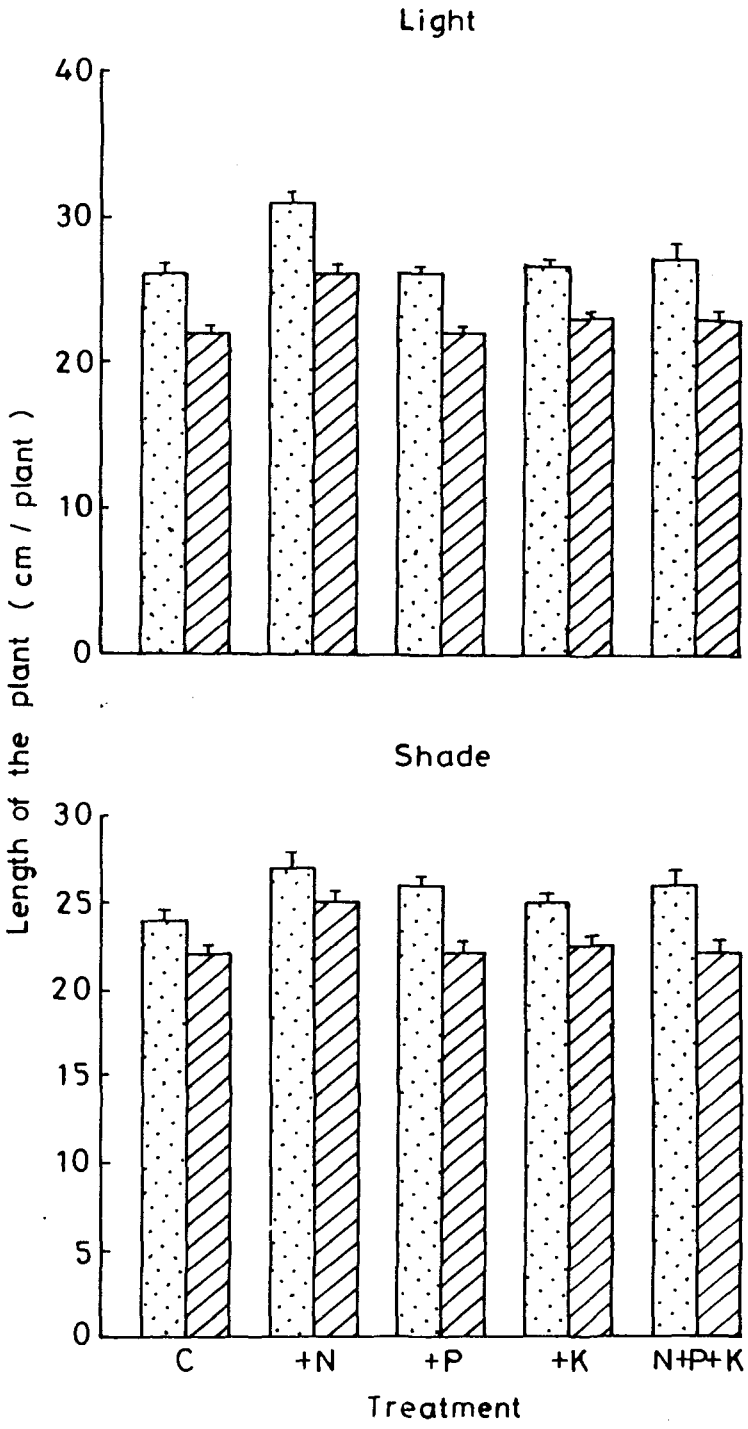


Fig. 9.2b Effect of soil amendment (addition of nutrient) and light conditions on the increase in plant length of *P. insigne* (⊡) and *P. villosum* (▨). C - Control

of nitrogen, phosphorus and potassium together produced best result both under light and shade. However, the increase was higher in case of *P. insigne* than *P. villosum* (Fig.9.3a). Phosphorus application has a suppressing effect on root number in both the species as compared to other nutrient treatments particularly, in lighted condition, whereas in shade addition of nitrogen caused a marked decline in the root number (Fig.9.3b).

Root length

Nitrogen application favoured the root growth of *P. insigne* and *P. villosum* in both the light regimes. Addition of P and K alone and NPK together had a suppressing effect on *P. insigne*. In case of *P. villosum* addition of nutrients other than N did not show any marked change in root length. Response of *P. insigne* to nutrient amendment was better under light than in the shade. Such a trend was not seen in case of *P. villosum* (Fig. 9.4).

Offshoot

P. insigne showed higher offshoot production under nitrogen treatment in light, but in shade, response was better with potassium application. Lighted condition significantly ($P < 0.05$) increased offshoot formation in *P. villosum* under all the nutrient treatments. But in shade new offshoots were formed only in phosphorus and potassium treatments. Timing of new offshoot formation was neither altered by nutrient addition to soil nor by the change in the light intensity (Table 9.1).

Leaf number

Although new leaves formed in both light and shade, K application significantly increased ($P < 0.05$) the leaf number under lighted condition while the increase was significantly

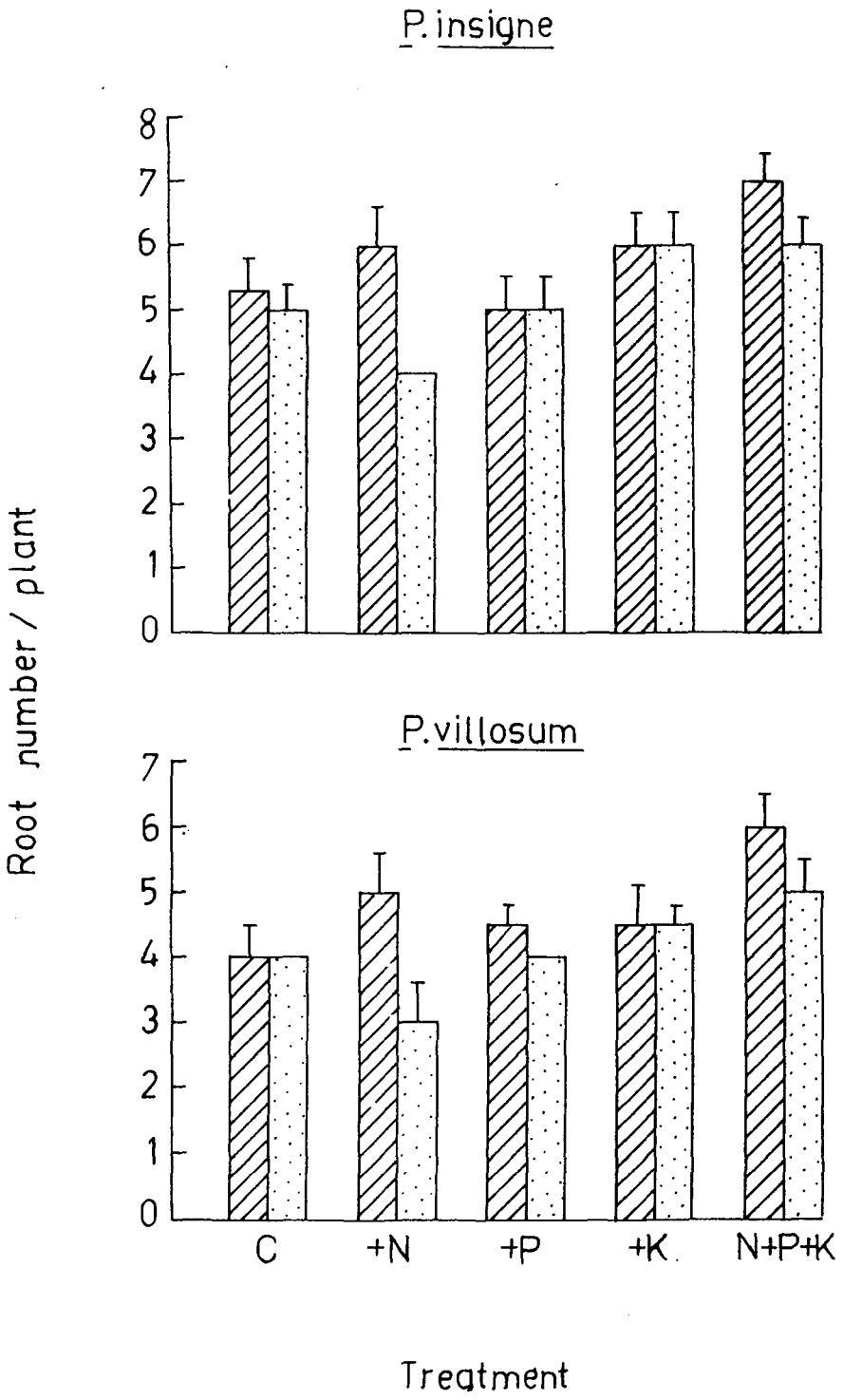


Fig. 9.3a Effect of soil amendment (addition of nutrient) and light conditions (▨ light; ⁘ shade) on the increase in root number of *P. insigne* and *P. villosum*. C - Control

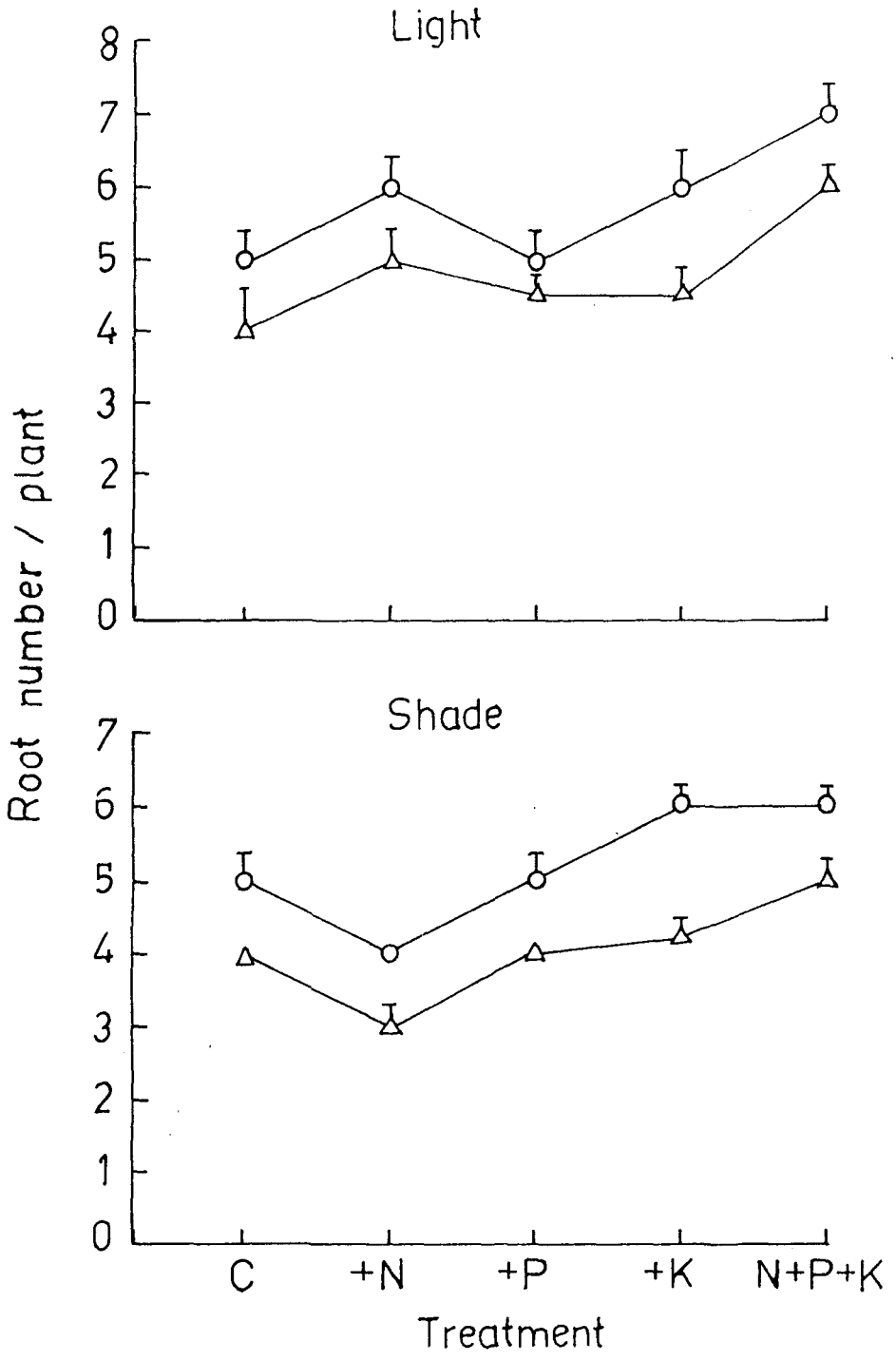


Fig. 9.3b Effect of soil amendment (addition of nutrient) and light conditions on root number of *P. insigne* (—o—) and *P. villosum* (—△—). C - Control

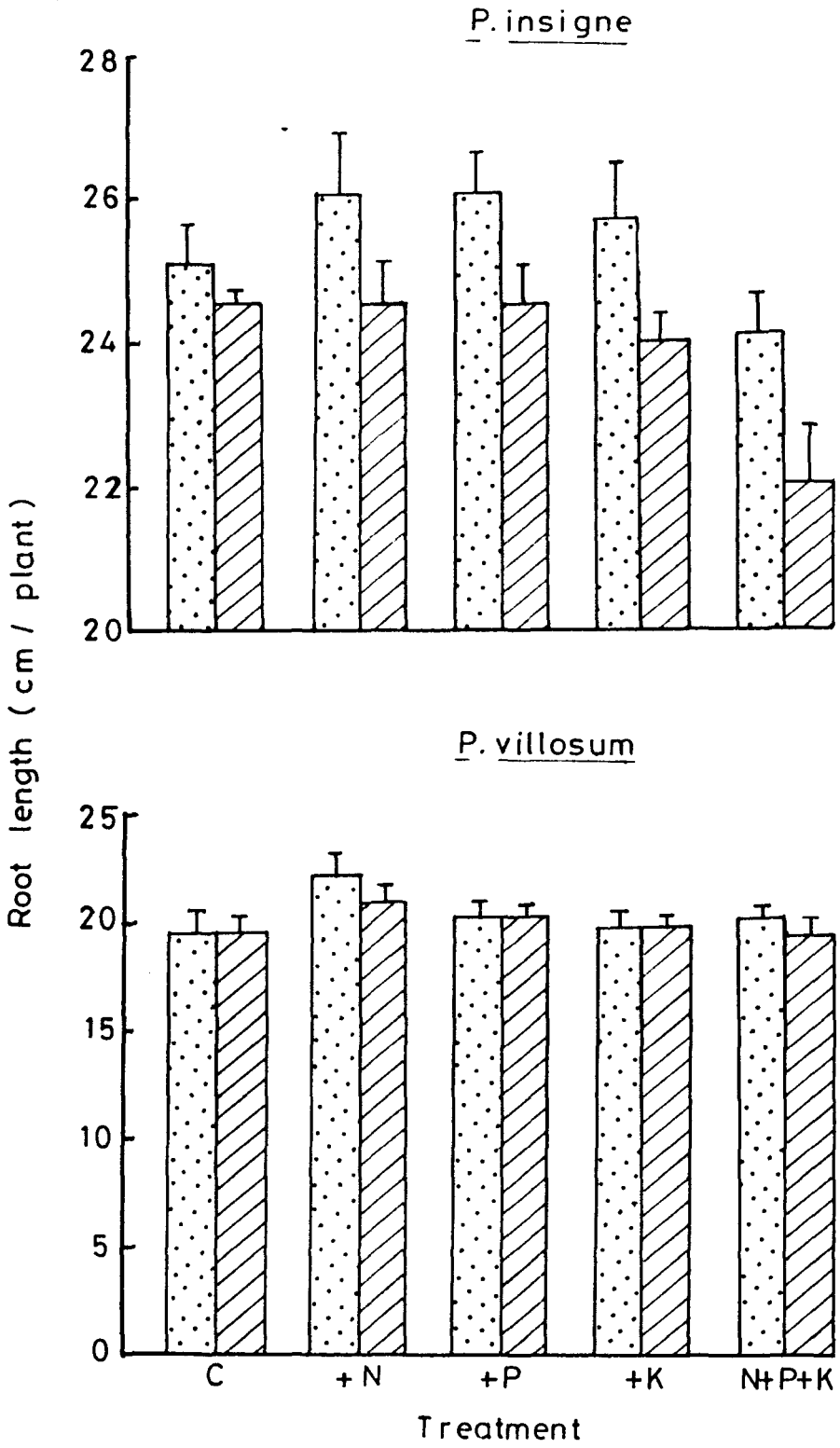


Fig. 9.4 Effect of soil amendment (addition of nutrient) and light conditions (⁘ light; ▨ shade) on the increase in root length of *P. insigne* and *P. villosum*. C - Control

Table 9.1 . Effect of soil nutrient amendment on the offshoot growth (number/plant ± SEM) of *P. insigne* (Pi) and *P. villosum* (Pv) under two light conditions.

Treatment	Condition	Species	MONTHS											
			M	A	M	J	J	A	S	O	N	D	J	F
Control	L	Pi	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	2.50 ±0.28	2.50 ±0.28	2.50 ±0.28	2.50 ±0.28	2.50 ±0.28	2.50 ±0.28
		Pv	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00
	S	Pi	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00
		Pv	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.50 ±0.28	1.50 ±0.28	1.50 ±0.28	1.50 ±0.28	1.50 ±0.28	1.50 ±0.28
	L	Pi	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	2.00 ±0.57	2.00 ±0.57	2.00 ±0.57	2.00 ±0.57	2.00 ±0.57	2.00 ±0.57
		Pv	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.50 ±0.28	1.50 ±0.28	1.50 ±0.28	1.50 ±0.28	1.50 ±0.28	1.50 ±0.28
	S	Pi	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.50 ±0.28	1.50 ±0.28	1.50 ±0.28	1.50 ±0.28	1.50 ±0.28	1.50 ±0.28
		Pv	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00

Table 9.1 (contd.)

Treatment	Condition	Species	MONTHS											
			M	A	M	J	J	A	S	O	N	D	J	F
		Pi	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00
	L													
		Pv	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.50 ±0.28	1.50 ±0.28	1.50 ±0.28	1.50 ±0.28	1.50 ±0.28	1.50 ±0.28
+P														
		Pi	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.50 ±0.28	1.50 ±0.28	1.50 ±0.28	1.50 ±0.28	1.50 ±0.28	1.50 ±0.28
	S													
		Pv	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.50 ±0.28	1.50 ±0.28	1.50 ±0.28	1.50 ±0.28	1.50 ±0.28	1.50 ±0.28
		Pi	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00
	L													
		Pv	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.50 ±0.28	1.50 ±0.28	1.50 ±0.28	1.50 ±0.28	1.50 ±0.28	1.50 ±0.28
+K														
		Pi	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	2.00 ±0.57	2.00 ±0.57	2.00 ±0.57	2.50 ±0.86	2.50 ±0.86	2.50 ±0.86
	S													
		Pv	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.50 ±0.28	1.50 ±0.28	1.50 ±0.28	1.50 ±0.28	1.50 ±0.28	1.50 ±0.28

Table 9.1 (contd.)

Treat- ment	Condi- tion	Species	MONTHS M	A	M	J	J	A	S	O	N	D	J	F
			±0.00	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00
	L													
		Pv	1.00	1.00	1.00	1.00	1.00	1.00	1.50	1.50	1.50	1.50	1.50	1.50
			±0.00	±0.00	±0.00	±0.00	±0.00	±0.00	±0.28	±0.28	±0.28	±0.28	±0.28	±0.28
N+P+K														
		Pi	1.00	1.00	1.00	1.00	1.00	1.00	2.00	2.00	2.00	2.00	2.00	2.00
			±0.00	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00
	S													
		Pv	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
			±0.00	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00

C - Control; L - Light; S - Shade.

Analysis of variance

Source of variation		Significance level	
		Light	Shade
Nutrient	-	P <0.05	P <0.05
Time	-	P <0.05	P <0.05
Species	-	P <0.05	P <0.05
Nutrient x Time	-	NS	NS
Nutrient x Species	-	P <0.05	P <0.05

higher in the shade under N application. The rest of the treatments had little effect in this respect. The period of new leaf formation (June - December) was not influenced either by nutrient amendment or by change in light regime (Table 9.2).

Leaf length and leaf area

Growth in leaf length began from May and continued till the end of the experiment without any seasonal trend. Amongst all the nutrient treatments, N addition caused significant increase ($P < 0.05$) in length under both the light regimes (Table 9.3), the increase was, however, more in lighted than in shaded condition in both the species. Leaf area also followed a similar trend in both the species (Table 9.4).

Flower

Variation in light regime and application of nutrient did not influence flowering time which started with the initiation of flower buds in August. The length of floral stalk under different nutrient treatments showed a negligible variation from the control. The effect on the flower size was also indistinct in both the species (Table 9.5).

Root /shoot ratio (total root length /total shoot length)

Both the species showed minimum root/shoot ratio under nitrogen application, in both the light regimes (Fig. 9.5a). The ratio was higher in *P. insigne* than *P. villosum*. (Fig. 9.5b).

DISCUSSION

From the results obtained , it is clear that both the species of *Paphiopedilum* were benefited by nitrogen application

Table 9.2 . Effect of nutrient amendment on leaf growth (leaf number/plant ± SEM) in *P. insigne* (Pi) and *P. villosum* (Pv) under two light regimes.

Treatment	Condition	Species	MONTHS M	A	M	J	J	A	S	O	N	D	J	F
Control	L	Pi	3.50 ±0.28	3.50 ±0.28	3.50 ±0.28	4.00 ±0.40	4.00 ±0.40	4.50 ±0.28	4.50 ±0.28	5.00 ±0.40	5.00 ±0.40	5.00 ±0.40	5.00 ±0.40	5.00 ±0.40
		Pv	3.00 ±0.00	3.00 ±0.00	3.00 ±0.00	3.00 ±0.00	3.25 ±0.25	3.25 ±0.25	3.75 ±0.47	3.75 ±0.47	3.75 ±0.47	3.75 ±0.47	3.75 ±0.47	3.75 ±0.47
	S	Pi	3.00 ±0.00	3.00 ±0.00	3.00 ±0.00	3.50 ±0.28	3.50 ±0.28	3.50 ±0.28	3.50 ±0.28	3.75 ±0.25	3.75 ±0.25	3.75 ±0.25	3.75 ±0.25	3.75 ±0.25
		Pv	3.00 ±0.00	3.00 ±0.00	3.00 ±0.00	3.50 ±0.50	3.50 ±0.50	3.50 ±0.50	3.50 ±0.50	3.50 ±0.50	3.50 ±0.50	3.75 ±0.47	3.75 ±0.47	3.75 ±0.47
	L	Pi	3.00 ±0.00	3.00 ±0.00	3.00 ±0.00	3.50 ±0.28	3.50 ±0.28	4.00 ±0.00	4.00 ±0.00	4.00 ±0.00	4.75 ±0.25	5.50 ±0.50	5.50 ±0.50	5.50 ±0.50
		Pv	3.50 ±0.28	3.50 ±0.28	3.50 ±0.28	4.00 ±0.40	4.00 ±0.40	4.00 ±0.40	5.00 ±0.40	5.00 ±0.40	5.00 ±0.40	5.00 ±0.40	5.00 ±0.40	5.00 ±0.40
	S	Pi	3.00 ±0.00	3.00 ±0.00	3.00 ±0.00	3.50 ±0.28	4.00 ±0.00	4.00 ±0.00	5.00 ±0.40	5.00 ±0.40	5.00 ±0.40	5.00 ±0.40	5.00 ±0.40	5.00 ±0.40
		Pv	3.00 ±0.00	3.00 ±0.00	3.00 ±0.00	3.75 ±0.25	4.25 ±0.25	4.75 ±0.47	4.75 ±0.47	5.00 ±0.57	5.00 ±0.57	5.00 ±0.57	5.00 ±0.57	5.00 ±0.57

Table 9.2 (contd.)

Treatment	Condition	Species	MONTHS M	A	M	J	J	A	S	O	N	D	J	F
		Pi	3.50 ±0.28	3.50 ±0.28	3.50 ±0.28	4.00 ±0.40	4.00 ±0.40	4.50 ±0.28	4.50 ±0.40	5.00 ±0.40	5.00 ±0.40	5.00 ±0.40	5.00 ±0.40	5.00 ±0.40
	L													
		Pv	3.00 ±0.00	3.00 ±0.00	3.00 ±0.00	3.00 ±0.00	3.50 ±0.28	3.50 ±0.28	4.00 ±0.57	4.00 ±0.57	4.00 ±0.57	4.00 ±0.57	4.00 ±0.57	4.00 ±0.57
+P														
		Pi	3.50 ±0.28	3.50 ±0.28	3.50 ±0.28	3.50 ±0.28	3.75 ±0.25	3.75 ±0.25	4.00 ±0.00	4.00 ±0.00	4.00 ±0.00	4.00 ±0.00	4.00 ±0.00	4.00 ±0.00
	S													
		Pv	3.00 ±0.00	3.00 ±0.00	3.00 ±0.00	3.50 ±0.05	4.00 ±0.00	4.00 ±0.00	4.00 ±0.00	4.00 ±0.00	4.00 ±0.00	4.00 ±0.00	4.00 ±0.00	4.00 ±0.00
		Pi	3.50 ±0.28	3.50 ±0.28	3.50 ±0.28	4.00 ±0.00	4.00 ±0.00	4.75 ±0.25	4.75 ±0.25	5.25 ±0.47	6.00 ±0.40	6.50 ±0.28	6.50 ±0.28	6.50 ±0.28
	L													
		Pv	3.00 ±0.00	3.00 ±0.00	3.00 ±0.00	3.50 ±0.50	3.50 ±0.50	4.25 ±0.25	4.25 ±0.25	4.50 ±0.28	4.50 ±0.28	5.00 ±0.57	5.00 ±0.57	5.50 ±0.28
+K														
		Pi	3.50 ±0.28	3.50 ±0.28	3.50 ±0.28	4.25 ±0.25	4.25 ±0.25	4.25 ±0.25	4.75 ±0.25	4.75 ±0.25	4.75 ±0.25	4.75 ±0.25	4.75 ±0.25	4.75 ±0.25
	S													
		Pv	3.00 ±0.00	3.00 ±0.00	3.00 ±0.00	3.75 ±0.25	4.50 ±0.28	4.50 ±0.28	4.75 ±0.47	4.75 ±0.47	5.00 ±0.57	5.00 ±0.57	5.00 ±0.57	5.00 ±0.57

Table 9.2 (contd.)

Treatment	Condition	Species	MONTHS M	A	M	J	J	A	S	O	N	D	J	F
N+P+K	L	Pi	3.50 ±0.28	3.50 ±0.28	3.50 ±0.28	3.50 ±0.28	3.75 ±0.25	3.75 ±0.25	4.00 ±0.25	4.00 ±0.00	4.00 ±0.00	4.00 ±0.00	4.00 ±0.00	4.00 ±0.00
		Pv	3.00 ±0.00	3.00 ±0.00	3.00 ±0.00	3.25 ±0.25	3.25 ±0.25	3.25 ±0.25	4.00 ±0.40	4.00 ±0.40	4.50 ±0.40	4.50 ±0.40	4.50 ±0.40	4.50 ±0.40
	S	Pi	3.25 ±0.25	3.25 ±0.25	3.25 ±0.25	3.50 ±0.25	3.50 ±0.25	3.50 ±0.25	4.25 ±0.47	4.50 ±0.28	4.50 ±0.28	4.50 ±0.28	4.50 ±0.28	4.50 ±0.28
		Pv	3.50 ±0.28	3.50 ±0.28	3.50 ±0.28	3.50 ±0.28	4.00 ±0.40	4.00 ±0.40	4.00 ±0.40	4.00 ±0.40	4.00 ±0.40	4.00 ±0.40	4.00 ±0.40	4.00 ±0.40

Analysis of variance

Source of variation		Significance level	
		Light	Shade
Nutrient	-	P <0.05	P <0.05
Time	-	P <0.05	P <0.05
Species	-	P <0.05	NS
Nutrient x Time	-	P <0.05	P <0.05
Nutrient x Species	-	P <0.05	NS

Table 9.3 . Effect of nutrient amendment on leaf length (cm/plant ± SEM) in *P. insigne* (Pi) and *P. villosum* (Pv) in light and shade conditions.

Treatment	Condition	Species	MONTHS											
			M	A	M	J	J	A	S	O	N	D	J	F
Control	L	Pi	30.25 ±0.94	30.25 ±0.94	31.50 ±1.04	32.75 ±1.03	33.75 ±1.25	35.00 ±1.08	35.75 ±0.85	36.75 ±0.75	38.00 ±0.70	39.75 ±1.10	41.00 ±1.35	42.25 ±1.31
		Pv	32.25 ±1.03	32.25 ±1.03	33.00 ±0.91	34.25 ±1.03	35.00 ±0.91	35.75 ±0.75	37.00 ±0.91	38.00 ±1.15	39.25 ±0.75	40.25 ±0.75	41.00 ±0.57	41.75 ±1.03
	S	Pi	28.75 ±2.86	28.75 ±2.86	29.25 ±2.65	30.50 ±2.84	30.75 ±3.09	31.25 ±2.89	32.00 ±2.91	32.50 ±2.72	33.50 ±2.72	34.25 ±2.49	35.50 ±2.46	37.50 ±2.46
		Pv	32.50 ±1.04	32.50 ±1.04	33.75 ±0.62	35.25 ±0.75	36.00 ±1.08	37.25 ±1.18	37.75 ±0.94	38.75 ±0.94	39.50 ±1.04	40.75 ±1.10	42.25 ±0.85	43.50 ±1.32
+N	L	Pi	30.50 ±1.04	30.50 ±1.04	31.75 ±1.03	33.50 ±1.04	35.50 ±0.50	37.50 ±0.28	40.00 ±0.00	40.50 ±0.28	45.00 ±0.40	47.00 ±0.40	48.50 ±0.28	50.75 ±0.47
		Pv	32.25 ±0.85	32.25 ±0.85	34.00 ±0.81	36.25 ±0.47	38.75 ±0.62	41.50 ±0.64	43.50 ±1.04	46.50 ±1.25	48.50 ±1.04	50.75 ±1.10	53.25 ±1.37	55.00 ±1.29
	S	Pi	29.25 ±1.49	29.25 ±1.49	30.00 ±1.58	31.00 ±1.22	32.75 ±1.18	35.50 ±1.65	37.00 ±1.77	38.25 ±2.17	40.00 ±2.12	41.25 ±1.93	43.50 ±1.89	46.25 ±1.60
		Pv	32.00 ±1.29	32.00 ±1.29	34.00 ±1.08	36.50 ±0.95	39.00 ±1.08	42.00 ±1.22	44.00 ±1.08	45.50 ±0.50	47.25 ±0.62	47.50 ±1.10	50.75 ±0.85	52.50 ±1.04

Table 9.3 (contd.)

Treatment	Condition	Species	MONTHS											
			M	A	M	J	J	A	S	O	N	D	J	F
		Pi	30.50	30.50	32.50	34.50	36.00	36.75	38.75	40.25	41.50	43.00	44.50	46.00
			±1.32	±1.32	±1.65	±1.19	±1.08	±0.85	±0.85	±1.03	±0.95	±0.91	±1.19	±1.22
	L													
		Pv	32.25	32.25	33.75	35.50	36.75	38.75	41.50	43.50	45.75	47.75	49.50	50.50
			±0.85	±0.85	±0.85	±0.64	±1.43	±1.31	±1.19	±1.19	±1.45	±1.03	±1.04	±0.64
+P														
		Pi	29.50	29.50	30.50	31.75	32.75	34.00	34.50	36.50	38.75	40.50	42.00	43.75
			±1.32	±1.32	±1.32	±1.65	±1.79	±2.12	±2.21	±1.84	±1.10	±0.64	±0.91	±1.10
	S													
		Pv	32.50	32.50	34.25	36.25	38.00	39.50	40.50	41.50	43.00	44.50	46.50	48.00
			±0.64	±0.64	±0.94	±1.10	±1.22	±0.95	±0.64	±0.50	±0.70	±0.64	±0.64	±0.70
		Pi	30.00	30.00	31.75	33.75	35.00	36.25	37.25	38.25	39.75	40.50	43.00	44.25
			±0.91	±0.91	±0.62	±0.47	±0.91	±0.75	±1.10	±1.31	±1.37	±0.95	±1.15	±1.31
	L													
		Pv	32.25	32.25	33.50	35.25	37.00	38.50	39.50	41.00	42.50	44.25	46.50	47.75
			±1.03	±1.03	±0.91	±0.86	±0.86	±0.91	±0.64	±0.91	±1.04	±1.18	±1.04	±1.10
+K														
		Pi	29.75	29.75	30.50	31.50	32.50	32.75	33.50	35.00	36.25	37.25	38.75	40.25
			±0.43	±0.43	±1.93	±1.93	±1.55	±1.31	±1.25	±1.22	±1.25	±1.25	±1.43	±1.49
	S													
		Pv	32.50	32.50	34.50	35.50	37.00	38.50	39.75	41.50	42.25	43.50	45.00	46.50
			±0.86	±0.86	±0.64	±0.28	±0.41	±0.28	±0.62	±0.64	±0.62	±0.64	±0.57	±0.64

Table 9.3 (contd.)

Treatment	Condition	Species	MONTHS M	A	M	J	J	A	S	O	N	D	J	F
N+P+K	L	Pi	30.75 ±0.94	30.75 ±0.94	34.25 ±1.18	33.00 ±1.41	31.25 ±1.54	35.25 ±1.79	36.50 ±1.55	37.75 ±1.31	39.00 ±1.35	40.50 ±1.50	41.75 ±1.65	43.00 ±1.41
		Pv	31.25 ±1.10	31.25 ±1.10	32.25 ±1.31	33.25 ±1.31	34.75 ±0.85	36.00 ±0.70	36.75 ±0.85	38.00 ±0.70	38.75 ±0.75	39.50 ±0.64	41.00 ±0.57	42.00 ±0.91
	S	Pi	29.25 ±1.10	29.25 ±1.10	30.50 ±1.06	31.50 ±0.86	32.50 ±0.86	34.50 ±0.50	36.00 ±0.70	37.50 ±0.86	39.25 ±1.03	39.75 ±1.03	41.25 ±0.75	42.25 ±1.10
		Pv	32.25 ±1.93	32.25 ±1.93	33.75 ±1.88	35.25 ±1.60	36.50 ±1.50	38.00 ±1.22	39.00 ±1.29	40.50 ±1.04	41.50 ±1.19	42.00 ±1.47	43.50 ±1.75	45.00 ±2.04

Analysis of variance

Source of variation		Significance level Light	Shade
Nutrient	-	P <0.01	P <0.01
Time	-	P <0.01	P <0.01
Species	-	P <0.01	P <0.01
Nutrient x Time	-	P <0.01	P <0.01
Nutrient x Species	-	P <0.01	P <0.01

Table 9.4 . Effect of nutrient amendment on leaf area (cm^2/plant ± SEM) of *P. insigne* (Pi) and *P. villosum* (Pv) in light and shade conditions.

Treatment	Condition	Species	MONTHS											
			M	A	M	J	J	A	S	O	N	D	J	F
Control	L	Pi	70.66 ±2.83	70.66 ±2.37	73.79 ±2.61	76.93 ±2.58	79.44 ±3.13	82.58 ±2.71	84.46 ±2.14	86.97 ±1.88	90.11 ±1.77	94.50 ±2.78	97.64 ±3.39	100.78 ±3.30
		Pv	93.15 ±3.33	93.15 ±3.33	95.58 ±2.95	99.63 ±3.33	102.06 ±2.95	104.50 ±2.43	108.47 ±2.98	111.64 ±3.81	115.83 ±3.33	119.07 ±2.43	121.50 ±1.87	123.93 ±3.33
	S	Pi	67.52 ±8.87	67.52 ±8.87	68.14 ±6.67	70.86 ±8.90	71.91 ±7.76	73.16 ±7.27	75.05 ±7.31	76.30 ±6.83	78.80 ±6.83	80.69 ±6.26	83.83 ±6.19	88.86 ±6.19
		Pv	96.66 ±2.47	96.66 ±2.47	98.01 ±2.03	102.87 ±2.43	105.30 ±3.49	109.35 ±3.82	110.97 ±3.06	114.21 ±3.06	116.64 ±3.37	120.56 ±3.70	125.55 ±2.76	129.60 ±4.28
+N	L	Pi	71.29 ±2.61	71.29 ±2.61	74.42 ±2.58	78.82 ±2.61	83.84 ±1.25	88.86 ±0.72	95.13 ±0.00	100.78 ±0.62	107.69 ±1.02	113.70 ±1.43	116.47 ±0.72	122.11 ±1.20
		Pv	93.15 ±2.76	93.15 ±2.76	98.07 ±2.74	106.11 ±1.55	114.21 ±2.03	123.12 ±2.09	129.60 ±3.37	139.32 ±4.07	145.80 ±3.37	153.09 ±3.59	161.19 ±4.46	166.87 ±4.17
	S	Pi	68.14 ±3.74	68.14 ±3.74	70.03 ±3.96	72.54 ±3.07	76.93 ±2.96	84.08 ±3.61	87.60 ±3.86	90.73 ±5.45	95.13 ±5.32	98.26 ±4.84	103.91 ±4.75	110.19 ±3.54
		Pv	92.40 ±4.13	92.40 ±4.13	98.82 ±3.49	106.92 ±3.10	115.02 ±3.49	125.74 ±3.96	131.22 ±3.49	136.08 ±1.62	141.75 ±2.03	147.42 ±2.29	153.09 ±2.76	158.76 ±3.37

Table 9.4 : (contd.)

Treatment	Condition	Species	MONTHS											
			M	A	M	J	J	A	S	O	N	D	J	F
		Pi	71.29	71.29	76.30	81.33	85.09	86.97	91.99	95.76	98.90	102.66	106.43	110.19
			±3.31	±3.31	±4.16	±2.98	±2.71	±2.14	±2.14	±2.58	±2.40	±2.29	±2.98	±3.07
	L													
		Pv	93.15	93.15	98.01	103.68	108.54	114.21	123.12	129.60	136.08	143.37	149.04	152.28
			±2.76	±2.76	±2.76	±2.09	±3.96	±4.26	±3.85	±3.85	±4.28	±3.33	±3.37	±2.09
+P														
		Pi	68.78	68.78	71.29	74.42	76.93	80.07	81.32	86.34	91.99	96.38	100.15	104.54
			±3.32	±3.32	±3.32	±4.14	±4.51	±5.32	±5.56	±4.63	±2.78	±1.62	±2.29	±2.78
	S													
		Pv	93.96	93.96	99.63	106.11	111.78	116.64	119.88	123.12	127.98	132.84	139.32	144.18
			±2.09	±2.09	±3.06	±3.59	±3.96	±3.10	±2.09	±1.62	±2.29	±2.09	±2.09	±2.29
		Pi	70.03	70.03	74.42	79.45	82.60	85.71	86.35	88.22	94.50	98.27	102.66	105.80
			±2.29	±2.29	±1.57	±1.20	±2.29	±1.88	±1.62	±2.78	±3.45	±3.30	±2.89	±3.30
	L													
		Pv	93.15	93.15	97.20	102.87	108.54	112.65	116.64	121.50	126.36	132.03	139.32	143.37
			±3.33	±3.33	±2.80	±2.76	±2.95	±3.29	±2.09	±2.95	±3.37	±3.82	±3.37	±3.59
+K														
		Pi	69.40	69.40	71.29	73.79	76.30	76.93	78.82	82.58	85.71	88.22	92.74	95.75
			±4.27	±4.27	±4.86	±4.85	±3.90	±3.30	±3.15	±3.07	±3.13	±3.13	±3.72	±3.74
	S													
		Pv	93.96	93.96	100.44	103.68	108.54	113.40	117.45	123.12	125.55	129.60	134.46	139.32
			±2.80	±2.80	±2.09	±0.93	±1.32	±0.93	±2.03	±2.09	±2.03	±2.09	±1.87	±2.09

Table 9.4 : (contd.)

Treatment	Condition	Species	MONTHS											
			M	A	M	J	J	A	S	O	N	D	J	F
N+P+K	L	Pi	71.91 ±2.37	71.91 ±2.37	75.68 ±2.96	77.60 ±3.54	80.70 ±3.88	83.20 ±4.51	86.35 ±3.90	89.48 ±3.30	92.62 ±3.30	96.39 ±3.76	99.52 ±4.14	102.66 ±3.54
		Pv	89.91 ±3.59	89.91 ±3.59	93.15 ±4.26	96.37 ±4.27	101.25 ±2.76	105.30 ±2.29	107.66 ±2.78	111.78 ±2.29	114.21 ±2.43	116.64 ±2.09	121.50 ±1.87	124.74 ±2.95
	S	Pi	68.15 ±2.78	68.15 ±2.78	71.29 ±2.98	73.79 ±2.17	76.30 ±2.17	81.32 ±1.25	85.09 ±1.77	88.85 ±2.17	93.24 ±2.58	94.50 ±2.58	98.26 ±1.88	101.01 ±2.84
		Pv	93.15 ±6.25	93.15 ±6.25	98.01 ±6.11	102.87 ±5.18	106.92 ±4.86	111.80 ±3.97	115.02 ±1.18	119.88 ±3.37	123.12 ±3.85	124.74 ±4.76	129.60 ±5.68	134.46 ±6.61

Analysis of variance

Source of Variation		Signifcance level	
		Light	Shade
Nutrient	-	P <0.01	P <0.01
Time	-	P <0.01	P <0.01
Species	-	P <0.01	P <0.01
Nutrient x Time	-	P <0.01	P <0.01
Nutrient x Species	-	P <0.01	P <0.01

Table 9.5 . Effect of nutrient amendment on floral stalk (cm/plant ± SEM) of *P. insigne* (Pi) and *P. villosum* (Pv) in light and shade conditions.

Treatment	Condition	Species	MONTHS					
			A	S	O	N	D	J
Control	L	Pi	9.00 ±0.40	17.25 ±1.60	23.00 ±1.80	26.25 ±1.65	27.50 ±1.00	27.50 ±1.00
		Pv	8.25 ±0.50	15.80 ±1.03	20.75 ±0.50	24.00 ±0.70	25.80 ±0.90	25.80 ±0.90
	S	Pi	9.00 ±0.80	17.00 ±1.00	21.33 ±0.90	25.33 ±1.33	26.33 ±0.90	26.33 ±0.90
		Pv	8.00 ±0.57	15.00 ±1.00	21.00 ±0.60	25.00 ±0.60	26.00 ±0.33	26.00 ±0.33
+N	L	Pi	10.50 ±0.30	19.50 ±0.90	25.50 ±0.90	27.75 ±1.03	29.30 ±0.50	29.30 ±0.50
		Pv	7.50 ±0.60	15.00 ±0.81	20.75 ±0.47	26.00 ±0.40	27.00 ±0.40	27.00 ±0.40
	S	Pi	6.70 ±0.90	13.33 ±1.70	18.33 ±1.20	24.70 ±1.45	27.00 ±1.15	27.00 ±1.15
		Pv	7.25 ±0.75	13.50 ±1.32	21.00 ±0.40	27.30 ±0.50	27.80 ±0.30	27.80 ±0.30
+P	L	Pi	8.50 ±0.60	16.75 ±0.75	24.25 ±1.31	27.25 ±1.03	28.00 ±1.00	28.00 ±1.00
		Pv	7.25 ±0.80	16.25 ±1.18	22.00 ±1.94	24.75 ±1.65	25.80 ±1.30	25.80 ±1.30
	S	Pi	8.00 ±0.50	17.33 ±0.70	26.00 ±1.20	28.70 ±0.90	29.00 ±0.57	29.00 ±0.57
		Pv	7.33 ±1.04	16.33 ±1.70	21.70 2.33	25.00 ±1.52	26.00 ±1.45	26.00 ±1.45

Table 9.5 (contd.)

Treatment	Condition	Species	MONTHS A	S	O	N	D	J
+K	L	Pi	6.25 ±0.80	16.50 ±1.20	23.50 ±1.55	26.00 ±1.70	27.00 ±1.20	27.00 ±1.20
		Pv	9.50 ±1.00	13.00 ±1.08	20.50 ±0.50	25.25 ±0.50	26.00 ±0.70	26.00 ±0.70
	S	Pi	10.33 ±0.90	17.33 ±1.20	22.33 ±1.45	26.00 ±1.00	26.00 ±1.00	26.00 ±1.00
		Pv	6.00 ±0.90	12.70 ±1.45	20.70 ±0.70	26.00 ±1.00	27.00 ±0.70	27.00 ±0.70
N+P+K	L	Pi	10.50 ±0.60	17.00 ±1.50	24.00 ±1.50	27.00 ±1.80	28.50 ±0.95	28.50 ±0.95
		Pv	7.00 ±0.91	15.25 ±1.30	21.25 ±0.80	25.25 ±0.85	26.25 ±0.50	26.25 ±0.50
	S	Pi	10.00 ±0.60	17.00 ±2.08	23.00 ±1.52	27.33 ±1.20	28.00 ±1.45	28.00 ±1.45
		Pv	8.70 ±0.33	16.33 ±1.20	21.00 ±0.60	26.33 ±0.90	27.00 ±0.70	27.00 ±0.70

Analysis of variance

Sources of variation		Significance level Light	Shade
Nutrient	-	P <0.01	P <0.01
Time	-	P <0.01	P <0.01
Species	-	P <0.05	P <0.01
Nutrient x Time	-	NS	NS
Nutrient x Species	-	P <0.01	P <0.01

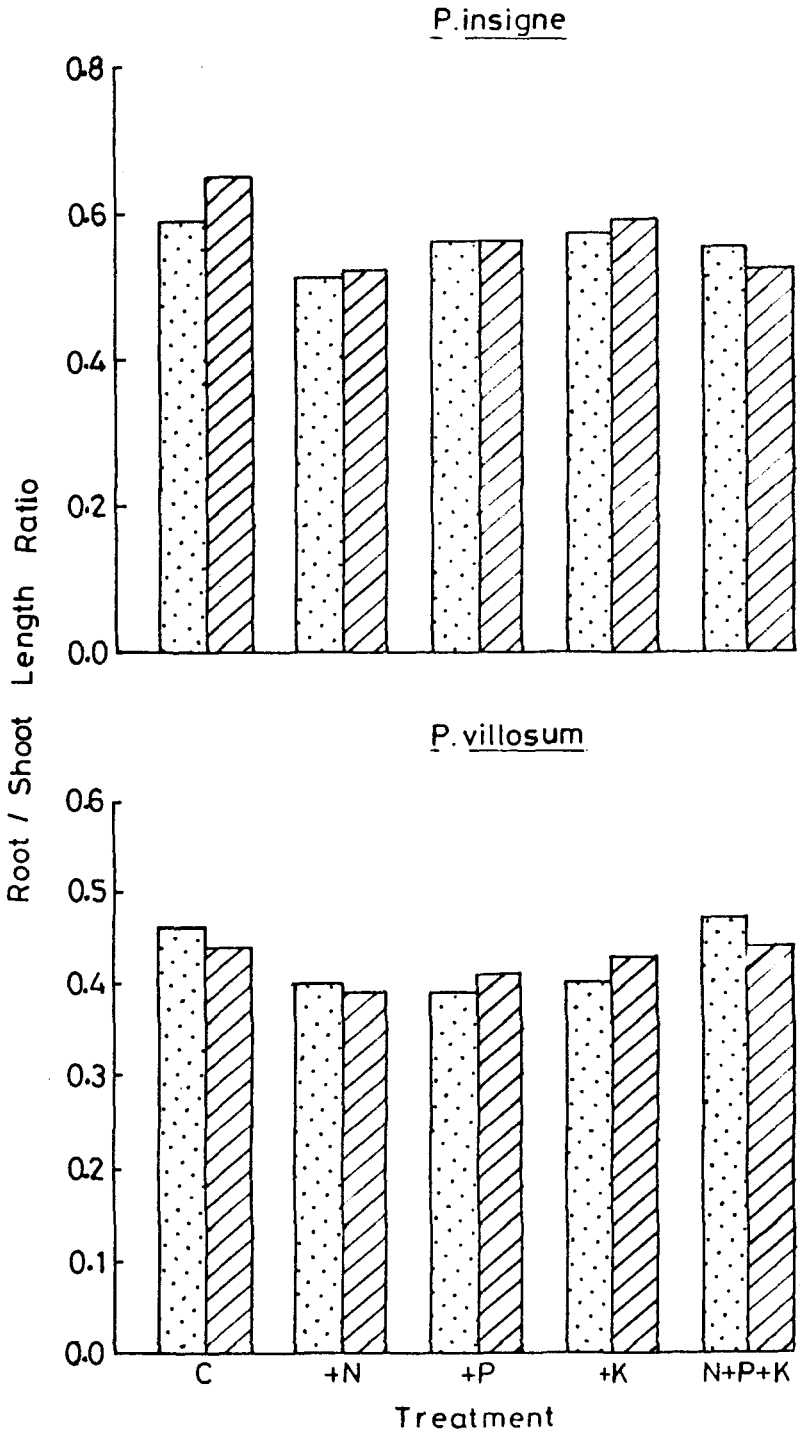


Fig. 9.5a Effect of soil amendment (addition of nutrient) and light condition (⁘ light; ▨ shade) on root-shoot ratio of *P. insigne* and *P. villosum*. C - Control

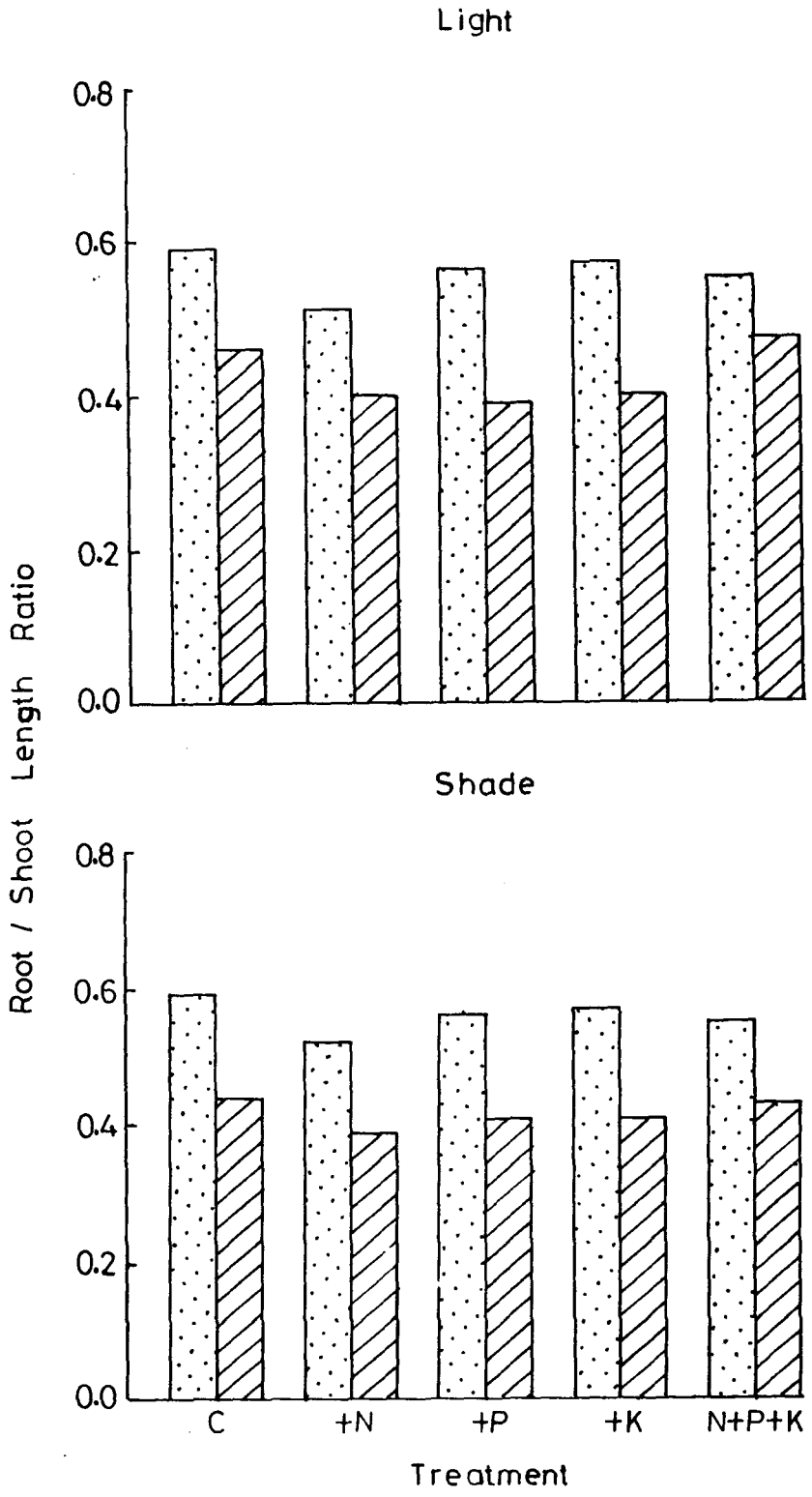


Fig. 9.5b Effect of soil amendment (addition of nutrient) and light intensity on root-shoot ratio of *P. insigne* (⊡) and *P. villosum* (▨). C - Control

when the light intensity ranged between 14400 lux and 23600 lux during the one year growth period. However, significantly greater plant length of *P. insigne* than that of *P. villosum* in nitrogen amended soil suggests that the former species can utilize nitrogen in a better way than the latter. Further, nitrogen supply enhanced offshoot production more than any other nutrient in *P. insigne* under lighted condition. This indicated that relatively bright light and higher soil nitrogen level helped offshoot production in the plant. This is in conformity with the results of Daniels (1986) who found that addition of even a small quantity of nitrogen in exposed sunlight, did produce greater number of fronds in *Pteridium aquilinum*. McIntyre (1977) reported that nitrogen application overcomes apical dominance in several plant species. Production of side shoots in *Diplacus aurantiacus* also increased with the increase in nitrogen supply (Gulmon and Chu 1981). Addition of nitrogen and phosphorus enhanced offshoot production in *Adenostoma* (McMaster *et al.* 1982). Higher nitrogen level stimulated offshoots or tillers in rhizomatous angiosperms (McIntyre 1964, Kirby 1980). The inhibition of new offshoot production in *P. villosum* in low light condition even after N and NPK applications to soil indicates that low light intensity was probably below the critical limit essential for the initiation of vegetative buds responsible for the formation of offshoot. Daniels (1986) reported that fewer fronds were produced in *Pteridium aquilinum* under reduced light intensity as compared to the higher light intensity.

Under relatively bright light condition and nitrogen

application both the species showed higher leaf length and leaf area as compared to other nutrient treatments. This observation conforms the results obtained in *Anthephora ampulacea* under nitrogen treatment in green house condition (Omaliko *et al.* 1987) as well as in field trials (Williams and Mohamed 1980, 1981). In sand culture Bradshaw *et al.* (1964) reported similar results on several grass species grown under different nitrogen levels. *Eupatorium* species also showed increased leaf area with increasing nitrogen level in the soil (Tripathi & Yadav 1982) and in *Diplacus aurantiacus*, individual leaf area was reduced due to reduction in nitrogen supply (Gulmon & Chu 1981). Vermeer (1986) observed greater shoot biomass in *Circio-Molinietum* with nitrogen application than other fertilizer treatments.

With nitrogen application light seemed to have no effect on the root length of both the species in which better growth were observed in both the light regimes whereas P, K and NPK application showed supressed root length of *P. insigne* particularly in shade. The effect was, however, insignificant in case of *P. villosum*. Relatively brighter light condition and nutrient application favoured root production in both the species. Daniels (1986) reported an increase in rhizome length when treated with NPK and the increase was almost double than that of the untreated plants.

The overall results of the study suggest that both the species responded better to nitrogen amendment under relatively higher light intensity.

Chapter 10

EFFECT OF OFFSHOOT DENSITY

The clonal growth habit is one of the most widespread and important forms of asexual reproduction in plants (Cook 1983, Hartnett & Bazzaz 1983). The population growth of perennial clonal plants is an interesting field of study both for geneticists and ecologists (Nobel *et al.* 1979), basically due to intractable problems associated with research on such plants. Sagar & Mortimer (1976) ascribed the problem to the occurrence of overlapping generations whereas Jansen (1977) explained the difficulty in defining an individual plant, but the most critical problem is the presence and existence of both vegetative propagation and sexual reproduction in the clonal plants (Thomas & Dale 1975).

Studies on demographic analysis and dynamics of many perennial plants under natural habitats have been undertaken by a large number of workers (Nobel *et al* 1979, Barkham 1980, Lovett Doust 1981c, Kushwaha *et al* 1983b). In explaining the dynamics and regulation of plant populations, effect of intra and interspecific competition on different species have been intensively investigated by many workers (Barkham 1980, Reader 1985, Brown *et al* 1985, Keith & Levin 1986). But studies dealing with the effect of offshoot density on the growth of orchids in general and on these two terrestrial orchid species - *P. insigne* and *P. villosum* in particular, have not yet been carried out.

Germination of orchid seeds either *in vitro* or *in vivo* is

extremely low therefore they generally multiply by vegetative means. In the genus *Paphiopedilum* also seed germination is very difficult (Pierik *et al* 1988). This is compensated by vegetative propagation through offshoots whose number differs from species to species. This chapter examines the effect of offshoot density on the vegetative and reproductive growth in the two species of *Paphiopedilum*.

MATERIALS AND METHODS

Originally an experiment was planned to study the effect of population density on the growth of plant in natural populations of these two species. For this purpose field surveys were carried out in different parts of Meghalaya and the information about their occurrence in nature was gathered from different sources. But it was found that even in Cherrapunjee and Jaintia Hills, from where the earlier workers have reported maximum occurrence of these species, the population has been drastically reduced, leaving only few plants here and there. Therefore the study of the effect of population density on the growth behaviour in natural habitat could not be conducted. Thus an experiment was conducted in a nursery situated at Upper Shillong about 5.63 Km west of Shillong city, where both the species are raised in field under semi - natural condition. The nursery beds where the plants were raised, were shaded by means of bamboo sticks with climbers entwined over it. The nursery beds in which the experiment was conducted were not disturbed for one year before the commencement of the experiment, that is, no plant was either pulled or dug out

from the experimental beds for any purpose.

Six quadrats of 50cm x 50cm, three quadrats for *P. insigne* and three for *P. villosum*, were laid down in the month of January 1990. Number of plants as well as the number of offshoot on each plant were counted in each quadrat. The density of plant per quadrat was more or less the same for both the species, but the number of offshoots per plant varied from 4 - 6 in *P. insigne* and 1-3 in *P. villosum*. The plants bearing different offshoot number were marked in each quadrat and they were grouped into different categories viz., D_1 (4 offshoots and 1 offshoot/plant), D_2 (5 offshoots and 2 offshoots/plant) and D_3 (6 offshoots and 3 offshoots/plant) for *P. insigne* and *P. villosum* respectively. Growth parameters of these plants were measured at monthly intervals during January 1990 to January 1991 and the results are discussed in this chapter.

RESULTS

Offshoot number

The difference in offshoot density per plant showed a marked effect on offshoot production in both *P. insigne* and *P. villosum*. It can be seen from data presented in Table 10.1 & 10.2, that both the species produced maximum number of offshoots in the second category i.e., plant bearing 5 offshoots for *P. insigne* and 2 offshoots for *P. villosum*. New offshoot formation started in May and culminated in November. A slight deviation was, however, observed in *P. villosum* where formation of offshoot was initiated a little late in the first (one offshoot/plant) and

Table 10.1. Effect of offshoot density of parent plant on the growth of new offshoot in *P. insigne*

Month	number of offshoots/parent plant		
	4	5	6
Feb	4.00±0.00	5.00±0.00	6.00±0.00
Mar	4.00±0.00	5.00±0.00	6.00±0.00
Apr	4.00±0.00	5.00±0.00	6.00±0.00
May	4.33±0.33	5.33±0.33	6.33±0.33
Jun	4.33±0.33	5.33±0.33	6.66±0.33
Jul	4.33±0.33	5.33±0.33	6.66±0.33
Aug	4.66±0.33	5.66±0.33	7.00±0.50
Sep	4.66±0.33	6.33±0.33	7.00±0.50
Oct	5.00±0.00	6.33±0.33	7.33±0.33
Nov	5.00±0.00	7.00±0.05	7.33±0.33
Dec	5.00±0.00	7.00±0.05	7.66±0.33
Jan	5.00±0.00	7.00±0.05	7.66±0.33

Table 10.2. Effect of offshoot density of the parent plant on the growth of new offshoots in *P. villosum*

Month	number of offshoots/parent plant		
	1	2	3
Feb	1.00±0.00	2.00±0.00	3.00±0.00
Mar	1.00±0.00	2.00±0.00	3.00±0.00
Apr	1.00±0.00	2.00±0.00	3.00±0.00
May	1.00±0.00	2.00±0.00	3.33±0.33
Jun	1.33±0.33	2.66±0.33	3.33±0.33
Jul	1.33±0.33	2.66±0.33	3.66±0.33
Aug	1.66±0.33	2.66±0.33	3.66±0.33
Sep	2.00±0.00	3.00 0.00	4.00±0.00
Oct	2.33±0.33	3.33±0.33	4.33±0.33
Nov	2.33±0.33	3.66±0.33	4.33±0.33
Dec	2.66±0.33	3.66±0.33	4.33±0.33
Jan	2.66±0.33	4.00±0.00	4.33±0.33

second (two offshoot/plant) categories.

Leaf number

Production of new leaves followed the trend of the offshoot; it increased significantly ($P < 0.05$) with the increase in offshoot density in both the species (Table 10.3 and Table 10.4). The timing of new leaf formation did not show any change, in both the cases it occurred during April to November.

Leaf length and leaf area

In both the species total leaf length and leaf area attained the peak where the offshoot density was maximum i.e 6 offshoots per plant in *P. insigne* and 3 offshoots per plant in *P. villosum*, but the growth rate in *P. insigne* was significantly ($P < 0.05$) higher at 5 offshoot density level and in *P. villosum* at 3 offshoot density level as compared to other densities (Tables 10.5 & 10.6). In *P. insigne* at highest offshoot density level the rate of increase was the lowest, whereas the reverse was seen in case of *P. villosum*. The growth in leaf length as well as in leaf area in both the species continued till the end of the experiment (Table 10.7 and 10.8).

Flower

All plants in each quadrat produced flower (Fig. 10.1). The number of flower increased with an increase in the number of offshoot in case of *P. insigne* but not in *P. villosum* (Fig 10.2).

Fig 10.3 shows the growth rate of floral stalk of the two species. The length of the floral stalk increased almost in linear fashion upto 90 days, thereafter, the growth slowed down and became stable after 120 days till the end of the observation period. Offshoot density did show significant effect on the

Table 10.3. Effect of offshoot density on the parent plant on leaf growth (leaf number/plant) in *P. insigne*.

Month	number of offshoots/parent plant		
	4	5	6
Feb	16.66±0.33	18.00±1.15	24.00±0.57
Mar	16.66±0.33	18.66±0.88	24.33±0.33
Apr	17.33±0.66	19.00±1.15	24.66±0.33
May	17.33±0.66	19.00±1.15	25.66±0.33
Jun	17.66±0.33	20.00±1.15	25.66±0.33
Jul	17.66±0.33	20.00±1.15	26.33±0.66
Aug	18.33±0.66	20.00±1.15	26.66±0.33
Sep	18.33±0.66	21.00±1.15	26.66±0.33
Oct	18.66±0.88	21.00±1.15	27.00±0.57
Nov	18.66±0.88	22.00±1.15	27.33±0.33
Dec	18.66±0.88	22.00±1.15	27.33±0.33
Jan	18.66±0.88	22.00±1.15	27.33±0.33

Analysis of variance

Sources of variation	Significance level
Density	$P < 0.05$
Time	$P < 0.05$

Table 10.4. Effect of offshoot density on the parent plant on leaf growth (leaf number/plant) in *P. villosum*

Month	number of offshoots/parent plant		
	1	2	3
Feb	6.66±0.33	9.00±0.57	11.66±0.66
Mar	6.66±0.33	9.33±0.33	12.33±0.88
Apr	7.33±0.66	10.00±0.57	12.66±0.66
May	8.00±0.57	10.00±0.57	13.33±0.88
Jun	8.00±0.57	10.66±0.33	13.33±0.88
Jul	8.66±0.33	11.00±0.57	14.00±0.57
Aug	9.33±0.66	11.00±0.57	14.00±0.57
Sep	10.00±0.57	11.33±0.88	14.66±0.66
Oct	10.00±0.57	12.00±0.57	15.33±0.88
Nov	10.00±0.57	12.00±0.57	15.33±0.88
Dec	10.00±0.57	12.00±0.57	16.00±1.00
Jan	10.00±0.57	12.00±0.57	16.00±1.00

Analysis of variance

Sources of variation	Significance level
Density	$P < 0.05$
Time	$P < 0.05$

Table 10.5. Effect of offshoot density on the parent plant on the growth of leaf length (total leaf length, cm/plant ±SEM) in *P. insigne*

Month	number of offshoots/parent plant		
	4	5	6
Feb	181.66±5.78	185.66±1.33	359.66±1.56
Mar	183.33±5.49	188.00±2.08	362.33±1.76
Apr	185.67±4.91	190.33±2.18	364.00±1.52
May	187.67±4.33	193.00±2.51	366.00±2.08
Jun	191.00±4.04	195.33±3.18	368.33±2.33
Jul	193.33±3.18	198.33±3.28	370.33±2.18
Aug	196.00±2.89	201.33±3.84	373.00±2.00
Sep	198.00±3.79	204.33±3.84	374.66±1.33
Oct	200.00±3.21	206.67±3.93	377.00±1.00
Nov	201.33±3.53	209.00±3.51	378.66±1.33
Dec	204.00±3.60	212.66±3.33	380.00±1.00
Jan	206.67±4.26	215.33±3.67	382.00±1.52

Analysis of variance

Sources of variation	Significance level
Density	P <0.01
Time	P <0.01

Table 10.6. Effect of offshoot density on the parent plant on the growth of leaf length (total leaf length, cm/plant) in *P. villosum*.

Month	Number of offshoots/parent plant		
	1	2	3
Feb	91.33±2.66	131.33±0.66	155.00±3.00
Mar	92.33±2.66	132.66±0.88	157.00±3.00
Apr	93.33±2.66	135.00±1.15	159.33±3.33
May	95.00±2.08	137.00±1.52	162.00±3.00
Jun	96.33±1.76	140.00±1.52	164.00±3.00
Jul	97.33±1.76	141.66±1.33	166.67±2.66
Aug	98.67±1.85	143.00±1.52	169.00±2.51
Sep	100.67±2.40	145.33±1.20	171.33±2.85
Oct	102.33±2.73	147.00±1.52	174.00±2.51
Nov	104.33±2.73	149.00±2.08	176.00±2.51
Dec	106.33±2.66	151.66±2.03	178.33±2.85
Jan	108.33±3.18	152.66±2.45	179.33±2.85

Analysis of variance

Sources of variation	Significance level
Density	P <0.01
Time	P <0.01

Table 10.7. Effect of offshoot density on the parent plant on the growth of leaf area (total leaf area, cm^2/plant ± SEM) in *P. insigne*.

Month	Number of offshoots/plant		
	4	5	6
Feb	449.04±13.82	458.24±3.35	897.49±5.09
Mar	453.19±13.00	464.10±5.22	904.19±4.43
Apr	459.08±11.59	469.96±5.49	908.34±3.83
May	463.26±10.88	475.65±7.31	913.39±5.22
Jun	471.63±10.14	482.51±7.98	919.25±5.86
Jul	477.48±7.98	490.04±8.24	924.26±5.49
Aug	484.18±7.25	497.57±9.65	930.96±5.02
Sep	489.72±9.50	505.10±9.65	935.14±3.35
Oct	494.21±8.07	510.95±9.86	941.00±2.51
Nov	497.57±8.85	516.81±8.81	945.18±3.35
Dec	504.26±9.05	526.01±8.37	948.53±2.51
Jan	510.95±10.68	532.71±9.20	953.61±3.78

Analysis of variance

Sources of variation	Significance level
Density	P <0.01
Time	P <0.01

Table 10.8. Effect of offshoot density on the parent plant on the growth of leaf area (total leaf area, cm^2/plant) in *P. villosum*.

Month	Number of offshoots/plant		
	1	2	3
Feb	284.58±7.73	414.18±2.16	490.86±9.72
Mar	287.82±7.40	418.50±2.86	497.34±9.72
Apr	291.06±8.64	426.06±3.74	504.90±10.80
May	296.46±6.74	432.54±4.95	513.54±9.72
Jun	302.93±6.49	442.27±4.94	520.02±9.72
Jul	304.02±5.71	447.66±4.32	528.66±8.64
Aug	308.34±6.01	451.98±4.95	536.22±8.15
Sep	308.34±6.01	459.54±3.89	538.55±7.53
Oct	320.23±8.84	464.94±4.95	552.42±8.15
Nov	326.70±8.84	471.42±6.74	558.90±8.15
Dec	333.18±8.64	480.06±7.79	566.41±9.17
Jan	339.66±18.30	483.30±7.79	571.86±9.72

Analysis of variance

Sources of variation	Significance level
Density	P <0.01
Time	P <0.01

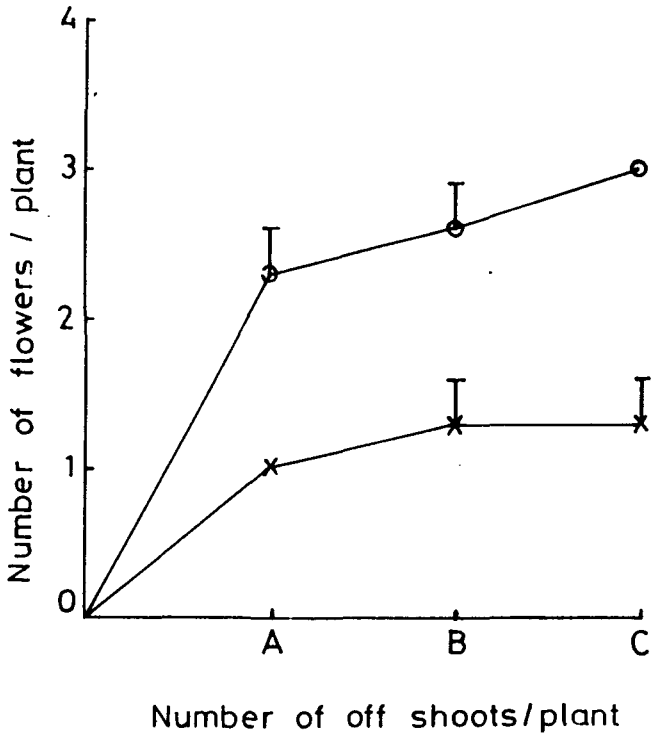


Fig. 10.1 Effect of offshoot density on flower production per plant of *P. insigne* (—o—) and *P. villosum* (—×—); where, A, B and C represent 4, 5 and 6 offshoots in *P. insigne* and 1,2 and 3 offshoots in *P. villosum.*

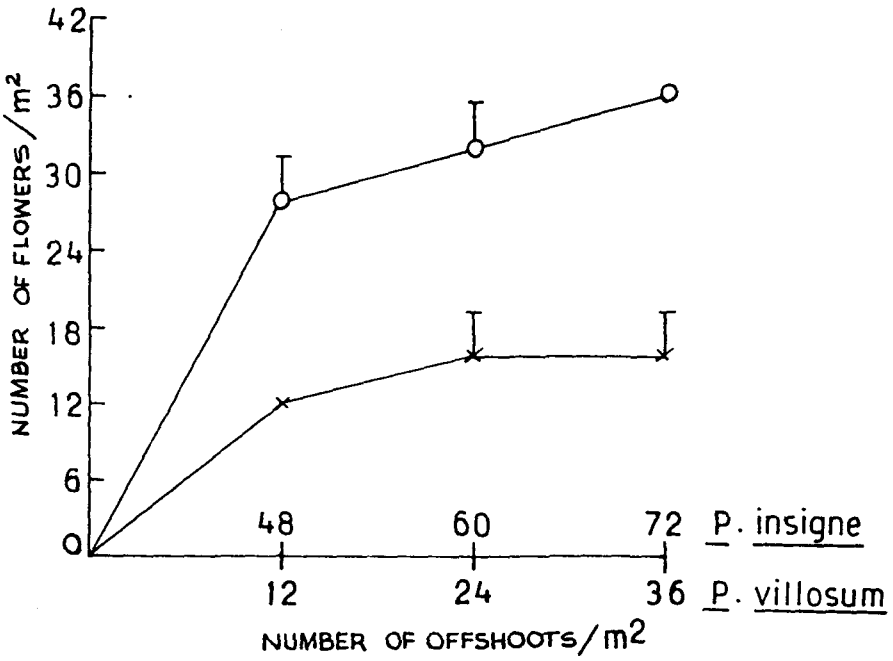


Fig. 10.2 Effect of offshoot density on flower production per m^2 in *P. insigne* (—o—) and *P. villosum* (—×—).

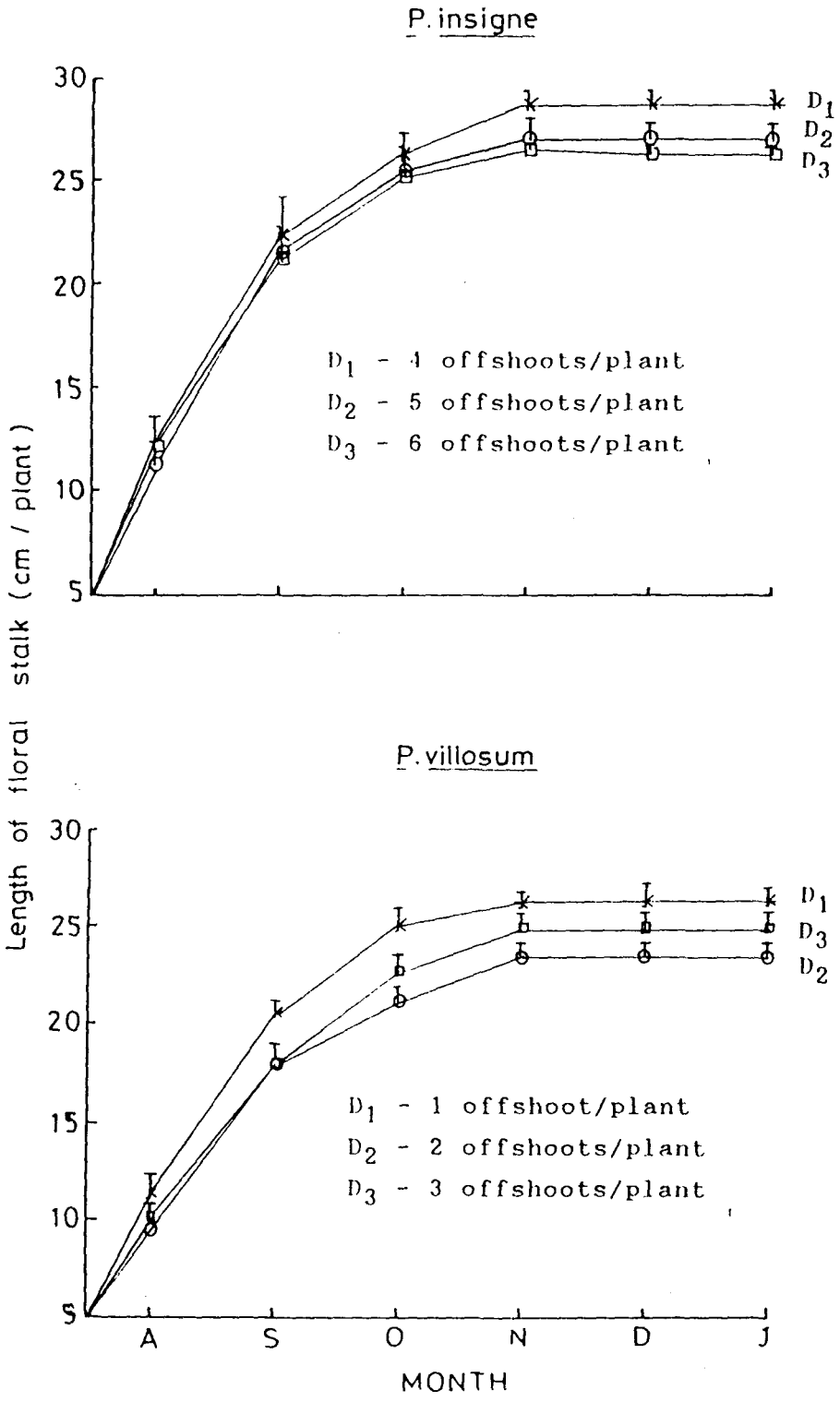


Fig. 10.3 Effect of offshoot density on floral stalk growth of *P. insigne* and *P. villosum*.

stalk length but not on the floral characters. In both the species plants with lesser number of offshoot (D_1) showed longer floral stalk than the other two densities.

DISCUSSION

All the measurements in this experiment were done on the aboveground parts without disturbing the plants in any way. The offshoots originate at the base of the parent plant and they lie very close to each other. Since in the new offshoots roots arise relatively late, they depend for water and nutrient requirements on the root system of the parent plant therefore, there is every likelyhood of competition for resources among the offshoots. In this experiment it was not possible to know precisely whether there existed any competition or not, but the results suggest that as the number of offshoot increased on the parent plant, it influenced mainly the vegetative growth. In case of *P. villosum* the number of new leaves and its growth increased as the number of offshoot per plant increased while in *P. insigne* it declined after 5 offshoot density. Partitioning of resources in relatively larger number of offshoots could be the probable reason for such a response by *P. insigne*. Findings of Kirby (1980) and Hartnett and Bazzaz (1983) show that resources for which new seedlings depend on parents during establishment play important role in their survival rate.

During the study period, mortality in offshoot and leaf was not observed in the two species. It seems that offshoot crowding on the parent plant did not reach to that level where it could

cause mortality of newly emerged offshoots due to resource competition, rather addition of new offshoots and new leaves contributed to the increase in vegetative growth of the plant thus helping in vegetative propagation. This agrees with the findings of Tamm (1972), Barkham (1980) and Pitelka *et al* (1984). Nobel *et al.* (1979) observed that the dynamics of plant population of *Carex arenaria* depends on birth and death of its clonal modules.

Chapter 11

GENERAL DISCUSSION

The great demand of *P. insigne* and *P. villosum* as ornamental plants, both within and outside the country is the main reason of overexploitation of these species leading to the decline of their populations to the extent that they have almost reached the verge of extinction from their natural habitats, which is restricted to certain pockets of north-east India. The findings of the present study dealing with certain aspects of ecology of these two orchid species are discussed in the following pages:

Distribution

Paphiopedilum species are distributed world wide, except Australia (Veitch and Sons 1894). Rao (1979) reported 7 species of *Paphiopedilum* (*P. insigne*, *P. villosum*, *P. hirsutissimum*, *P. venustum*, *P. spicerianum*, *P. fairieanum*, and *P. druryi*) from India and Kataki (1984) added two more, *P. wardii* Summerh. from Arunachal Pradesh and *P. charlesworthii* (Royle) Pfitz. from Mizoram to this list. All species except *P. druryi*, are found in north-eastern part of the country and Sikkim. Meghalaya is the abode of *P. insigne*, *P. venustum*, and *P. hirsutissimum* whereas *P. insigne*, *P. villosum*, and *P.charlesworthii* are found in Mizoram. *P. spicerianum* is restricted to Cachar district of Assam and *P. hirsutissimum* to Nagaland. *P. wardii* is reported from Arunachal Pradesh and *P. venustum* from Sikkim and *P. fairieanum* from both Arunachal Pradesh and Sikkim. The lone species, *P. druryi* is found in south India on the top of Calcad hills (Travancore -

Kerala).

The two species of *Paphiopedilum* selected for experimental purpose are terrestrial in nature and endemic to north-east India. *P. insigne* was originally reported from Chittagong hills now in Bangladesh and Meghalaya and *P. villosum* from Tenasserim (Burma) and Mizoram (Kataki 1984).

Both the species are now rarely found in their natural habitat, as a result of which they have been called by various workers as rare, endangered etc. The main reasons for their decline are variety of human activities, such as large scale commercial exploitation of the species, increase in urbanisation and extention of agriculture on forest lands which were hitherto under protection, clearing of forests for making roads and other construction activities, cutting of trees for timber and fuel-wood purposes.

Phenology

The phenological study of *Paphiopedilum* starting from seedling stage to seed setting phase reveals that warm and humid condition is conducive for germination of seeds, as a result of which seedlings were observed during wet summer. The seedling takes several years to become an adult plant which flowers during autumn season and flowering is completed during early winter. Vegetative reproduction through off shoot is the chief means of maintaining its population, since seed germination is very poor and depends on various external conditions including mycorrhizal association.

Morphology

Apparently, morphology of these two species is very similar, but *P. insigne* generally has more offshoots than *P. villosum* and *P. villosum* has larger leaf than *P. insigne*. The floral stalk is longer in *P. insigne* while flowers are bigger in *P. villosum*.

Anatomy

Rosso (1966) reported the presence of 10 xylem strands in the root of *P. insigne* and 8 xylem strands in case of *P. villosum*, but in the present study 8 xylem strands and 8 phloem strands with a well developed pith in the centre were observed in both the species. Anatomy of other plant parts viz., leaf and floral axis is similar in both the species.

Effect of watering

The study dealing with the effect of soil moisture level revealed that in monthly watering treatment when the soil moisture level ranged between 14 % and 16 %, growth of both the species was poorer than in the high moisture regime (ca 32 %) in weekly watering treatment. Under low moisture condition, all the growth parameters showed a marked reduction. This result is in agreement with the findings of Sobrado and Turner (1986) on *Helianthus annus* and *Helianthus petiolaris* and McIntyre (1986) on *Trifolium repens*. Tripathi and Yadav (1985) observed similar effect of soil moisture condition on dry matter yield of *Eupatorium adenophorum* and *Eupatorium riparium* and Omaligo and Ene-Obong (1987) in *Anthephora ampulacea*. The peak dry matter yield under fortnightly watering when soil water content varied between 21-23 % indicate that this watering interval was suitable for the growth of these two orchid species.

Effect of substrate quality

The study of their growth behaviour in the different prepared media showed that presence of organic matter in the soil had a marked favourable effect on plant growth. The mixture of mineral soil and humus in 1:3 ratio, proved to be the most favourable for leaf growth, both leaf length as well as leaf area, which led to the maximum dry weight accumulation in both the species under this treatment. The mineral soil provided most unfavourable condition for growth.

Effect of light intensity

The response of *P. insigne* and *P. villosum* to light intensity showed that their growth behaviour was far better under high light (*ca*15800) than under low light (*ca*8300) conditions. Reduction in light intensity below this level was more critical for reproductive growth of plants, since flowering was completely inhibited in shade where light intensity was below this level. Although similar studies on other orchids are not available to compare the present findings, several studies including those of Pitelka *et al.* (1985) on *Aster acuminatus*, Woledge (1986) on white clover,Skuterud (1984) on *Elymus repens* and *Agrostis gigantia*, Longstreth and Mason (1984) on *Alternanthera philoxeroides* show that reduction in light intensity below a threshhold level may significantly reduce plant growth and adversely influence flowering behaviour.

Effect of soil nutrient level and light intensity

The experiment conducted to study the combined effect of soil nutrient level and light intensity revealed that addition of nitrogen to soil significantly increased growth of both *P.*

insigne and *P. villosum*, both in the shade and light. Other nutrients such as P and K when added either alone or in mixture, caused additional improvement. Yadav and Bose (1986) reported that nitrogen treatment is very effective in improving growth and flowering of *Aerides multiflorum* Roxb., while P and K addition though effective, but their effect was less pronounced than that of nitrogen. The positive effect of nitrogen addition on other plant species has also been reported by many workers (Ingestad 1979, Gulmon and Chu 1981, Daniels 1986, McIntyre 1986). In these two species of *Paphiopedilum*, nitrogen application at the rate of 0.2g Ammonium Nitrate per pot as surface dressing in light condition (*ca* 18500 lux) caused a significant increase in growth of above ground parts, whereas, addition of P, K and N together at the rate of 0.2g each of Ammonium Nitrate, Super Phosphate and Potassium Chloride per pot markedly increased root growth. Studies on *Pteridium aquilinium* by Daniels (1986) also showed that N, P and K treatments enhanced rhizome growth.

Effect of offshoot density

Analysis of shoot growth in relation to offshoot density showed that in case of *P. villosum*, offshoot density has no significant effect on the growth of plant, but in case of *P. insigne*, after 5 offshoots per plant, there was a marked decline in the growth of leaf length and leaf area per plant. However, when the effect of offshoot density was evaluated on the growth behaviour of offshoot itself it was found that in both the species, there was a decline in growth of leaf length and leaf area with the increase in number of offshoot per plant.

The present investigation was marred by several constraints including rarity of plants in nature, its extremely slow growth and paucity of literature on the ecology of orchids. Even then, with limited amount of data collected on the ecophysiological aspect of two rare terrestrial orchids, it may be concluded that environmental requirements of both the species of *Paphiopedilum* are similar and both of them prefer nitrogen rich soil, warm, humid and lighted habitat for their growth, development and successful flowering.

SUMMARY

The thesis presents the results of ecophysiological studies on two species of a terrestrial orchid *Paphiopedilum*, viz., *P. insigne* Pfitz. and *P. villosum* Stein. *P. insigne* is found in Khasi and Jaintia Hills of the state of Meghalaya (India) and Bangladesh, while *P. villosum* occurs naturally in Mizoram (India), Burma and Thailand. Both the species are well known ornamental plants and therefore have been exploited by plant collectors. Besides this, destruction of humid subtropical broadleaved forests has led to drastic reduction in the natural populations of these species, so much so, that they have been included in the list of rare plant species.

The present investigation deals with the geographical distribution, morphology, anatomy and effects of important climatic and edaphic factors on the growth and reproductive attributes of these species.

Chapter 1 of the thesis gives a general introduction about orchids, their importance, abundance and exploitation during the British rule around the world, their uses and conservation measures.

The review of literature presented in Chapter 2 reveals that research works on orchids deal mainly with their taxonomy, pollination biology and physiology. Ecological studies on orchids are rare both in India and abroad.

The details of soil, climate and vegetation of Shillong, where the study was conducted during 1987-1991, are described in Chapter 3.

Phenology

Both the species grow (grow) very slow and major portion of their life cycle is passed in vegetative phase. The initiation of flower in the month of August marks the beginning of the reproductive phase of the life cycle. After full blooming in autumn (September - November), growth of the flower bearing offshoot ceases and pod matures in the month of May in the following year when the seed are shed. The offshoot(s), the chief mode of propagation, in both the species, develops from the base of the parent plant during February - March and it takes 2 - 3 years to reach to the flowering stage.

Anatomy

Anatomically, both the species are similar. The root consists of 8 xylem and 8 phloem strands while in the stem closed and amphivasal vascular bundles were scattered in the ground tissue, similar to other monocot plants. In case of floral axis, the vascular bundles were arranged in two rings in the periphery leaving a large pith in the centre. The leaves as well as the floral axis possessed amphivasal vascular bundles. The floral axis as well as root bore trichomes.

Effect of watering

Growth of both the species was studied under three watering intervals viz., weekly, fortnightly and monthly watering and in rain fed (control) conditions. Fortnightly watering (21-23 % soil moisture content) was most favourable for the growth and development of both the species. In monthly watering where moisture content in the soil varied between 14-16 %, a drastic reduction in shoot and root growth of both the species was

observed. With fortnightly watering, the plant exhibited greater plant length, leaf length, leaf area and greater offshoot number, but the root number, root length and leaf number were significantly higher in weekly watering than the control and other treatments.

Root-shoot ratio suggests that weekly watering favoured growth in underground parts of the plants while fortnightly watering favoured more aboveground parts than the root.

Total dry weight was maximum in fortnightly watering and minimum in monthly watering treatments, thereby indicating that in the former treatment, where soil moisture ranged between 21-23 %, provided the best condition for the growth and development of *P. insigne* and *P. villosum*. When the soil moisture declined below this level as in monthly watering treatment, it caused an adverse effect on the plant growth in both the species.

Effect of substrate quality

Since these two species of *Paphiopedilum* are found on the forest floor rich in organic matter, an experiment was conducted to examine their growth performance in different types of soil containing humus and mineral soil in different proportions. Results of this experiment suggest that most of the growth parameters such as, length of the plant, root number, root length and leaf number were significantly higher in potting medium containing only humus as compared to the rest of the treatments. Other growth parameters particularly the leaf length and leaf area showed a significant increase in mineral soil and humus mixture (1 : 3) than the other treatments. The value of leaf area was, however, more in *P. villosum* than *P. insigne*.

Length of the floral stalk of both *P. insigne* and *P. villosum* was reduced significantly in mineral soil as compared to other treatments. The reduction was more drastic in *P. insigne* than *P. villosum*. These treatments did not have any significant effect on offshoot production. Total dry weight of plants was maximum in mineral soil and humus (1:3) mixture and minimum in mineral soil only.

Effect of light regime

This experiment was conducted in a net house , where the light intensity was artificially reduced by means of white and black muslin cloth. Both species showed better growth where light intensity ranged between 15000 lux and 22000 lux. Reduction in light intensity below this range adversely affected plant growth. The effect was more marked in reproductive growth. Both the species could not produce flower in shade where mean light intensity was about 8300 lux.

Effect of soil nutrient level and light regime

In this experiment, same amount (0.2g /pot) of N, P and K were added singly and in combinations with a view to study the effect of soil nutrients level on these species. Irrespective of nutrient addition, the plants, exhibited better growth in light than in shade. Among the different nutrient treatments either alone or in combination, plant's response to nitrogen amendment was the best since almost all the growth parameters viz., length of plant, root length, leaf length and leaf area attained peak in this treatment. This effect of soil nitrogen level was further magnified in light.

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