INFLUENCE OF HOST, LIGHT AND MINERAL NUTRITION ON THE GROWTH OF SANDAL SEEDLINGS (*Santalum album* L.)

By

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THESIS

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Declaration

I hereby declare that this thesis entitled **"Influence of host, light and mineral nutrition on the growth of sandal seedlings (*Santalum album* L.)"** is a bonafide record of research and that the thesis has not previously formed the basis for the award of any degree, diploma, fellowship or other similar title, of any other University or Society to me.

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We, the undersigned members of advisory Committee of **Mr. Samom Khelen Singh,** a candidate for the degree of **Master of Science in Forestry,** agree that this thesis entitled **"Influence of host, light and mineral nutrition on the growth of sandal seedlings (*Santalum album* L.)"** may be submitted by **Mr. Samom Khelen Singh** in partial fulfillment of the requirement for the degree.

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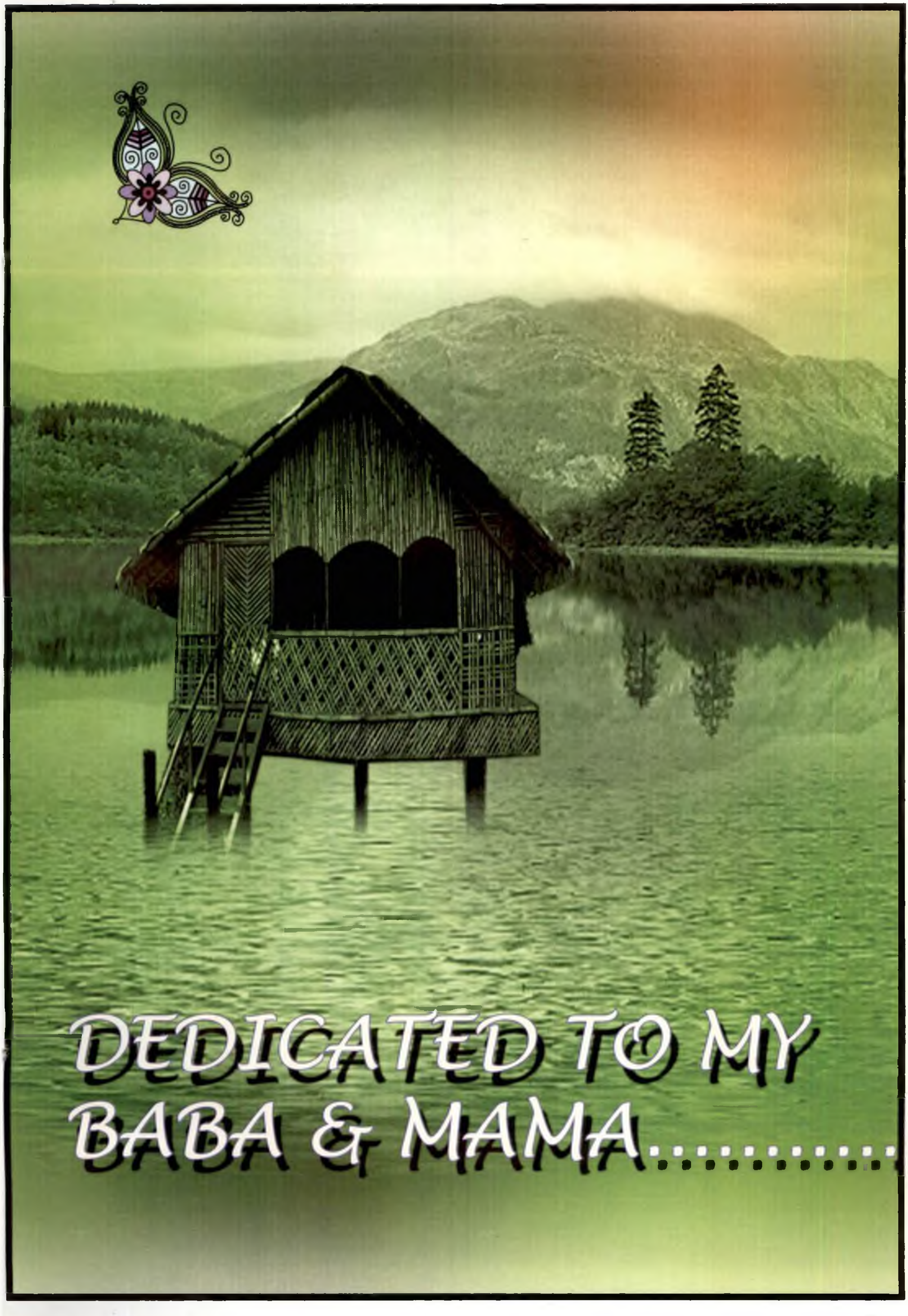

DEDICATED TO MY BABA & MAMA...........

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LIST OF ABBREVIATIONS

ADP	Adenosine Diphosphate
AMF	Arbuscular Mycorrhizal Fungi
ATP	Adenosine Triphosphate
CoA	Co-enzyme A
cpm	Counts Per Minute
CRD	Completely Randomized Design
FR	Far Red
GA	Gibberellic Acid
LAR	Leaf Area Ratio
MSL	Mean Sea Level
NAD	Nicotinamide Adenine Dinucleotide
NADP	Nicotinamide Adenine Dinucleotide Phosphate
OD	Optical Density
PAR	Photosynthetically Active Radiation
PFD	Photon Flux Density
PPFR	Photosynthetic Photon Fluence Rates

ppm	Parts Per Million
RGR	Relative Growth Rate
RLI	Relative Light Intensity
RLR	Root Length Ratio
SRL	Specific Root Length

Introduction

INTRODUCTION

Santalum album L. commonly known as sandalwood or *chandan* is a semi-root parasite tree species of the family Santalaceae. It is highly valued for its scented wood and oil. It has also been intimately associated with human civilization since time immemorial and is a part of Indian culture and heritage (Srinivasan *et al.,* 1992). Over exploitation and illicit felling of sandalwood have resulted in decline of population and genetic erosion (Annapurna *et al.*, 2007). On the other hand natural regeneration of sandal is not in pace with the exploitation and is considered threatened in its habitats (Meera *et al.*, 2000). In order to meet growing demand and sustainable utilization of bio-resources of *S. album,* afforestation and plantations of high quality planting material is essential. Recent liberalized policies of sandalwood cultivation in Karnataka and Tamil Nadu states have resulted in heavy demand of quality planting stock of *S. album* (Annapurna *et al.*, 2007). The scented heartwood of sandal, commercially known as the East Indian sandalwood, yields the fragrant sandalwood oil on steam distillation. The cost of the heartwood is estimated to be fetching approximately Rs. 9 lakhs per tonne in the international market (Ananthapadmanabha, 2000).

Distribution of genus *Santalum* is in the tropical region in between 30°N and 40°S, from India in the West to Juan Fernandez islands in the East and from Hawaiian Archipelago in the North to New Zealand in the South (Brennan and Merlin, 1993). It comprises of 16 species (Hamilton and Conrad, 1990; Barret and Fox, 1997) and all of them are xylem tapping root hemi-parasites with highly valued aromatic heartwood (Shea *et al.*, 1998). Four *Santalum* species namely *S. spicatum* (R. Br.) A. Dc., *S. acuminatum* (R. Br.) A. Dc., *S. morrayanum* (Mitchell) C. Gar. and *S. lanceolatum* (R. Br.) are native to Western Australia (Sawyer and Jones, 2000). Among the *Santalum* species, *Santalum album* has the highest oil content (6-7%) while *S. spicatum* (2%) and *S. laneolatus* (3-5%) yield poorly scented wood and low quality oil (McKinnel, 1990).

S. album is found distributed in almost all the states of India covering a total area of 9040 sq. km. and more than 90% lies in Karnataka and Tamil Nadu (Dutt and Verma, 2005). In Kerala, natural stand of the tree is present in Marayoor forest area and isolated plants are seen in many homesteads and farmlands (Hiremath, 2004). In Himachal Pradesh, it occurs at Bilaspur near main town and in the Kangra Valley at Jawala Mukhi (Venkatesan *et al.*, 1995). Other important sandal bearing states include Andhra Pradesh, Orissa and Madhya Pradesh. A survey on the important sandal bearing areas of these states were done by Jain *et al.* (1998), which indicates that the sandal population has declined substantially due to biotic and abiotic factors.

An individual growing tree can put an increment of 1 kg of heartwood per year and can attain a girth of over 1.5 metres (Rai, 1990). India exports around 2000 tonnes of wood and 100 tonnes of oil annually to various countries. This accounts for 99 per cent of sandalwood oil produced in the world (Lakshmisita and Bhattacharya, 1998).

The sandalwood oil is present in the heartwood of stem and root and hence the tree is invariably harvested by uprooting (Hiremath, 2004). 30-60 year old trees having a girth of 40-60 cm generally have the best heartwood suitable for carving as well as for oil extraction (Shankaranarayana *et al.*, 1998). The depletion of sandal forest is attributed to factors like illicit felling, disease and smuggling, which are very rampant and is the major problem in all the sandal growing states (Rao *et al.*, 1999). Smuggling ultimately results in genetic erosion because smugglers remove genetically superior trees (Venkatesan, 1995). Umashankar *et al.* (2000) reported a decline in genetic diversity of natural population due to indiscriminate extraction of sandalwood.

The annual production of sandalwood has declined from 4000 tonnes in 1965-1975 to nearly 2000 tonnes during 1999-2000. The oil production has also decreased to 40-50 tonnes during 1999-2000 from 60 tonnes during 1981-1994 (Ananthapadmanabha, 2000). Production of sandal wood can be increased by extensive plantation of this species after properly understanding the host-parasite relationship, proper production of planting materials with prior knowledge of silviculture of this species. The regeneration and establishment of sandal has been problematic because of the poor understanding of host-parasite relationships (Surendran *et al.*, 1998). At the same time there are very few literatures indicating the relation of sandal with varying light quality and quantity. Understanding of the haustorial anatomy is also required as sandal takes up food materials from the host plants through this specialized tissue.

With these things in view, the present experiments were carried out with the following objectives:

1. To understand the effect of light quality and quantity in the growth of sandal seedlings.

2. To identify the nutritional deficiency symptoms in sandal seedlings.

3. To understand the translocation of photosynthates from hosts to sandal seedlings.

4. To elucidate the anatomy of sandal haustoria when grown with different host species.

Review of literature

REVIEW OF LITERATURE

The genus *Santalum* belongs to the family Santalaceae, which comprises herbs, shrubs and small trees. It has long been a source of sandalwood, a fragrant wood prized for its use in producing ornaments, cabinets and chests; incense for religious rites; and oil for perfume and medicines. *Santalum album* is the best known commercial species. It is found in southern India (but may have originally been introduced from Java, Indonesia), especially in Karnataka, Kerala and Tamil Nadu, and also in Sri Lanka and other parts of south-eastern Asia (Brandis, 1978). Various descriptions of it occur in Hindu mythology (Neil, 1990). Powdered wood in the form of a paste, with added pigments, is used in caste distinguishing marks (Drury, 1985).

Sandal (*Santalum album* Linn.) is a small to medium sized, evergreen hemi-parasitic tree with slender drooping branchlets, ordinarily attaining a height of 13.5 m to 16.5 m and a girth of 1.0 m to 1.5 m, though larger specimens are sometimes met with. In natural forests, the tree is observed in dry tropical forests. It is also seen in isolated farms and homesteads in Kerala.

Due to hemi parasitic nature of sandal, there are various problems associated with it. Sandal-host relationships, propagation methods, spike diseases, seed pre-treatment methods were the topic of interest for the sandal researchers. Tree improvement programmes, micropropagation of sandal and establishment of sandal plantations were getting attention in some parts of the world during the last few years. The literatures available on the relevant topics are reviewed in this chapter.

2.1 Host Plants

The hemi parasitic nature of sandal was established for the first time by Scott (1871). Later on, the parasitic behaviour of *Santalum* had been described by Barber

(1902 and 1907), Pilger (1935) and Rao (1942*a*). Barber (1902) found an abundance of root connections between sandal seedlings and other plants growing nearby. Rao (1903) and Lushington (1904) also could observe haustoria, which connect sandal roots to host plants and extract nutrients from the host.

The anatomy of the haustorial connections has been well studied. The haustoria of sandal, which rise laterally on roots, are exogenous. A young haustorium is formed by the epidermis and cortex of the root (Rao, 1942*a*). According to Pilger (1935), haustorium is derived from the root by the divisions of the cells of pericycle, endodermis and cortex. The young haustoria appear as small hemispherical outgrowths. The free end after coming in contact with the host gradually flattens.

Sandal tree is known to have sent out its roots up to a distance of 30 m for establishing the parasitic relationship (Rai and Sarma, 1986). Rao (1911) reported that the host, which is attacked by sandal, influences the extent and structure of haustoria. Taide (1991) in an anatomical study of sandal haustorium found that the sandal root and the host show direct vascular connections, which later undergoes secondary growth. The author also observed that vascular connection between the host and sandal becomes so intimate that host root and parasite root becomes almost a single physiological unit, catering to the nutritional requirements of the sandal.

The formation of haustoria is more or less confined to younger roots; the main roots probably take little part in the absorption of nutrients. If no host is met with, the haustoria remain small and ultimately wither away, but if a rootlet of a suitable host is met with, it grows rapidly assuming the shape of flattened bell. The experiments have found that sandal seedlings are incapable of growing beyond a year at the most unless nourished by attachment to the roots of other plants (Rao, 1903).

The obligate parasitic nature of sandal is known since long, but there is no precise information about the nature and degree of its dependence on host. The presence of favoured host is considered to improve the establishment and growth of sandal.

Various researches have identified and classified several hosts of sandal. Iyengar (1965) has published a list of all known hosts till that time. The sandal hosts have been classified as good, medium and poor based on the complementary influence of the host species on sandal growth (Ananthapadmanabha *et al.,* 1984). In Australia the hosts are generally categorized into three groups namely pot, intermediate and long term hosts (Fox *et al.,* 1990). All the three are critical for adequate survival and growth of sandal at various stages of growth of sandal and at various stages of the plantation growth. Characteristics of suitable pot host include fine root growth and even distribution of roots within the pot, ability to withstand top pruning, low level of competition, low allelopathic influences, low growth structure and persistence in the field after planting out (Fox and Doronila, 1993). Srinivasan *et al.* (1992) has recommended *Cajanus cajan* as a good primary host for sandal in the seedling stage-whereas Surendran *et al.* (1998) reported *Albizia saman* as the best life time host for sandal based on growth attributes and amenability for pruning.

In India, earlier researchers have identified a range of pot hosts for the establishment of sandal plantations. Barber (1907) gave a list of 122 species and later Rao (1918) for 144 species of sandal hosts. Out of a large number of associates of sandal found in its natural habitat, it is difficult to classify the most favorable or suitable host species as sandal may show preference for different plants in different situations. The favoured hosts reported are *Desmanthus virgatus* (L.) Willd, *Alternanthera* spp. Forskal, *Crotalaria juncea* in Timor (Surata, 1992), *Calotropis procera* (Aiton) W.T. Aiton, *Cassia siamea* L., *Calliandra calothyrus* Meissn (Shinde *et al.,* 1993), *Cajanus cajan* Huth (Rai, 1990) and *Casuarina equisetifolia* (Taide, 1991 and Varghese, 1997).

Radomiljac (1998) reported that considerable variation exists between pot hosts in increasing the sandal survival and growth. Consequently, the utilization of appropriate pot hosts is critical to ensure successful sandal plantation establishment.

Establishment of sandal plantations was mostly not successful due to several reasons. Being a semi parasite, the silvicultural requirements are unique and there is no adequate understanding of the same. Even though many investigations for identifying the best host for sandal in India and other countries are available, the growth stage at which the sandal needs the presence of a host and the complementary and competitive interactions between sandal and the host plants are not available in both India or abroad.

Thus, it can be concluded that host selection and its management require close investigations, as it is the single most important silvicultural parameter deciding the establishment and growth of sandal plantations. Although many plant species have been described by various authors as host plants of sandal, the requirement stages of the host plants in *Santalum album* are still unknown. At the same time, the classification of various host plant species into different categories needs further improvements and investigations.

2.2 The Role of Host

The role of host plants in sandal tree, which is having independent root system and evergreen canopy capable of photosynthesizing, has aroused a lot of curiosity among the researchers. There are several reports indicating the necessity of host plants for acquiring some of the plant nutrients by sandal.

Srimathi *et al.* (1961) found that leaves of sandal plants did not have the basic amino acids in the absence of host, but when grown with leguminous plants, the sandal leaves showed high concentration of basic amino acids. Therefore, the authors concluded that for the supply of amino acids, sandal plant is dependent on its host. Iyengar (1965) reported that the dependence of sandal on the host is mainly confined to N and P, whereas it can directly absorb Ca and K.

Self-parasitism, a phenomenon in which a plant establishes haustorial connections with the same species was also observed in sandal by Iyengar (1965). Ananthapadmanabha *el al.* (1984) in a pot culture study observed that in many instances sandal seedlings have drawn the nutrients from hosts, but there are instances where some hosts derived benefit from sandal, by getting some amount of P, Ca, Mg. Rangaswamy *et al.* (1986) also suggested that sandal depends on its host for P, K and Mg and that in the absence of a host plant, it is incapable of growing normally.

Comparative analysis of leaves of sandal plants grown independent or with host shows appreciable differences in the mineral constituent of the leaves. The associations of host brought about higher accumulation of minerals and consequently better growth of sandal plants. In treatments without association of host plants, in spite of higher N content in the leaves, sandal showed poor growth. The experiments further indicated that the sandal plants depend on the host for P, K and Mg, although the plants not associated with hosts are capable of absorbing some minerals, but not enough to sustain growth (Rangaswamy *et al.*, 1986).

Kamalolbhavan (2002) reported the occurrence of sandal-Arbuscular Mycorrhizal Fungi (AMF) associations in natural sandal growing forests and investigated the response of sandal seedlings to inoculation with commonly available cultures of AMF, shade levels and nature of host in a pot culture experiment. He reported that 50 per cent shade is the most favourable for the growth of sandal as well as for the better colonization of AMF.

Hence, it can be concluded that the interactions of sandal and host plants for the uptake and translocation of various mineral nutrients are very complex and need very precise and vivid researches. The manner of uptake of the mineral nutrients also needs to be understood very clearly in order to identify the physiological and anatomical formation of haustorium in sandal.

2.3 Haustorial Anatomy

The ecology, growth and host preference of the root hemiparasite *Santalum album* L. have been well documented (Ananthapadmanabha *et al.*, 1984; Radomiljac *et al.*, 1998; Radomiljac, 1999; Tennakoon *et al.*, 2001). While the functional attributes of *Santalum*-host interactions are relatively well understood, the structure and development of the *Santalum*-host interface and its implications for parasite nutrition have received little attention in the literature.

Parasitism in the angiosperms has evolved on at least seven separate occasions (Nickrent and Duff, 1996). Parasitic plants are a diverse polyphyletic group containing 3000 species and representing around 1 per cent of all plant species (Musselman and Press, 1995). They access their host's resources through a key organ called the haustorium, which provides a physical as well as a physiological bridge between the parasite and host, directing the host's resources to the parasite and functioning at the multiple stages in the parasitism (Kujit, 1969). A broad diversity is found in the internal structure of haustoria belonging to the different parasitic plant species (Hibberd and Jescheke, 2001). The morphology of the haustorium is directly related to the mechanism employed by the parasite to access host resources through either direct vascular continuity, interfacial parenchyma, or a combination of both (Pate *et al.*, 1990). Furthermore, there is variability in the extent to which different nutrients and solutes are obtained by parasitic plants (Jiang, 2004). Riopel and Timko (1995) highlighted a structure of *Santalum album* called hyaline body, which is rich in nuclei, believed to be involved in resource translocation and processing. The other structures are the endophyte or the penetration peg (the projection of which enters the host root tissue), and the ellipsoidal disc (laterally flattened, relative to the host root, against the host's stele and the point of contact between the parasite and its host's vascular system) (Tennakoon and Cameron, 2006). Solute acquisition by *S. album* is not fully understood; increasing evidence points to the important role played by the unique structure and morphology of the juncture between *S. album* and its host. The type and magnitude of resource fluxes (nutrients, hormones and water) from the parasitized host via haustoria directly affect the growth and development of *S. album* (Tennakoon and Cameron, 2006).

There are few studies investigating the anatomy and development of haustoria formed by *S. album* on any of its common hosts. Barber (1906, 1907) and Rao (1942*a*) undertook the first studies of the interaction between *S. album* and some of its hosts. In contrast to many other root parasitic genera in the Orobanchaceae, Balanophoraceae, Rafflesiaceae and Lennoaceae, no involvement of chemical signals derived from the host roots of *S. album* in relation to the successful haustorial initiation and establishment was observed (Stewart and Press, 1990). However, close examination of the fully functional young haustoria revealed the presence of a darkly staining (purple) mucilaginous substance produced by the initial contact surface of the haustorium (Tennakoon and Cameron, 2006). The role and identity of this substance is unknown, although Baird and Riopel (1983) reported such exudation by the parasitic plant *Agalinis purpurea* and concluded that it was a hemicellulose compound.

Following attachment to compatible host roots, intrusive cells of haustoria penetrated the host epidermis and cortex between host cells. Concurrent with this endophytic development, the cortical fold of the haustorium partly encircled the host root (Tennakoon and Cameron, 2006). Similar observations have been reported for species of *Orobanche* (Lane *et al.*, 1991), *Striga* (Losner-Goshen *et al.*, 1998) and

Rhinanthus (Cameron *et al.*, 2005) species. The mature *S. album* haustorium consists of two regions, one external to the host root, the hyaline body, a structure with high metabolic activity and the penetration peg that makes the initial contact with the host root and penetrates the host tissue (Riopel and Timko, 1995).

According to Tennakoon and Cameron (2006), the finger-like projections of the developing endophyte extend up to the cambial tissue of the host root during the initial establishment of the haustorium. This tissue is mainly composed of characteristically elongated (tubular) thin walled parenchyma cells. As the projections elongated towards the host root xylem, they entwined with each other and gave a tubular appearance to the cells.

There was no biochemical evidence to support the involvement of either pressure or cell-wall-degrading enzymes in the development of *S. album* haustoria, although these factors are associated with the penetration process of haustoria formed by many other species of parasitic plants (Fineran and Hocking, 1983; Calladine and Pate, 2000), including Santalaceae (Rao, 1942*b*).

Darkly staining material at the host parasite interface of many parasitic plants has been described in many literatures (Dobbins and Kujit, 1974; Musselman and Dickison, 1975; Losner-Goshen *et al.*, 1998; Kuo *et al.*, 1989; Cameron, 2004). Tennakoon and Cameron (2006) illustrated the presence of darkly staining material at the host-parasite interface in the *S. album* – *Tithonia diversifolia* association. They also concluded that these may be the secretions (tip lysis) of tubular contact parenchyma emptied onto the surface of the host. This extruded material potentially aids in the firm adhesion of parasite tissue to host. However, some reports have suggested that these substances may aid penetration into host tissue (Heide-Jorgensen, 1989) or, in incompatible interactions, may represent induced defenses in the host (Gurney *et al.*, 2003; Cameron, 2004).

Santalum album haustoria resembled the majority of other root hemiparasites' haustoria in lacking phloem connections with hosts (Pate, 2001; Shen *et al.*, 2006; Tennakoon and Cameron, 2006). There are relatively few xylem elements in the haustorium that are typically short tracheary elements. Investigation by Tennakoon and Cameron (2006) revealed that direct lumen-lumen xylem connections between the xylem of the host and parasite are absent.

Hence, it can be concluded that haustorial formation is a very complex physical and physiological processes between host plants and sandal, which still need many researches and investigations before coming to a conclusion.

2.4 Nutrients Uptake

Many of the earlier workers were of the view that sandal probably is an obligate parasite entirely dependent upon the host for its nutrients (Barber, 1903; Lushington, 1904; Rangaswami and Griffith, 1939). But Brandis (1903) suggested that sandal may derive part of its nutrition from soil also. Later many workers have conducted isolation experiments by trenching to assert the extent of parasitism. But there was no consensus of opinion, to some it seemed like an obligate parasite while for others it was not so (Iyengar, 1965).

Rao (1933) after studying the parasite with and without host *Acacia farnesiana*, concluded that sandal depends on its hosts for N, P and K while Ca and Fe appear to be directly derived from soil. After studying soils under healthy and spiked sandal Iyengar (1965) concluded that sandal depends on the hosts for N and P while Ca and K are absorbed through roots from soil. He thus negated the view that sandal is an obligate parasite. He suggested that Ca/N ratio in the sandal may represent the balance of activity between root ends and haustoria. Rao (1938) reported that certain principles of the host such as the bitter principle in *Strychnos nuxvomica* and *Azadirachta indica* were translocated to the leaves of sandal. Iyengar

(1965) in a study of physiology of root parasitism in sandal stressed the Barber's view that in a healthy sandal both root ends and haustoria are very active, while in spiked sandal both of them have ceased to function.

Tracer technique studies have shown that calcium could be absorbed by the roots of sandal seedlings, while phosphate, organic substances, amino acids, sugar and mineral phosphates were drawn from the host plant (Kunda *et al.*, 1974*a*, 1974*b*). Rangaswamy *et al.* (1986) after examining the soil and leaf nutrient levels of a sandal experimental plot indicated that sandal wood depends on the host for P, K and Mg and in the absence of a host plant it is not capable of growing normally. Subbarao *et al.* (1990) observed that sandal formed direct haustorial connections with root nodules of nodulating legumes in the field. In pot culture studies with sandal, *Cajanus cajan* and *Pongamia pinnata,* it was confirmed and the number of nodules and the N content of plants decreased in parasitized nodulating species with corresponding increase in N content of sandal plants.

Nayar and Ananthapadmanabha (1974) in a bioassay of tetracycline uptake in spiked sandal observed that there is movement of tetracyclines from sandal to the host and host to sandal. The authors concluded that the haustorial connections may be permitting movement of substances in both the ways. Ananthapadmanabha *et al.* (1988) in a pot culture study observed that in most instances sandal plants have drawn nutrients from hosts, but some hosts derived benefit from sandal in getting some amount of P, Ca, Mg and N. This increase in the mineral elements in the hosts, when found associated with sandal might be possible by reverse transfer or by antagonistic processes, to the extent that the haustorial connections may serve as two way traffic.

Srimathi *et al.* (1961) found that leaves of sandal plants did not have the basic amino acids in the absence of host, but when grown with leguminous plants, the sandal leaves showed high concentration of basic amino acids. Therefore, the authors concluded that for the supply of amino acids, sandal plant is dependent on its host.

Varghese (1997) using radiotracer technique found that sandal plants could take up Ca directly from soil and its dependence on host for calcium was negligible. The author also concluded that redgram parasitized by sandal had a higher uptake of Ca than the redgram grown alone, which may have been caused by the increased cation exchange capacity of roots of the parasitized plant. It was also observed that sandal could take up S directly from soil and its dependence on hosts for sulphur was negligible. Haustoria acted as a two directional path way in the translocation of S *i.e.* from sandal to host and host to sandal. He also found that sandal could take up P directly from soil and host may also provide a small fraction of the P requirement of sandal. If the soil source is not limiting, sandal may not have to depend on the hosts for P. It was also found that hosts differed in their ability to supply P to sandal and casuarina was superior in supplying P to sandal than erythrina. He also concluded that there was a translocation of carbon compounds between sandal and hosts and the extent of transfer varied depending upon the host plants.

Thus, it can be concluded that sandal needs a host plant for its normal growth as it depends on the host plants for a variety of nutrients. However, the reasons for the uptake of nutrient elements by the sandal plant from the host species are still unclear. At the same time, the nutrient elements needed by the sandal from the host species for normal growth and physiological functioning are also not clearly known.

2.5 Effects of Light on Plant Growth

Sunlight is the primary source of energy for all life activities and all living beings depend on sunlight for their sustenance, either directly or indirectly. Light, as a main environmental trigger, plays a central role in regulating plant development. Most terrestrial plants grow by selective absorption of natural light from the sun. The green plants fix carbondioxide in the form of soluble carbohydrates in the presence of water and sunlight. This is the basis of dry matter production. Requirement of sunlight varies between different species of plants. However, it is a well established fact that sunlight is the prime factor determining the physiological activities and growth of plants. Light is the visible part of the spectrum of solar radiant energy and it comprises radiation of wave lengths, ranging from 390 nm to 670 nm. Among seven spectrum of sunlight, blue (430-460 nm) and red (610-700 nm) light has greater contribution in photosynthesis. Both light intensity and quality affect germination, growth and differentiation (Ichihashi, 1982 and Economou and Read, 1987). The intensity, duration and amount of light falling on earth vary greatly. The degree of shade is a key determinant of light related functions of the plant body. The most effective components of the spectrum of light are red (R), far-red (FR) and blue. These lights are involved in the regulation of photosynthesis, pigment biosynthesis, photoperiodism, phototropism and photomorphogensis. The photomorphogenetic response of plants to light include seed germination, inhibition of hypocotyl elongation, cotyledon and leaf expansion, pigment synthesis, stem elongation and induction of flowering (Weller *et al.*, 2000). Some of the studies were conducted on the effect of various levels of shade and light quality on the growth and productivity of plants. However, such studies are very scanty in tropical tree species, particularly in *Santalum album.*

2.5.1 Effect of light on growth of shoot

Fairbarian and Neustein (1970) reported that seedlings of six species *viz. Ricea sitchensis, Pseudotsuga menziesii, Tsuga heterophylla, Abies grandis, Picea abies* and *Abies alba* showed highest shoot length when grown under 50 per cent shade. However, collar diameter, ratio of collar diameter to shoot length and total dry weight showed highest values when grown under full sunlight. In *Casuarina equisetifolia,* height of seedlings was reported to be unaffected by shading, but dry weight was maximum in full sunlight (Shafiq *et al.*, 1974).

Seedlings of *Pinus sylvestris, P. nigra, Tilia tomentosa, Acer pseudoplatanus, Quercus petraea* and *Fagus sylvatica* when grown in 100, 50, 25 and 12.5 per cent of full sunlight upto a period of eight years showed that except *Tilia tomentosa,* all other species produced greater aerial biomass under full sunlight, whereas *T. tomentosa* performed well under 50 per cent shade (Lyapova and Palashev, 1982).

Rao and Singh (1985) studied the growth of seedlings of *Pinus roxburghii* and *Quercus butrichopleorea* under 100, 70, 50 and 18 per cent sunlight and concluded that *P. roxburghii* was less tolerant to shade. Studies on the effect of shade on seedlings of *Shorea almon, Parashorea malanonan, Anisoptera thurifera, Shorea polyspermum, Hopea parviflora* and *Vatica mangachopi* indicated that in all the species, maximum growth in height, diameter and dry weight was observed when plants were grown in full sunlight (Suzuki and Jacaline, 1986).

Bush and Auken (1987) showed that light intensity had substantial relationship with the growth of aerial parts of plants, especially at seedling stage of *Prosopis glandulosa*. Light intensity increased stem length, dry weight and basal diameter of the seedlings. Decrease in sunlight leads to a reduction in the diameter growth and number of side shoots in seedlings of *Pinus sibirica* (Yushkov and Zavi'yalova, 1988).

Platanus orientalis performed best in full sunlight with respect to height, diameter and biomass, while *S. torminalis* did best at 50 per cent light and *C. avelana* in both 50 and 25 per cent light (Lyapova and Palashev, 1988).

In the seedlings of *Pinus contorta*, simulated shade was found to increase tracheid number and diameter and wall thickness of xylem and phloem. There were all anatomical modifications caused due to shade (Caesar, 1990). Orians (1991) studied the response of *Inga oerstediana* grown under three different light environments viz., the under storey, tree fall gap and full sunlight. Growth of the plant was found to be better when grown under full sunlight compared to other situations. The three evergreen conifers *Abies scholinensis, Picea jenfonensis* and *P. glehnii,* showed variations in tolerance to shade levels. Ability to tolerate shade stress was higher for *A. schalinensis* compared to *Picea* sp. (Tujimoto and Shimada, 1991).

Responses of shade on growth of Douglas fir (*Pseudotsuga menziesii*), Western hemlock (*Tsuga heterophylla*) and Western red cedar (*Thuja plicatus*) was studied by Carter (1992) and found that Western red cedar performed better at lower light levels compared to other species.

Quercus lobata, Q. douglasii and *Q. agrifolia* were grown under different shade levels and full sunlight. No variations were noticed in growth with regard to different shade levels. In *Q. lobata* and *Q. douglasii* shade did not affect the seedling biomass (Callaway, 1992). Cornelissen (1992) studied the growth of *Gordonia acuminata* grown under four shade levels (55%, 33%, 18% and 0%). Best growth was noticed at 33 per cent shade. Studies done by Oscinkoya and Ash (1992) with six species at 37, 10 and 2.5 per cent shades showed the positive effect of 37 per cent shade on shoot growth of all the species.

Seedlings of *Azadirachta indica* recorded more height and collar diameter under open conditions, while seedlings of *Leucaena leucocephala* recorded more girth when grown under 25 and 50 per cent shade levels. However, height was more when *L. leucocephala* was grown under 25 per cent shade (Vimal, 1993). Cregg and Teskey (1993) in loblolly pine observed a reduction in growth in the shaded seedlings. Studies using seedlings of *Pinus brutia, Cupressus sempervirens* and *Casuarina equisetifolia* showed that in *P. brutia,* plant height and weight of branches were greatest and number of branches least when grown under 25 per cent shade. However, in *Cupressus sempervirens* maximum plant height, weight and number of branches were produced under 75 per cent shade.

Sharma *et al.* (1994) conducted a study on the growth behaviour of *Enicostemma littorale,* a medicinal plant grown under full light and shade conditions. Vegetative growth attributes, including height, fresh weight, dry weight, number of leaves and number of branches, were enhanced when grown under shade compared to full sunlight. However, flower production was found to be reduced due to shade. The effect of shade on seedlings of *Dalbergia sissoo, Acacia catechu* and *Casuarina equisetifolia* were studied under nursery conditions in Uttar Pradesh (Saxena *et al.*, 1995). Artificial shade was provided by using varying layers of muslin clothes. Growth of *D. sissoo* and *A. catechu* was the maximum when grown under low shade condition while *C. equisetifolia* showed maximum growth in unshaded conditions. Root/shoot ratio was found to be lowest in *C. equisetifolia.* In all the species, increment in height and stem diameter per unit dry weight was greater when grown under higher shade conditions. Barizan *et al.* (1996) studied the growth and survival of *Hopea odorata* grown under different light conditions and fertilizer levels in Malaysia. Three different conditions were selected viz., open area with compacted soil (80-100% of opening), a partially shaded gap with less compacted soil (30-60% opening) and closed canopy areas, not subjected to silvicultural treatments. The mean growth of seedlings in terms of height and girth was significantly better under first and third situations. The height increment of seedlings under the third condition was very low compared to the others.

In *Phyllanthus stipulatus* the plant height was found to be higher when grown under 30 per cent shade than in sun in a study done in Brazil (Silva *et al.,* 1997). The effect of light quality on the growth and flowering of Chrysanthemum cultivars under glass house conditions provided with three different colour filters indicated the plant height was significantly affected by light quality and temperature. The plant height was found to be regulated by the action of both phytochrome and a blue acting photoreceptor (Khattak *et. al.,* 1997).

A study done to find out the effect of shade (0, 55 and 95%) on *Hibiscus syriacus* L. showed that the shoot lengths of most of the cultivars were longer in shade grown plants compared to control plants. Two cultivars showed a reduction in height compared to control plants. However, shoot dry weights under 95 per cent shade, compared to control plants did not show any substantial variations. But there was a reduction of root dry weight in some cultivars (Yoo and Kim, 1997).

Alphalo and Lehto (1997) studied the effect of quality of light on the growth of birch seedlings. During the first 15 days, largest effect of light was on height growth, which was greater for seedlings grown in simulated shade light. During this period, light quality was found to have little effect on dry weight and N allocation to stem.

Chen (1997) studies on interspecific responses of planted seedlings to light availability revealed that with decreasing light availability, did not affect survival of *Pseudotsuga menziesii* and *Picea engelmannii* seedlings while in *Pinus ponderosa* seedlings survival rate was reduced significantly. The seedlings of *Picea engelmannii* recorded maximum reduction in height growth, while *P. menziesii* recorded maximum reduction in diameter growth with decreasing light. Height-diameter ratio remained almost constant in *P. ponderosa*. They also observed that morphological characters were more plastic in shade tolerant species.

Growth of *Cryptocaria aschersoniana* seedlings under different light regimes viz.; 0, 50, 70 and 90 per cent in the nursery was studied by Rezende *et al.* (1998). Maximum height growth was recorded for 90 per cent shade followed by 50 per cent shade. More or less similar trend was noticed with regard to collar diameter also. Williams *et al.* (1999) found that the shade tolerance of Douglas fir *(Pseudotsuga menziesii)* and Lodgepole pine *(Pinus contorta)* was found to be more when grown in dry sites compared to moist sites.

The seedlings of *Grevillea robusta, Tectona grandis* and *Ailanthus triphysa* were grown under varying shade conditions and full light. Seedlings of *G. robusta* and *T. grandis* performed well under full sunlight, while *Ailanthus triphysa* performed well under 75 per cent shade with regard to stem height, diameter and shoot dry weight (Saju *et al.,* 2000). The leaf and root growth parameters were also found to be influenced by shade.

Taulavuori *et al.* (2005) reported that the elongation of Scots pine seedlings was increased by the removal of blue light only at high latitudes. Mateen and Simon (2005) also reported that Antirrhinum plant showed maximum height when grown under blue absorbing filter as compared to plants under different filters *viz.* 'red absorbing', 'blue absorbing', 'blue and red absorbing' and two 'partially blue absorbing' and one clear polythene as a control. Baiyeri (2006) also reported that plant height was the maximum in *Carica papaya* when grown under green polyethylene shade when it was grown under different filters *viz.* blue, green, yellow, red, colourless polyethylene, palm-frond (*Elaeis guineensis* Jacq) and non-shaded frame. Ravindra (2007) found that twig weight was highest in open condition followed by 25 per cent, 50 per cent and 75 per cent in *Mucuna pruriens* (L.) DC.

Hence it is clear that plant species respond to varying light conditions in a variety of ways with regard to shoot growth parameters and the responses differ from one species to another species. The response may sometimes differ in the same species according to the environmental conditions as plant responds to an array of environmental factors.

2.5.2 Effect of light on leaf growth parameters

Wadsworth and Lawton (1968) conducted studies on the effect of shade in *Pinus caribea, Eucalyptus deglupta* and *Khaya grandifolia* seedlings and reported an increase in leaf area ratio with increase in shade. In maple and aspen, increase in shade reduced the leaf thickness while number of layers and length of palisade cells increased in the intercellular spaces in spongy parenchyma. In oak and birch, however, shading had less marked effect on structure and thickness of leaf (Malkina and Kovalev, 1973). On the contrary, Scifres *et al.* (1973) reported that increase in shading decreased leaf area of seedlings of *Prosopis glandulosa.* In *Betula pendula* and *B. pubescens* seedlings, shading was found to increase the specific leaf area with a decrease in leaf mesophyll thickness and amount of chlorophyll per unit area of leaf (Nygren and Kēllōmaki, 1983).

Masarovicova (1985) reported that *Fagus sylvatica* grown under different shade levels showed an increase in average leaf area, specific leaf area and leaf mass with increased light intensity. In seedlings of *Guarea gindimia,* larger leaves were produced in shade, but with thinner blades and lower specific weight (Fischer, 1986). Singh (1986) studied the effect of light intensity on growth and yield of rain fed cotton and found that low irradiance increased the Leaf Area Ratio (LAR), but decreased the relative growth rate, leaf area and net assimilation rate.

Studies by Bush and Auken (1987) using *Prosopis glandulosa* seedlings revealed that maximum leaf and leaf dry weight were produced as a result of full sunlight. In *Acacia tortilis,* leaf area ratio increased with decreasing light intensity (Smith and Shackleton, 1988). In *Betula pendula,* as PAR decreased, reduction in leaf extension was observed. However, in *Acer pseudoplantanus,* it had no effect (Taylor and Davies, 1988). Fitter and Ashmore (1989) found that *Veronica montana* seedlings were unaffected by supplementary far red radiation, while *V. persica* showed a reduction in leaf area in response to supplementary far-red radiation. *Shorea trapezifolia* seedlings showed no effect with regard to number of leaves when grown in partial shade or full sunlight (Ashton and Zoysa, 1989). Kim (1989) found that in *Pinus torainensis* seedlings, growth in leaf area was most rapid at 63 per cent Relative Light Intensity (RLI) and slowest at 19 per cent RLI. Hazra (1989) reported that there was an increase in the leaf production in pulses, for plants exposed to sunlight when compared to those under tree canopy. The seedlings of *Nothofagus procera* when grown under partial shade resulted in the production of less number of leaves (Igboanugo, 1990).

Allard *et al.* (1991) reported an increase in leaf area under shade in tall fescue grass. Low irradiance was found to increase the leaf area ratio, but decreased the relative growth rate and net assimilation rate. Callaway (1992) studied the changes in leaf area of *Quercus lobata, Q. douglas* and *Q. agrifolia* seedlings when grown under 10 per cent, 30 per cent and 100 per cent sunlight. Total leaf area of *Q. lobata* and *Q. douglasii* did not increase due to shade whereas at 10 per cent shade, *Q. agrifolia* seedlings produced greater leaf area.

Kuapp (1992) studied the rate of net photosynthesis, stomatal conductance to water vapour and leaf xylem pressure potential of deciduous *Quercus macrocarpa* when grown under attenuating periods of sun and shade. Photosynthesis was found to be high under full sun while stomatal conductance to water vapour was higher in shade.

Potted seedlings of *Acacia mangium, A. auriculiformis* and *A. mearnsii* were grown under different shade condition. Leaf area was reported to be in maximum in *A. mearnsii* and least in *A. auriculiformis* due to shade. The chlorophyll ratios were found to be reduced with decrease in light levels (Lovelock, 1992). In *Pongamia pinnata,* the leaf area was found to be increased due to increase in shade (Naidu and Swami, 1993). *Ailanthus triphysa* and *Leucaena leucocephala* seedlings showed maximum leaf weight under 25 per cent shade while *Azadirachta indica* showed the maximum weight under 50 per cent shade (Vimal, 1993).

Sharma *et al.* (1994) studied the growth behaviour of *Enicostemma littorale* grown under light and shade conditions. The number of leaves and branches was enhanced when grown under shade compared to full sunlight. Saebo *et al.* (1995) also reported that the highest chlorophyll content in *Betula pendula* was found in cultures irradiated with blue light. McKendrick (1996) studied the influence of different photosynthetic photon fluence rates (PPFR) of 24, 54 and 225 μ mol m^{-2} s^{-1} on the British orchids namely *Orchis morio* and *Dactylorhiza fuchsii* and also on dicotyledonous perennial *Leontodon hispidus*. Orchids tolerated more shade than *L. hispidus*. A decrease in PPFR caused a decrease in dry weight and an increase in specific leaf area. Growth of *L. hispidus* was found to be affected by reduction in PPFR compared to orchids.

Gross *et al.* (1996) has reported the effect of shade on stomatal conductance, net photosynthesis, photochemical efficiency and growth of oak saplings in relation to full and 50 per cent sunlight. Stomatal conductance and photosynthesis were found to be increased in open field while shaded plants produced larger leaves with fewer stomata per unit leaf area. The chlorophyll content was also found higher under shade.

Studies on seedling development under varying photon flux density (PFD) and spectral quality (red to far red) along with various shade levels of 40, 12 and 3 per cent PFD revealed that total height, internode distance, stem length, leaf area, percentage allocation to leaf, stem and root mass, specific leaf mass, mean leaf area and stomatal density were dependent on light intensity (Lee *et al.,* 1996*a*).

Influence of shade on specific leaf weight, leaf thickness and internal structure of leaves of *Euonymus japonicus* cv. Luna was studied by Hosni and Shehata (1996) in Egypt. Compared to control, shade increased leaf area with reduced leaf thickness per leaf. Leaf fresh weight was found to be reduced, when grown under 65 per cent shade. The specific leaf weight was also reduced by shading. Moreover shading reduced the thickness of palisade layer by 37 to 45 per cent.

Production of pigment, proline, protein and polyamines in *Aloe arborescence, A. saponaria* and *A. vera* grown under sunlight and shade was studied by Lee *et al.* (1996*b*). Plants grown in open field under full sunlight contained more chlorophyll than those grown in shade. *Aloe arborescence* and *A. saponaria* when grown under shade was found to contain less anthocyanins and carotenoids than those grown in open sunlight. The proline, protein and polyamine contents of *A. arborescence* and *A. saponaria* decreased due to shade. However, the shade was not having any effect on *A. vera* with regard to above parameters.

Hampson *et al.* (1996) conducted a study to quantify the effect of shade on reproduction and photosynthetic rate in seedlings of Hazelnut, a shade tolerant species. Plants were grown under 30, 47, 63, 73 and 92 per cent shade levels. Leaf area increased by 49 per cent and chlorophyll concentration by 157 per cent as shading increased from 0 to 92 per cent. The 92 per cent shading treatment reduced specific leaf weight, stomatal density and light compensation point compared to the control. Grubb *et al.* (1996) studied the interaction of irradiance and soil nutrient supply on growth of *Fagus sylvatica* and *Juniperus communis. Fagus sylvatica* responded moderately to irradiance and not to nutrient supply. In shade, allocation of nutrients to roots decreased while that to stem and leaves increased. In all the species, shade was found negatively affecting the number of leaves, total leaf area, and shoot and root length.

Studies on chlorophyll content, N and non structural carbohydrates in leaves with a natural light gradient in *Acer platanoides, Padus avium, Populus tremula* and *Quercus robur* seedlings showed that leaf dry mass per area increased linearly with increasing relative irradiance. Decreasing irradiance enhanced chlorophyll per leaf dry mass. Average N content per mass increased and maximum concentrations of leaf N shifted towards more open habitats with decreasing shade tolerance. More tolerant species recorded greater concentration of foliar N at low irradiance. The leaf N concentration in relation to irradiance was found to play a central role in shade tolerance of species (Niinemets, 1997). A functional relationship was proposed between leaf area, shade tolerance and light availability of tree species by Raulier and Ung (1997). Shade was found to have no effect on dispersal, establishment and survival of *Ceriops tagal* propagules in North Australian mangrove forest (McGuinness, 1997).

Nam *et al.* (1997) studied the effect of shade (0, 50, 80 or 95%) on chlorophyll content and degree of variegation of *Epipremnum aureum* and *E. aureum* (cv. Lime). Chlorophyll content in variegated plants was highest under 50 per cent shade, whereas in *E. aureum* (cv. Lime), highest chlorophyll content was noted under 80 per cent shade. Ratio between chlorophyll-a and chlorophyll-b decreased as light intensity increased. In variegated *E. aureum*, 23 and 7 per cent of the leaf area was seen to be variegated respectively under 0 and 95 per cent shade. Number of variegated leaves also increased with increasing light intensity.

The effect of three levels of irradiance (100%, 56% and 33%) on C and N allocation in *Dicanthium aristalum* was studied in pot experiments under well watered and well fertilized conditions. Under 100 and 50 per cent of full sunlight, more N was allocated to the thicker shoot component. This situation was reversed in lowest radiation level, indicating that N reserves might limit the growth of this perennial grass under high levels of shade. A higher shoot to root ratio under shade was also noticed here (Cruz, 1998).

Studies on growth and nutrient uptake of *Dicanthium aristatum* grown in full sunlight or under tree shade with light transmission levels (ranging from 80-30% of total PAR) were conducted by Cruz (1997). It was found that dry matter production and leaf area index were not depressed by reduction of incoming PAR. Johnston and Onwueme (1998) studied the effect of shade on the production of photosynthetic pigments in tropical root crops. Total chlorophyll concentration was higher while the chlorophyll-a to chlorophyll-b ratio and carotenoides per unit area of leaf were lower under shade particularly with regard to *Dioscorea esculenta, Colocasia esculenta, Xanthosoma sagittifolium, Manihot esculenta* and *Ipomea batatas*. All the species produced larger leaves and more chlorophyll per leaf when grown under shade. Depending on shade tolerance their leaf size and weight also varied.

Studies done on some broad leaved trees and conifers revealed that more shade tolerant species generally possessed a lower leaf area ratio. Leaf N content was generally lower in more shade tolerant broad-leafed species (Kerstiens, 1998).

Suk and Ja (1998) studied the growth and flowering of *Orostachys iwarenge* as influenced by day length and light intensity. Leaf width and leaf length increased more under short or intermediate photoperiods than under long day conditions. The leaf number decreased significantly with increase in shade. In shade, leaf orientation turned downward as against upward orientation in full sunlight.

Mazzei *et al.* (1998) studied the growth of *Schefflera morototoni* seedlings in the nursery at 0, 50, 70 and 90 per cent shade. Seedlings grown under open recorded the smallest average with regard to all growth parameter except for root and shoot ratio which was the least under 90 per cent shade. Generally, an intermediate shade was found most favourable for development.

Vyas and Nein (1999) studied the effect of shade on growth of *Cassia angustifolia*. Shade was found to increase node number, leaf number, leaf area and length of internodes. The leaf area of plants exposed to shade also increased and followed the pattern similar to other growth parameters. The leaf: stem ratio and leaf: area ratio increased by 37.4 and 30.4 per cent respectively at 25 per cent shade compared to unshaded plants. Studies conducted at Vellanikkara revealed that in *Grevillea robusta* and *Tectona grandis* seedlings, shade reduced leaf area, leaf size and leaf dry weight (Saju *et al.*, 2000).

Baiyeri (2006) also reported that *Carica papaya* under green polyethylene shade gave the highest leaf-count when grown under different light qualities *viz.* blue, green, yellow, red, colourless polyethylene, palm frond (*Elaeis guineensis* Jacq) and non-shaded frame. Zalewska and Wozny (2006) also reported that Chrysanthemums grown while exposed to blue light and short day demonstrated fewer leaves as compared with plants exposed to daylight.

In *Mucuna pruriens* (L.) DC., shade significantly affected N and K content in leaf tissues (Ravindra, 2007). The maximum N concentration was found in 75 per cent shade when compared to plants grown in 25 per cent, 50 per cent and open conditions. The highest K concentration was found in plants grown under 75 per cent shade level.

Thus, it can be concluded that different plant species respond differently to varying light conditions with regard to various leaf growth parameters.

2.5.3 Effect of light on growth of root

The growth and development of roots in relation to light availability was studied by many scientists. Seedlings of *Pinus dorsifolia* showed a reduction in root weight when grown under shade conditions (Negisi and Magi, 1986). The stem to shoot ratio of *Pinus koraiensis* was found to increase when grown under shade (Kim, 1987).

In *Pinus palustris* and *P. taeda* seedlings, root growth showed greatest response to light when grown in full sunlight conditions (Barret, 1989). Burmeister and Auken (1989) reported an increase in number and weight of root nodules with increasing light intensity. Seedlings of *Leucaena leucocephala* and *Azadirachta* *indica* showed maximum dry root weight when grown in open and minimum when grown under 75 per cent shade. However, *Ailanthus triphysa* recorded maximum root dry weight under 25 per cent and minimum under full sunlight (Vimal, 1993).

Kung-Fang *et al.* (1998) studied the root to shoot albometry and root architecture of understorey saplings grown in deciduous forests. Root to shoot ratio was found to be decreased rapidly with increasing plant height for saplings shorter than 1.5 m. Less shade tolerant species showed smaller root: shoot ratio. The planting depth was not found to be significantly related to shade tolerance.

Influence of light on the growth of nine tree species was studied by Reich *et al.* (1998). They found that under full sunlight conditions, the root length per unit plant mass *i.e.* root length ratio (RLR) increased in all the species. The shade intolerant deciduous tree species showed higher Relative Growth Rate (RGR) and specific root length (SRL), compared to evergreen species. Variations in interspecific RGR under high and low light intensities were found to be positively correlated with SRL and RLR.

A study was conducted to investigate the effect of different light conditions on germination and seedling growth of some selected forest tree species by Chathurvedi and Bajpai (1999) under three light conditions viz., semi shade, shade and full sunlight. The study revealed that root length was the maximum under semi shady condition in *Bridelia retusa* and *Holarrhaena antidysenterica*, while in *Lagerstroemia parviflora* and *Wrightia tinctoria,* it was maximum in full sunlight. Root to shoot ratio was highest under shady condition in *Holorrhena antidysenterica, L. parviflora* and *W. tinctoria.* The dry weight of root was found to be the maximum when grown under full sunlight in *Grevillea robusta* and *Tectona grandis*, whereas *Ailanthus triphysa* seedlings recorded more root weight when grown under shade (Saju *et al.*, 2000). Baiyeri (2006) reported that fresh weight of root in *Carica papaya* seedlings grown under green polyethylene shade performed the best among various types of filters *viz.* blue, green, yellow, red, colourless polyethylene, palm frond (*Elaeis guineensis* Jacq) and non-shaded frame. The highest root biomass in *Mucuna pruriens* (L.) DC. was recorded in case of seedlings grown under 75 per cent shade followed by 50 per cent and 25 per cent (Ravindra, 2007).

Hence, it can be concluded that root growth pattern differs from species to species with varying light qualities and quantities, which directly or indirectly affect the physiological functioning of the plant.

2.5.4 Effect of light on biomass production and yield

Robert (1971) found that in red oak (*Quercus rubra* L.), the tallest seedlings grown under 30 per cent light recorded lowest dry matter production. The author also observed that heavy shade leads to a higher concentration of nutrients in foliage. Lyapova and Palashev (1982) studied the growth of seedlings of *Pinus sylvestris, P. nigra, Tilia tomentosa, Acer psuedoplatanus, Quercus petrae* and *Fagus sylvatica* grown under 100, 50, 25 and 12.5 per cent of full sunlight up to eight years. The study revealed that except *Tilia tomentosa,* all other species produced greater aerial biomass under full sunlight. *Tilia tomentosa* performed well under 50 per cent shade.

Pathak *et al.* (1983) reported that *Leucaena leucocephala* seedlings raised under 45 per cent light conditions showed higher total dry matter production. Leong *et al.* (1985) reported that the CO_2 assimilation rates in *Asplenium australasicum* grown under red light were lower on a unit area or fresh weight basis, but higher on a chlorophyll basis, reflecting the higher levels of electron carriers and electron transport in the thylakoids when comparison was done with plants grown in blue and white light of equal intensity (50 microeinsteins per square meter per second). Studies on the effect of shade on seedlings of *Shorea almon, Parashorea malanonan, Anlsoptera thurifera, Shorea polyspermum, Hopea parviflora* and *Vatica mangachopi* seedlings indicated that in all the species, maximum growth in height, diameter and dry weight were observed when plants were grown under full sunlight (Suzuki and Jacaline, 1986). Bush and Auken (1987) reported that light intensity increased stem length, dry weight and basal diameter of seedlings of *Prosopis glandulosa.* A decrease in illumination was found to result in reduction of diameter growth and number of side shoots resulting more dry matter production in seedlings of *Pinus sibirica* (Yushkov and Zavi'yalova, 1988).

The seedlings of *Platanus orientalis, Sorbus torminalis* and *Corylus avelana* were grown under 100, 50, 25 and 12.5 per cent of full sunlight to study the impact of shading on growth (Lyapova and Palashev, 1988). Mortensen and Sandvik (1988) reported that seedling of Norway spruce (*Picea abies* L.) grown under blue light with a high red/far-red ratio decreased shoot length as well as total plant dry weight compared to natural light while yellow light with a low blue/red ratio did not significantly affect the plants when the seedlings were grown under three different light qualities in "fluid-roof" growth chambers *viz.* blue light with a high red/far-red ratio, yellow light with a low blue/red ratio and natural light. Biomass production in *S. torminalis* recorded the maximum at 50 per cent light while *C. avelana* at both 50 and 25 per cent light. Seedling biomass was seen unaffected due to shade in *Quercus agrifolia, Q. douglasii* and *Q. lobata* (Callaway, 1992).

Seedlings of *Amphopterugium adstringens, Caesalpinia eriostachys, C. playtylotia, Apoplanesia paniculata* and *Helicarpus pollidus* were grown under two light treatments viz. high (400 μ mol m^{-2} s^{-1}) and low (80 μ mol m^{-2} s^{-1}) to study the impact of light on growth. In all the species, relative growth rate and net assimilation rate were greater when grown under high light treatments (Rincon and Huante, 1993). Morphological features of the hemi-parasite *Santalum album* Linn. (Indian sandalwood) were examined on tree seedlings raised under different shade treatments by Barrett and Fox (1994). Treatment levels were varying from full sunlight to 80%

shade. They found that the level of shade significantly affected many morphological characteristics. Leaf area was the least in full sun and greater under all shade levels. Leaves were thicker, shorter and narrower in full sun than in 80% shade. Leaf length/width ratio was greater when shade exceeded 50%. Petioles were shorter in 50% and more shade. Leaves in 80% shade had more chlorophyll and were of greater weight. Stomatal numbers were higher and internodes longer in 80% shade than in full sun. They also found that plant heights, leaf numbers, crown widths and stem diameters were not significantly different. Effect of shade on physiology of *Coffea arabica* was studied by Aldazabal and Alarcon (1994). They found that fruits produced under shade condition were found to be larger than those produced under open sunlight. The time taken for fruit development was not affected by sunlight. Saxena *et al.* (1995) reported that seedling growth of *Dalbergia sissoo* and *Acacia catechu* was the maximum under lower shade treatment, while *Casuarina equisetifolia* showed maximum growth in unshaded conditions. Root to shoot ratio was found to be lowest in *C. equisetifolia.* In all the species, production of stem dry matter was greater under higher shade conditions. Saebo *et al.* (1995) also reported that *Betula pendula* recorded the highest photosynthetic capacity when exposed to blue light and lowest when irradiated with light high in red and/or far-red wavelengths. *Leontodon hispidus,* a perennial bush, showed reduced dry weight under low PPFR (photosynthetic photon fluence rates) while *Orchis morio,* an orchid showed only slight reduction in dry weight due to low PPFR (McKendrick, 1996).

Seedlings of *Betula peapyrifera, B. alleghaniensis, Ostrya virginiana, Acer saccharum* and *Quercus rubra* were grown to study the effects of light and N and their inter relationships on survival and growth. In very low light conditions, greater growth and survival rates were shown by shade tolerant species, while shade intolerant species performed best under higher light conditions. They concluded that light requirement depended on species (Walters and Reich, 1996).

A study done to find out the effect of shade (0, 55 and 95%) on *Hibiscus syriacus* L. showed that the shoot lengths of three cultivars were longer in shade grown plants compared to control plants. However, compared to control, there was no much variation in dry matter production. There was also a reduction in root dry weight of some cultivars (Yoo and Kim, 1997).

Cruz (1997) studied the effect of shade on growth and mineral nutrition of *Dicanthium aristatum* seedlings grown under full sunlight and under *Gliricidia sepium* and *Leucaena leucocephala* with light transmission levels ranging from 80-30 per cent of insolation. Dry matter production was not found to be reduced by reduction in PAR. Light quality had little effect on dry weight during initial stages as is evident from a study conducted by Alphalo and Lehto (1997) using silver birch (*Betula pendula*). However, at the end of the experiment, after 29 days, there was an increase in unit dry weight of leaves and stems of the seedlings along with high nutrient supply. The effect of organic manure on biomass production of *Phyllanthus stipulatus* showed that total plant biomass remained unchanged when grown under open and shade conditions (Silva *et al.,* 1997). Rezende *et al.* (1998) observed that *Cryptocaria aschersoniana* seedlings recorded more dry weight of roots, leaves and stems when grown under 50 per cent light conditions. Mazzei *et al.* (1998) also conducted similar studies in *Schefflera morototoni* seedlings, a shade loving plant. Intermediate (50-70%) shades were found to be best suited for this species with regard to all growth attributes. Vyas and Nein (1999) reported that increasing shade increased the dry matter accumulation in *Cassia angustifolia.* Increase of leaf dry weight was more, when compared to that of stem.

Kamalolbhavan (2002) found that 50 per cent shade is the most favourable for the growth of sandal as well as for the better colonization of AMF. Baiyeri (2006) also reported that fresh weight of root, stem and total dry matter yield of the seedlings of *Carica papaya* grown under green polyethylene shade performed the best among various types of filters *viz.* blue, green, yellow, red, colourless polyethylene, palm frond (*Elaeis guineensis* Jacq) and non-shaded frame. Ravindra (2007) found that *Mucuna pruriens* (L.) DC. produced maximum biomass in full sunlight followed by 25 per cent and 50 per cent shade.

Biomass production is a function of light and different species responds differently to the varying light conditions. The production of fresh weight and dry weight of the parts of a plant, which adds directly to biomass, also depends on the amount of light reaching the plant and the actual amount needed by the plant. Hence, it can be concluded that different plant species need different light condition according to which they respond physiologically and morphologically.

2.6 Nutrient Deficiency Symptoms

Many studies have been done to understand the nutrient deficiency symptoms and disorders in tree seedlings, mostly on seedlings grown under stress in pots or on the basis of field experience. However, reported work in these lines in tropical trees is confined mostly to plantation crops. Only a few works were seen to be carried out on the mineral nutritional aspects of tropical forest tree species.

Balanced supply of both macro- and micronutrients are required for the production of healthy and vigorous seedlings in forest nurseries (Sujatha, 2008). The recent practice of growing seedlings in root trainers containing compost as potting media has resulted in poor growth due to micronutrient deficiencies (Chacko *et al.* 2002). The importance of micronutrients in the normal life process and the expression of various types of symptoms under conditions of their deficiency have been subjected to detailed studies in various agricultural crops (Dewaard, 1969; Bunt, 1976; Smith and Scudder, 1981; Nene *et al.*, 1994; Tandon, 1995). The visual symptoms expressed due to the deficiency of a particular element usually vary with plant species. So, also depending upon the mobility of the deficient element in the plant, the position of leaves on which the symptom initially appears varies.

2.6.1 Nitrogen

Nitrogen is regarded as the fourth most abundant element in plants next to C, H and O. Nitrogen content of the tissues was found to control the use of carbohydrates and hence determined whether the plant will make vegetative or reproductive growth (Kraws and Kraybill, 1918). It is reported to be the most important structural constituent of the cell. Nitrogen containing compounds constitute 5 to 30 per cent of the dry weight of plants (Kramer and Kozlowski, 1960). Stocking and Origun (1962) noted that as much as 70 per cent of the leaf N was present in the chloroplasts. Ferrari and Varner (1969) reported that N as NO_3^- ions is involved in the activation of nitrate reductase enzyme. It plays an important role in the synthesis of proteins, chlorophyll and nucleic acids and at the same time associated with cell division and cell enlargement (Pandey and Sinha, 1972).

Greulach (1973) found that N being a constituent of organic compounds such as amino acids, proteins, purines, pyramidines, chlorophyll and many co-enzymes, was found to be involved in all processes, associated with enzyme reactions and photosynthesis. Marschner (1982) found that N has a major role in maintaining the phytohormone balance in plants. An interruption in N supply enhanced the abscisic acid content of tissues, which subsequently favoured the leaf senescence.

2.6.2 Phosphorus

Phosphorus is known to be associated with phosphorylation of various intermediates in CO_2 assimilation. In the two photochemical reactions occurring during photosynthesis, P is involved in the conversion of light into physiologically useful chemical energy by the formation of NADPH and ATP. Phosphate affects more directly the true photochemical events of photosynthesis than does CO_2 (Arnon, 1959).

Phosphorus occurs in both organic and inorganic forms. It is translocated readily in both forms (Kramer and Kozlowski, 1960). Phosphorus is said to be essential for sugar to starch transformation reactions in tree species (Edmond *et al.*, 1964). Phosphorus is also a component of sugar phosphates, phytic acid and other components in plants (Evans and Sorger, 1966).

According to Pandey and Sinha (1972), P promotes healthy root growth and fruit ripening by helping translocation of carbohydrates. As a constituent of nucleoproteins, P constitutes a major portion of protoplasm concerned with the cell division and the transfer of hereditary characteristics by the chromosomes (Gauch, 1972). Phosphorus deficient plants produced purple bronze leaves since P played an important role in the synthesis of anthocyanin pigments (Gauch, 1972).

Like nitrogen, phosphorus also plays an important role as a structural component of the membrane system of the cell, the chloroplasts and the mitochondria. It forms the main part of sugar phosphates - ADP, ATP, nucleic acids, nucleoproteins, purine and pyramidine nucleotides, flavin nucleotides and several other enzymes and co-enzymes (Greulach, 1973 and Agarwala and Sharma, 1976).

Phosphorus is reported to play a major role in energy metabolism of all living cells even though the share of P was only 0.1 to 0.8 per cent of the total dry weight of the plants (Epstein, 1978 and Jain, 1981). Marschner (1982) found that P also favoured the movement of cytokinins from roots to other plant parts and hence, its deficiency resulted in a decline in cytokinin content in these tissues.

2.6.3 Potassium

Potassium is the only monovalent cation essential for all higher plants (Reed, 1942). It activates protein synthesis and N metabolism (Mulder and Bakema, 1956). It is an activator of the respiratory enzyme pyruvate kinase (Evans, 1963) and succinyl CoA synthesis (Bush, 1969). Potassium also plays a role in the translocation of photosynthates from leaves to other portions of the plants (Spragu, 1964 and Hartt, 1969).

Most plants require relatively large amounts of K. However, isolation of K containing compounds from plants has not yet become completely possible. Evans and Sorger (1966) reported that more than 50 plant enzymes that need K for its maximal activity. Deficiency of K decreased starch synthesis because of reduced energy supply, since K is necessary for glycolysis, oxidative phosphorylation, photophosphorylation and for adenine synthesis (Evans and Sorger, 1966).

Potassium influenced stomatal opening and transpiration (Fischer and Hsiao, 1968). Investigations have established the involvement of K in starch synthesis in various plant species (Murata and Altazawa, 1968; Nitsos and Evans, 1969; Rajput *et al.*, 1978). Pandey and Sinha (1972) observed that K is essential for the synthesis of chlorophyll, though it is not a constituent of chlorophyll. Greulach (1973) stated that K deficiency may also be expressed as water imbalance as K is very important in regulating membrane permeability in plant cells. The property of K to occur primarily in the ionic form or as charged particles or colloidal surfaces has made it most apt to function as catalyst or as a co-factor for many enzymatic reactions of the cell (Ulrich and Ohki, 1975).

According to Agarwala and Sharma (1976), K increased the resistance power of plants to water stress, heat, pest and diseases. Potassium appears to be completely water soluble in plants and is readily mobile within the plant tissues (Salisbury and Ross, 1977).

2.7 Deficiency Symptoms of Nutrient Elements in Tree Species

2.7.1 Nitrogen

Visual symptoms of N deficiency have been described in various trees. Maskell *et al.* (1953) reported stunted growth, yellowing of older leaves, dieback and reduced rate of leaf production in cocoa. Similar reports have been made in citrus (Jones and Embleton, 1959), coffee (Muller, 1966), avocado (Jones, 1975) and apple (Pant *et al.*, 1976).

Deficiency symptoms first appear on older leaves as N is a mobile element (Gauch, 1972). Nitrogen deficiency resulted in chlorosis and it generally reduced the arte of photosynthesis. Chlorosis was reported to be a result of inadequate supply of N for chloroplast protein synthesis. Deficiency caused disproportionate amounts of secondary wall thickening due to carbohydrate accumulation that tend to make terminal growth slender and woody. Root growth was considerably better unless N was totally lacking in the media (Greulach, 1973).

Chlorosis, which was reported to be due to inadequate supply of N for chloroplast synthesis, was the most typical deficiency symptom in most of the tree species. The tissue analysis values for N were less firmly established compared to other elements, because of wide variations in N level in a given plant in relation to plant parts, type and age of tissues, seasons and also due to its high mobility within the plant. However, tissue analysis values for indicating the deficiency, optimum and excess levels of N have been well developed for a number of temperate and tropical fruit tree species (Jones, 1975).

Pale green colour of older leaves, which gradually changed to uniform yellow colour, was the major symptom of N deficiency observed in cashew seedlings grown in nursery (Ohler, 1979 and Gopikumar and Aravindakshan, 1988). In white spruce, yellowing of needles and reduced height are typical symptoms of N deficiency (Hallett, 1985). Yellowing of older leaves, necrosis, premature leaf fall and substantial reduction in growth has been reported as symptoms of N deficiency in Nutmeg (Philip, 1986).

According to Gopikumar and Aravindakshan (1988), visual deficiency symptoms such as leaf discolouration and stunting of growth of cashew seedlings associated with N deficiency was found to correlate with leaf content of this element. Similar observations were also made in cocoa seedlings grown in sand culture (Lockard and Asomaning, 1964).

Landis *et al.* (1989) reported chlorosis of older leaves coupled with stunting of growth in seedlings of paper birch. They also noted that stunting due to N deficiency was usually easy to diagnose and subsequently to correct, because deficiency seedlings rapidly respond to application of N fertilizers. According to Driessche (1989), the needles were pale yellow initially becoming brown at the tip and eventually dying in Douglas fir while in white spruce the yellowing of needles finally lead to red or brown needle development.

Studies conducted by Anoop (1993) using *Ailanthus* seedlings showed that N deficiency resulted in the development of yellow chlorotic patches in the older leaves of seedlings. At acute stages of deficiency, severe chlorosis of entire seedling followed by premature drying and defoliation were observed.

Nitrogen was reported to interact highly with several elements. In citrus, foliar level of Mg decreased with N deficiency (Lebanauskas *et al.*, 1958). The authors also found that N deficiency improved uptake of Zn, Cu and B. Antagonistic effect of N with P had been reported by Lockard and Asomaning (1964); Smith (1966); Dewaard (1969) and Nybe (1986). The uptake of N was higher in the presence of S, indicating a positive interaction between N and S (Kandaswamy and Arulmozhiselvan, 1987).

Varghese (1997) also found that teak seedlings deficient in N started to produce chlorotic leaves initially in the older leaves which gradually spread to entire plants resulting in premature drying and defoliation.

2.7.2 Phosphorus

Varied symptoms were expressed by plants deficient in P. Haas (1936) observed dull bronze green older leaves with burned areas followed by shedding due to P deficiency in lemon and orange. In apple, P deficiency symptoms are expressed as small dark green leaves with bronze to purple tinge, sparse foliage and restricted branching (Wallace, 1953). Maskell *et al.* (1953) observed that P deficiency resulted in general stunting of cocoa plants. In older leaves, loss of green colour occurred in areas between the veins giving rise to a blotchy appearance and interveinal chlorosis. Lockard and Asomaning (1964) stated that in cocoa, reduced dry weight was noticed when P was deficient in tissues.

The element being mobile, lower leaves were the first to exhibit hunger signs. Phosphorus deficiency induced formation of anthocyanin pigmentation resulting in purple colouration (Muller, 1966; Gauch, 1972 and Resh, 1978). Childers (1966) reported restricted growth of root and shoot, small leaves with dull bluish green colour with purple tint followed by brown spotting and premature defoliation as the symptoms of deficiency in avocado, citrus and strawberry. The lateral buds of P deficient plants remained dormant or sometimes dried resulting in reduced lateral shoots.

Phosphorus deficient plants accumulated carbohydrates to a higher level. Vascular tissues were found to be poorly developed and the nucleic acid synthesis was greatly reduced. The production of ATP, NAD and NADP was found to be reduced disrupting the metabolic pathways resulting in stunted growth of the plants (Greulach, 1973).

Swan (1971) observed remarkable difference in P deficiency symptoms in the two species of spruce studied. White spruce showed the characteristic stunting and purple leaf discolouration while red spruce, though stunted, exhibited no purpling. Bingham (1975) described the P deficiency symptoms in tree crops as slow growth and sparse foliage turning dull bronze to purple tinged resulting in early dropping of leaves.

The root system of P deficient plants was found to be poorly developed. Length of primary and secondary roots was reported to be increased and that of tertiary decreased in a study conducted by Narayanan and Reddy (1982). The dry weight decreased in 12 out of 14 species studies. Hormonal imbalance, especially those of auxins and cytokinins, was said to be the reason for increase in root elongation.

Hallett (1985) observed that in black spruce, primary needles, develop purplish tinge, a symptoms called 'purple heart'. Bronze green lower leaves, with purple and necrotic blotches followed by defoliation, have been described as symptoms of P deficiency in nutmeg (Philip, 1986).

Deficiency symptoms appeared first in the lower leaves indicating the mobile nature of P inside the plant. In the leaves of cashew seedlings when subjected to artificial P deficiency, a gradual transition from dark green leaves to bronze green was noticed Gopikumar and Aravindakshan, 1988). Deficiency also caused reduction in height and leaf number in cashew, even though girth reduction was not considerable.

According to Driessche (1989) in Douglas fir seedlings, P deficiency resulted in dull, greyish coloured foliage; while in white spruce bright purple gradually turning darker was observed. Foliar deficiency symptoms of hard wood seedlings included the development of reddish- pink patches in red maple, general yellowing in white ash, marginal chlorosis in sugar maple and general chlorosis of the older leaves in paper birch (Landis *et at.,* 1989). In ailanthus, P deficiency symptoms appeared first in older leaves as purple bronze patches. At later stages, these patches extended to the entire leaflet (Anoop, 1993).

Interaction of P with other elements had been reported by various workers. Phosphorus deficiency was found to be associated with a decrease in Mn (Lebanauska *et al.,* 1958) and N and Mg (Embleton *et al.,* 1958) content in tissues. According to Matsui *et al.* (1977), P level was found positively correlated with Ca and Mg levels and negatively with K in apple. El-Gazzar *et al.* (1979) after their experiments in orange, olive and guava have reported a positive relation between P and Mn and a negative trend with Fe and Zn whereas N and Cu remained without much change. Phosphorus has been reported to interfere greatly with Zn and Fe uptake in many crop species (Gardner *et al.,* 1985). Philip (1986) reported an increase in foliar concentration of N and Zn and a decrease in Mg and Mn in P deficient seedlings of nutmeg. Varghese (1997) also reported the appearance of purple bronze patches in the older leaves initially which extended to the entire leaf in teak seedlings.

2.7.3 Potassium

The deficiency symptoms of K were first manifested on lower leaves as K is a mobile inside the plant. According to Eckstein *et al.* (1937) in coffee, crowding of young leaves and darkening and irregular development of new growth were reported to be the characteristic symptoms of K deficiency. In coffee, Purseglove (1977) has observed scorching of entire leaf margins followed by defoliation when K was deficient in tissues. According to Muller (1966), necrosis of leaf margins of older leaves was the most conspicuous symptom of K deficiency in coffee. He also observed that K concentration was lowest near the leaf margins increasing gradually towards the midrib and K was readily translocated from older leaves to younger growth.

Chapman *et al.* (1947) described K deficiency symptoms in oranges as "fluting" or "tucking" of leaves with a variety of chlorotic spotting pattern. K deficient plants were found to produce and accumulate putriscine, a diamine that results necrosis in leaf lamina (Richards and Coleman, 1952). Evans and Murray (1953) described the K deficiency symptoms in cocoa as pale yellow areas with interveinal regions near leaf margins, quickly becoming necrotic. In cocoa, Lockard and Asomaning (1964) noted primary veins of older leaves first turning light green to yellow and then brown. The mid rib was also reported to be affected by the authors. They also noted that plants grown under K deficient conditions were less severely stunted compared to those grown under comparable deficiency levels of any other macronutrients. Leaf analysis of low yielder of mandarin with scorched leaves and non fruiting terminals showed more K and less Ca and Mg (Morchal and Laccevilhe, 1969).

The tip and marginal scorching of K deficiency in tree crops was reported by Ulrich and Ohki (1975). Development of necrotic older leaves associated with reduced height, number of branches and dry matter has been reported due to K deficiency in nutmeg (Philip, 1986). Acute deficiency of K in trees results in the entire plant showing typical symptoms including severe die back. Yellowing and necrosis of lower leaf tip, which later spread to other portion of the leaves, were the typical symptoms of K deficiency in cashew as observed by Gopikumar and Aravindakshan (1988).

In white spruce and Douglas fir, K deficiency resulted in dull green seedling, lower needles turning purple at tips, then into yellow or brown (Driessche, 1989). According to Anoop (1993), in ailanthus K deficient seedlings manifested chlorotic tips of the older leaves which in severe stages, turned completely chlorotic. Drying of terminal bud followed by death was also observed in many cases. Potassium strongly antagonizes with Ca and Mg (Cain, 1948; Smith, 1966; Dewaard, 1969; Hansen, 1970; Nybe, 1986 and Philip, 1986). Spiers (1987) reported reduced P, Ca and Mg uptake with increased K fertilization. In his study, high K content was found to decrease plant growth. Interactions involving other nutrients were studied by Tandon and Sekhon (1988). Potassium and Magnesium interactions were negative, which at times led to K induced Mg deficiency. Chlorotic tips in lower leaves were the initial symptoms of K deficiency which spread through the margin upwards as reported by Varghese (1997).

Barrett and Fox (1997) found that omission of all nutrients or individual minerals (N, K, P, S, Ca) from the growth medium of the pre-parasitic sandal seedlings produced significant morphological effects. Compared with fully fertilized seedlings, shoot and root length, leaf area, leaf length and width, leaf number, internode length, shoot length/root length ratio, chlorophyll levels, fresh mass and dry mass were all reduced. Leaf thickness increased however and stomatal numbers, petiole lengths, root lengths and haustorial numbers showed variable but significant responses.

Hence it can be concluded that plants respond to the deficiency of N, P and K by showing different types of hunger signs. At the same time, the morphology of plants also gets changed due to the lack of essential macronutrients *viz.* N, P and K. The symptoms are the characteristic signs of particular types of macronutrients as the symptoms vary from one another.

From these reviews we can conclude that very less work has been done related to the nutritional deficiency symptoms of *Santalum album* L. At the same time we can also say that limited works are done related to the haustorial anatomy and nutrients translocation from hosts to sandal. It can also be seen that only few experiments on the effect of light on *Santalum album* L. are performed. Hence, there is a need for us to perform more research works on the above topics.

Materials and Methods

MATERIALS AND METHODS

The present investigations were conducted at College of Forestry, Kerala Agricultural University, Vellanikkara for studying the effect of light, hosts and nutritional deficiency on the morphological symptoms, growth and vigour of seedlings of *Santalum album* Linn.

3.1 Location of the study

The College of Forestry, Kerala Agricultural University, Vellanikkara, comes under the Madakkathara panchayat of Thrissur district. The study area lies between 10°32' N latitude and 76°26' E longitude. The climate is warm and humid with an average annual rainfall of 2668 mm. The soil is of lateritic origin. The area has an altitude of about 40 m above MSL. The mean maximum temperature recorded at Vellanikkara varied from 28.4°C in July to 36.0°C in March. The mean minimum temperature varied from 21.6°C in November to 25.0°C in April. The temperature variation during the day is not very wide.

3.2 Raising seedlings for the study

Seeds of *Santalum album* collected from Marayoor, Kerala were used. The seeds were given pretreatment using 300 ppm GA for overnight. The seeds were then sown in sand beds which were prepared under partial shade. After sowing, the seeds were covered uniformly with a thin layer of sand. The seed beds were kept moist by regular watering. The seedlings of about one month old were transplanted to polybags of size 16 × 18 cm. They were also kept under partial shade and watered regularly.

Two months old seedlings of uniform growth in respect of height, collar diameter and leaf number were selected for the study.

EXPERIMENT NO. I

This experiment aims at understanding the effects of different light qualities and light quantities on the growth behaviours of sandal seedlings grown under the combination of various shade levels and filters as shown in Plate 1. For understanding the effect of light quality and light quantity on the growth of sandal, sandal seedlings were grown in polybags for a period of 7 months without any host plants.

3.3 Providing shades and filters

Artificial shade houses were made and shade was provided using nylon shade nets. For varying light quality, very thin colour plastic films *viz.* blue, green and red were used to cover the shade houses. Full sunlight was taken as the control. The shade houses were constructed in the nursery in the North South direction. The required shade levels and light quality were created by putting different layers of nylon shade nets and plastic colour film. The different types of shades will allow different amount of sunlight to pass through them. On the other hand, the different colour plastic films will transmit their respective colours inside the shade houses. The following were the treatments used for the study:

T_1 – 25 per cent shade and blue light

T_2 – 25 per cent shade and green light

T_3 – 25 per cent shade and red light

T_4 – 50 per cent shade and blue light

T_5 – 50 per cent shade and green light

T_6 – 50 per cent shade and red light

T_7 – 75 per cent shade and blue light

Plate 1: Sandal seedlings under treatments of different levels of shades and light qualities

Plate 2: Labeling of host plants of sandal with ^{14}C in a closed chamber

T_8 – 75 per cent shade and green light

T_9 – 75 per cent shade and red light

T_{10} – Open (Full sunlight)

3.4 Aftercare of seedlings

Watering of the seedlings was done daily. Weeding and necessary plant protection measures were also adopted periodically.

3.5 Experimental layout

The study was conducted in factorial CRD with three shade levels and three light qualities each having three replications. The number of bags for each treatment was 45, making the total number of 1,215 bags for the entire study excluding the seedlings in open condition.

3.6 Observations

3.6.1 Shoot growth parameters

Height

The height of individual seedlings was measured from collar region to terminal bud at monthly interval using a meter scale.

Collar diameter

The collar diameter was measured using a digital vernier caliper at monthly interval.

Number of leaves

The number of leaves produced by individual seedlings was counted at monthly interval.

3.6.2 Root growth parameters

Representative samples were selected and uprooted from each replication of all the treatments at monthly intervals for root observations.

Length of roots

Destructive sampling was done at monthly interval and the length of roots was measured from the collar region to the tip of the longest root and expressed in centimeter.

Root number

The number of secondary roots from the main root was counted and recorded.

3.6.3 Biomass production

Fresh weight of shoot and root

Representative seedlings were sampled from each treatment at monthly intervals for estimating the total biomass. The shoot and root portion of seedlings were separated and fresh weight was determined separately using precision balance.

Dry weight of shoot and root

The shoot and root portion of the samples were dried separately in hot air oven at a temperature of 80°C till constant weight was achieved. Dry weights were taken using a precession balance.

3.6.4 Relative Growth Rate

The Relative Growth Rates (RGRs) of dry weight of shoot and dry weight of root were found out by using the following formula:

$$\mathrm{RGR} = \frac{\ln W2 - \ln W1}{t2 - t1}$$

W_1 and W_2 are dry weights at the beginning and end of the sampling period, t_1 and t_2 are the dates of sampling respectively, and ln is the natural logarithm of the numbers (McGraw and Garbutt, 1990).

3.6.5 Incremental Growth

The Incremental Growth (IG) of root length, shoot length and collar diameter were found out by using the following formula:

$$\mathrm{IG} = \frac{\ln G2 - \ln G1}{t2 - t1}$$

G_1 and G_2 are the shoot length, root length and collar diameter at the beginning and end of the sampling period, and ln is the natural logarithm of the numbers.

3.7 Rate of photosynthesis

The rate of photosynthesis was measured using LI – 6400 Portable Photosynthesis System at monthly interval.

3.8 Chlorophyll content

Chlorophyll content of the leaves was estimated following the method suggested by Staner and Hardley (1967). Two samples per replication were collected from all the treatments for estimating the chlorophyll content. Leaf samples collected from the experimental seedlings were cut into pieces and mixed. For estimating chlorophyll, 0.1 g of the sample was weighed and finely ground using a clean mortar to extract the chlorophyll using 80 per cent acetone.

The extract was filtered using Whatman No.1 light quality paper and made up to 25 ml using 80 per cent acetone. The absorbance was read at wavelengths of 663 nm and 645 nm using a spectrophotometer. The chlorophyll a, chlorophyll b and total chlorophyll content of each sample was calculated using the following formulae:

$$\text{Chlorophyll-a} = 12.7 \text{ (OD at 663 nm)} - 2.69 \text{ (OD at 645 nm)} \times \frac{V}{1000 \times W}$$

$$\text{Chlorophyll-b} = 22.9 \text{ (OD 645 nm)} - 4.68 \text{ (OD at 663 nm)} \times \frac{V}{1000 \times W}$$

$$\text{Total chlorophyll} = 20.2 \text{ (OD at 645 nm)} + 8.02 \text{ (OD at 663 nm)} \times \frac{V}{1000 \times W}$$

where,

OD= Optical density

V = Final volume of chlorophyll extract

W = Fresh weight of the leaf extract in grams

EXPERIMENT NO. II

3.9 Effect of hosts on sandal

3.9.1 Anatomical studies

For examining the anatomical features of the haustorial connections between sandal and hosts, hand sections of the haustorial connections of 10 months old sandal seedling with *Casuarina equisetifolia, Tectona grandis* and *Theobroma cacao* were taken. Uniformly thin sections were stained using safranin and carefully observed under the microscope. Microphotographs were taken and nature of haustorial connections and anatomical features were studied.

3.9.2 Translocation of photosynthates

Radio isotope study using ^{14}C was conducted to understand the translocation of photosynthates. Healthy seedlings of *Casuarina equisetifolia, Pongamia pinnata, Dalbergia latifolia, Pterocarpus marsupium* and *Terminalia bellerica* were used for the study.

Labeling of plants with ^{14}C

The plants to be labelled were put into a specially fabricated air tight glass chamber (45 x 45 x 45 cm). In the chamber, $100\mu Ci$ ^{14}C in the form of $Na^{14}CO_3$ was placed in a petridish and a drip system for ensuring a controlled supply of dilute (0.1 N) HCl to the petridish was installed. Acid was dripped into $Na^{14}CO_3$ to liberate $^{14}CO_2$ in to the chamber. The plants were kept inside the chamber for a period of 20 minutes in full sunlight for effective assimilation of ^{14}C. Then they were taken out and planted in earthen pots filled with sand-soil mixture (1: 1).

Labeled host seedlings were put in the same pots with unlabeled sandal seedlings. The details of the sandal-host combinations are given below. The labelled plants are indicated by the parenthesis.

Sandal-host combinations:

1. (*Casuarina equisetifolia*) ^{14}C + *Santalum album*
2. (*Pongamia pinnata*) ^{14}C + *Santalum album*
3. (*Dalbergia latifolia*) ^{14}C + *Santalum album*
4. (*Terminalia bellerica*) ^{14}C + *Santalum album*
5. (*Pterocarpus marsupium*) ^{14}C + *Santalum album*

After a period of 150 days growth, the plants were cut at soil level and dried in a hot air oven at 65-70° C for 48 hours and subjected to radioassay.

Radioassay of plant samples

The dried, powdered plant samples of 0.2 g each was mixed with C-14 cocktail solution which contains 2,5-Diphenyloxazole (10 g) (PPO), 1,4-Di-2-(5-phenyloxazol) benzene (0.25 g) (POPOP) and Napthalene (100 g) in 1,4-dioxan. The radioactivity was then determined in a micro computer controlled liquid scintill ation system (Hidex-Triathler) and the activity was expressed in Counts Per Minute (cpm).

EXPERIMENT NO. III

3.10 Nutritional Deficiency Symptoms

The investigations pertaining to the nutritional deficiency symptoms of *Santalum album* L. seedlings were carried out during the period 2007 – 2008. The study consisted of two main parts; the first part involved the induction of nutrient deficiency symptoms in seedlings grown in sand culture while the second part aimed at diagnosis of these symptoms through analysis of growth behaviour, chlorophyll and tissue nutrient levels.

3.11 Development of nutrient deficiency symptoms

To induce deficiency symptoms in the seedlings of *Santalum album*, sand culture experiments were carried out in a green house.

3.12 Preparation of sand

Pure quartz silica sand of 250 mesh was used for sand culture studies. The sand was first washed with tap water and then soaked for eight hours and washed in dilute hydrochloric acid. The sand was then washed thoroughly with tap water and subsequently with deionized water until it became chloride free.

3.13 Preparation of planting material

The seeds were given pretreatment using 300 ppm GA for overnight. The seeds were then sown in sand beds which were prepared under partial shade. After sowing, the seeds were covered uniformly with a thin layer of sand. The seed beds were kept moist by regular watering. The seedlings of about one month old were transplanted to polybags of size 16 × 18 cm. They were also kept under partial shade and watered regularly.

Two months old seedlings of uniform growth in respect of height, collar diameter and leaf number were selected for the study.

3.14 Selection of polybags and planting of seedlings

Polybags of size 16 × 18 cm. were used for the experiment. The containers were rinsed with dilute hydrochloric acid and then washed with deionized water. Uniform holes were made so that water logging could not occur.

The containers were uniformly filled with acid washed sand to one-fourth the volume prior to the planting of seedlings. The seedlings were removed from the polybags and the sand and soil particles adhering to the roots were washed off first with tap water and then with deionized water.

After placing the seedlings in the centre of a pot, the container was filled with acid washed sand leaving one inch space from the top. The containers were arranged on concrete benches inside the green house at a spacing of 30 cm from one another.

All the experimental seedlings were supplied with complete Hoagland No. 2 (Hoagland, 1948) nutrient solution for a period of 10 days till they established well in the sand. Before imposing the nutrient treatments, the growth media were completely flushed with the deionized water repeatedly for three to four times to wash away the nutrient residues.

3.15 Treatments

The details of various treatments tried for the present study are furnished below.

1. Complete Hoagland nutrient solution
2. Hoagland nutrient solution lacking nitrogen
3. Hoagland nutrient solution lacking phosphorus
4. Hoagland nutrient solution lacking potassium

The experiment was laid out in completely randomized design with three replications and the total number of plants for the study was 840.

The chemical composition of complete Hoagland No. 2 (Hoagland, 1948) nutrient solution is furnished in Appendix 2. From the stock solution, the required quantities of each nutrient as mentioned were pipetted and made to one litre.

The nutrient solutions required for each treatment were carefully prepared in bulk by eliminating the desired nutrient from the stock. Analytically pure chemicals (AR grade) were used for the preparation of the solutions. Fresh nutrient solutions were prepared every week. Iron was added separately in order to avoid precipitation when mixed with solution containing other nutrient elements. Every alternate day, 50 ml of nutrient solution along with 2 ml of 0.1 per cent $FeSO_4$ solution was added to each plant. On the other days, deionized water was supplied, at the rate of 50 ml per plant. Sand in each container was flushed with deionized water at the end of every month to prevent the possible salt accumulation which may result in root injury. This was again followed by the application of fresh nutrient solution.

3.16 Diagnosis of nutrient deficiency symptoms

3.16.1 Observation of visual symptoms

The seedlings under each treatment were observed daily for the appearance of symptoms of deficiency. The time taken for the development of various visual symptoms was recorded and colour photographs were also taken.

The symptoms were confirmed only when at least one seedling in all the three replications coming under the same treatment developed identical symptoms. For convenience, an attempt was made to describe the symptoms during four stages of nutrient deficiencies viz., initial, moderate, severe and acute.

3.16.2 Growth of seedlings

Observations related to the shoot growth parameters, root growth parameters, dry matter content, Relative Growth Rate and Incremental Growth were taken as described in section 3.6.1 to 3.6.5.

3.16.3 Chemical analysis of leaf tissues

The following chemical analyses were carried out in the laboratory.

Chlorophyll content

Chlorophyll content was estimated using the procedure described under section 3.8.

Nitrogen

Nitrogen was determined at bimonthly intervals by using Kjeldahl method. 0.1 g of the plant samples was digested using conc. H_2SO_4 and digestion mixture (K_2SO_4 and $CuSO_4$). Distillation of the digested material was done using alkali NaOH and boric acid. Finally, the ammonium in the boric acid was titrated against 0.1 N H_2SO_4 taken in the burette. The end point was confirmed when the solution of boric acid regain its colour (Jackson, 1958).

Phosphorus

Phosphorus was determined in a known aliquot of the acid extract colorimetrically by the Vanado – molybdophosphoric yellow colour method. The yellow colour was read in a spectrophotometer at a wavelength of 470 nm (Jackson, 1958).

Potassium

The diacid extract prepared earlier was used to estimate potassium content. It was estimated in digital flame photometer (Jackson, 1958).

3.17 Statistical analysis

All the observations recorded were statistically analyzed using MSTAT-C computer software package.

Results

RESULTS

The results of the study on the effects of light quality and quantity, nutritional deficiency in the seedlings of *Santalum album* L. are presented in this section. The important findings on growth parameters of seedlings like dry weight of shoot and root, shoot and root length, collar diameter, chlorophyll content of leaves, rate of photosynthesis, RGR, foliar tissue nutrient concentration, anatomical characteristics of haustoria and translocation of photosynthates from the host species to sandal seedlings are presented in Tables 1 to 39, Figs. 1 to 26 and Plates 1 to 10.

EXPERIMENT NO. I

Effect of light quality and quantity on the growth behaviours of sandal seedlings:

4.1 Shoot growth parameters

The influence of various treatments on shoot growth parameters of the sandal seedlings like height, collar diameter and number of leaves recorded at monthly intervals is shown in Tables 1 to 3.

4.1.1 Height

The effect of different light qualities and light quantities on the growth of sandal seedlings is shown in Table 1 (a to c) and illustrated in Fig. 1 (a, b). The different light qualities and light quantities did not have any significant effect in the first month on height of sandal seedlings. The interaction effects however significantly influenced the height growth of seedlings. On the other hand, different treatments showed significant differences in the values of height in the second month (Table 1a) and the best performance among the varying shade levels was obtained in seedlings grown under 75 per cent shade (5.20 cm)

Table 1 (a): Two-way tables showing combined effects of shade and light quality on shoot length (cm) in sandal seedlings

Month 1

Light quality	Shade level 25	50	75	Mean
Blue	4.70^{ab}	4.63^{ab}	4.50^{ab}	4.61
Green	4.63^{ab}	4.67^{ab}	4.57^{ab}	4.62
Red	4.47^{b}	4.43^{b}	4.77^{a}	4.56
Mean	4.60	4.58	4.61	4.60 (control)

$F_{control}$ → 2.47 NS, SEm +/- = 0.136
F_{shade} → 0.17 NS, SEm +/- = 0.029
F_{filter} → 0.77 NS, SEm +/- = 0.062
$F_{interaction}$ → 4.60*, SEm +/- = 0.088

Month 2

Light quality	Shade level 25	50	75	Mean
Blue	5.17^{bc}	4.93^{cd}	5.10^{c}	5.07^{y}
Green	5.00^{c}	5.60^{a}	5.13^{bc}	5.24^{x}
Red	4.70^{d}	4.73^{d}	5.37^{ab}	4.93^{z}
Mean	4.96^{n}	5.09^{m}	5.20^{l}	4.87 (control)

$F_{control}$ → 14.19**, SEm +/- = 0.247
F_{shade} → 15.70**, SEm +/- = 0.212
F_{filter} → 25.52**, SEm +/- = 0.270
$F_{interaction}$ → 36.63**, SEm +/- = 0.187

Month 3

Light quality	Shade level 25	50	75	Mean
Blue	5.53^{c}	5.23^{de}	5.57^{c}	5.44^{y}
Green	5.40^{cd}	6.43^{a}	5.87^{b}	5.90^{x}
Red	5.03^{e}	5.07^{e}	5.90^{b}	5.33^{y}
Mean	5.32^{n}	5.58^{m}	5.78^{l}	5.37 (control)

$F_{control}$ → 4.81*, SEm +/- = 0.225
F_{shade} → 22.36**, SEm +/- = 0.396
F_{filter} → 38.64**, SEm +/- = 0.520
$F_{interaction}$ → 27.59**, SEm +/- = 0.254

* - significant at 5 %, ** - significant at 1 %, NS – non-significant
Values with the similar alphabets do not differ significantly.
Control – Full sunlight

Table 1 (b): Two-way tables showing combined effects of shade and light quality on shoot length (cm) in sandal seedlings

Month 4

Light quality	Shade level 25	50	75	Mean
Blue	5.93[c]	5.63[de]	6.07[c]	5.88[y]
Green	5.80[cd]	7.37[a]	6.77[b]	6.64[x]
Red	5.30[f]	5.50[ef]	6.53[b]	5.78[y]
Mean	5.68[n]	6.17[m]	6.46[l]	5.67 (control)

$F_{control}$ → 8.36*, SEm +/- = 0.505
F_{shade} → 86.94**, SEm +/- = 0.681
F_{filter} → 126.47**, SEm +/- = 0.821
$F_{interaction}$ → 60.81**, SEm +/- = 0.329

Month 5

Light quality	Shade level 25	50	75	Mean
Blue	6.40[e]	6.10[fg]	6.67[d]	6.39[y]
Green	6.27[ef]	8.40[a]	7.57[b]	7.41[x]
Red	5.57[h]	5.93[g]	7.20[c]	6.23[z]
Mean	6.08[n]	6.81[m]	7.14[l]	6.10 (control)

$F_{control}$ → 49.83**, SEm +/- = 0.670
F_{shade} → 148.89**, SEm +/- = 0.945
F_{filter} → 204.72**, SEm +/- = 1.108
$F_{interaction}$ → 89.78**, SEm +/- = 0.424

Month 6

Light quality	Shade level 25	50	75	Mean
Blue	6.80[e]	6.63[e]	7.33[d]	6.92[y]
Green	6.63[e]	9.27[a]	8.27[b]	8.06[x]
Red	5.93[g]	6.33[f]	7.73[c]	6.67[z]
Mean	6.46[n]	7.41[m]	7.78[l]	6.37 (control)

$F_{control}$ → 138.57**, SEm +/- = 0.985
F_{shade} → 299.57**, SEm +/- = 1.182
F_{filter} → 351.29**, SEm +/- =1.280
$F_{interaction}$ → 149.57**, SEm +/- =0.482

* - significant at 5 %, ** - significant at 1 %, NS – non-significant
Values with the similar alphabets do not differ significantly.
Control – Full sunlight

Table 1 (c): **Two-way tables showing combined effects of shade and light quality on shoot length (cm) in sandal seedlings**

Month 7

Light quality	Shade level			Mean
	25	50	75	
Blue	7.30[e]	7.30[e]	7.97[d]	7.52[y]
Green	7.33[e]	10.20[a]	8.80[b]	8.78[x]
Red	6.73[f]	6.80[f]	8.33[c]	7.29[z]
Mean	7.12[n]	8.10[m]	8.37[l]	6.77 (control)
$F_{control}$ → 538.125**, SEm +/- = 1.312				
F_{shade} → 603.75**, SEm +/- = 1.135				
F_{filter} → 1803.59**, SEm +/- = 1.962				
$F_{interaction}$ → 406.56**, SEm +/- = 0.538				

* - significant at 5 %, ** - significant at 1 %, NS – non-significant

Values with the similar alphabets do not differ significantly.

Control – Full sunlight

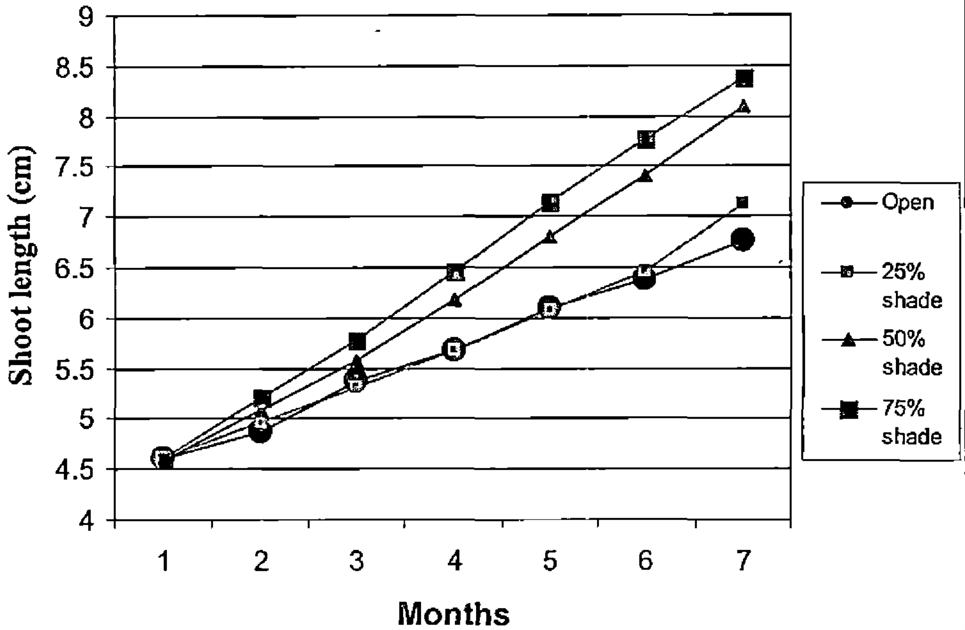

Fig. 1 (a): Effect of shade levels on shoot length of sandal seedlings

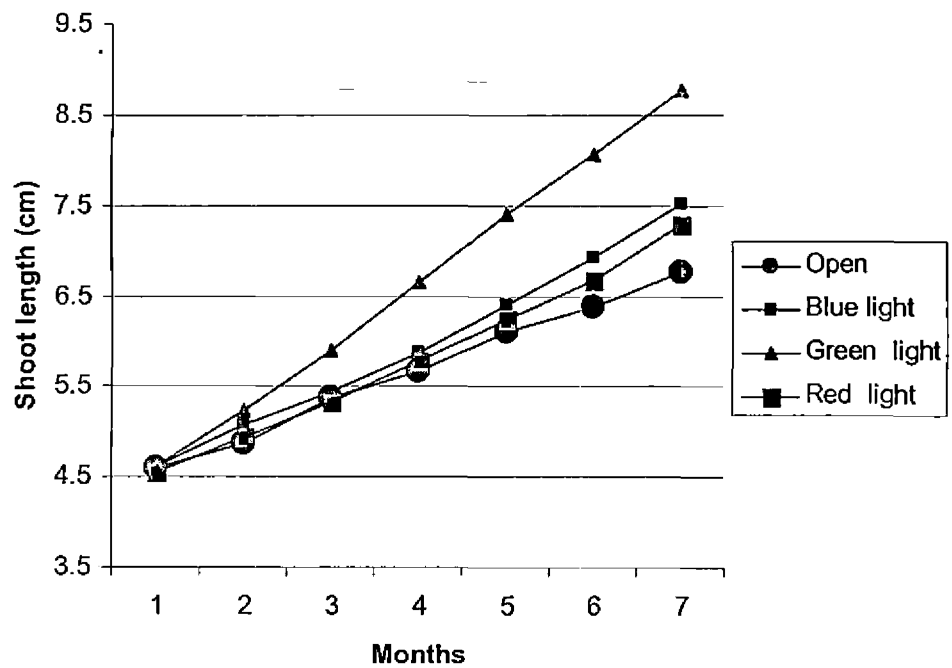

Fig. 1 (b): Effect of light quality on shoot length of sandal seedlings

followed by 50 per cent shade (5.09 cm). The lowest growth in height during the same month was observed in seedlings under full sunlight (4.87 cm). However, seedlings grown under 25 per cent shade (4.96 cm) had lesser shoot length as compared to the seedlings under 50 per cent shade during this month. The different light qualities also gave significant differences in the height growth of the seedlings and out of the three light qualities, green light quality had the best performance (5.24 cm) which was followed by seedlings under blue (5.07 cm) and red light qualities (4.93 cm) in descending order of their performances. The lowest height was recorded in seedlings grown under open condition (4.87 cm). From the second month to the seventh month, interaction between green light quality and 50 per cent shade gave the highest value. However, the lowest value of shoot length due to interaction of factors in the sandal seedlings in the seventh month was observed in seedlings under 25 per cent shade level and red light quality (6.73 cm) and 50 per cent shade level and red light quality (6.80 cm) at the end of the study period. Control had significant impact on the height of sandal seedlings throughout the study period except in the first month.

In the third month, the different light qualities and light quantities also gave significant differences in the growth of shoot. As far as shade level is considered, the best performance was given by seedlings grown under 75 per cent shade (5.78 cm) which was followed by 50 per cent (5.58 cm) and 25 per cent (5.32 cm) in the order of preference by the sandal seedlings. Open condition gave a value of 5.37 cm which is higher than the value given by seedlings grown under 25 per cent seedlings. The different light qualities also added some significant differences on the growth rate of height in sandal seedlings in the third month. The best performance was given by green light quality with a recorded height of 5.90 cm. On the other hand, seedlings grown under blue and red light qualities did not vary significantly with recorded values of 5.44 cm and 5.33 cm respectively. The lowest value was observed in the seedlings grown under red light qualities.

In the fourth month (Table 1b), the readings showed significantly different effects on the height of sandal seedlings due to varying light quality and quantity.

Seedlings growing under 75 per cent shade performed the best (6.46 cm), which was followed by seedlings under 50 (6.17 cm) and 25 per cent shade (5.68 cm). Open condition gave a value of 5.67 cm which was the lowest in the month. Light qualities also gave a significant difference in the performance of the seedlings. The best light quality was found to be green with a recorded growth rate of 6.64 cm. The use of blue and red light qualities did not significantly add to the variation in the height of the sandal seedlings for the fourth month. The lowest value of height was also found in control condition *i.e.* open.

In the fifth month, the effect of shade on the sandal seedlings was the same as that in the third and fourth months with the maximum recorded value in the seedlings under 75 per cent shade (7.14 cm) followed by 50 per cent (6.81 cm) and 25 per cent shades (6.08 cm). Seedlings grown in the open condition recorded the minimum value of 6.10 cm. With regard to the light qualities, green light quality performed the best (7.41 cm), which was followed by the seedlings under blue (6.39 cm) and red (6.23 cm) light qualities. The minimum gain in height was observed in seedlings grown in the open condition (6.10 cm).

During the sixth month (Table 1b), shades gave the similar trend on the height of the sandal seedlings as observed in the previous months. The best performance was observed in seedlings under 75 per cent shade (7.78 cm) followed by seedlings under 50 (7.41 cm) and 25 per cent (6.46 cm) shades. Open condition resulted in the production of lowest height (6.37 cm) in this sixth month. Use of different light qualities also produced significant differences in the growth of height in the sandal seedlings. Green light quality (8.06 cm) was the best followed by blue (6.92 cm) and red (6.67 cm) light qualities. Open condition gave the lowest value (6.37 cm) when the value was compared with the seedlings grown under different light qualities.

In the last month of the study period (Table 1c), the effect of different shades had significant impact on the height of the sandal seedlings. It followed the same pattern of effect as that of the previous month.

4.1.2 Collar diameter

Observations related to the effect of various shade levels and light quality on the collar diameter in sandal seedlings are given in Table 2 (a to c) and illustrated in Fig. 2 (a, b). There were no significant influence of light quality and light quantity except in the fifth month and 7th month. In both months light quality showed significant variations on the collar diameter. However, control showed significant effects on the collar diameter from the fourth month to seventh month. When the observations were taken in the last month *i.e.* in the seventh month, 50 per cent shade level and green light quality provided the best results. Interactions between the factors were significant only in the seventh month of the study period. The highest value was observed in seedlings under the combination of 50 per cent shade level and green light quality (2.30 mm). The lowest value was observed in seedlings under the combination 75 per cent shade level and blue light quality (2.07 mm).

In the fourth month of the study period, only control gave a significantly different value and there was no significant effect on the collar diameter due to different shades and light qualities. The maximum value was given by 50 per cent shade with a recorded mean of 1.55 mm with regard to shade levels and as far as light quality is concerned, maximum growth was put forth by seedlings under blue and green light qualities with mean values of 1.55 mm each in the same month.

The collar diameter was found to be the maximum in seedlings grown in green light quality in the fifth month of the study period and light qualities gave significant impacts in the performance in collar diameter. Light quantity did not give any significant effect with regard to collar diameter in the same month. In the same month, control was significantly different from other treatments.

The sixth month of the observation period showed that the use of different types of light qualities and shades did not confer any significant differences in the

Table 2 (a): Two-way tables showing combined effects of shade and light quality on collar diameter (mm) in sandal seedlings

Month 1

Light quality	Shade level 25	50	75	Mean
Blue	0.92	0.96	0.91	0.93
Green	0.91	0.95	0.90	0.92
Red	0.94	0.92	0.91	0.92
Mean	0.93	0.94	0.91	0.95 (control)

$F_{control}$ → 1.43 NS, SEm +/- = 0.032
F_{shade} → 1.79 NS, SEm +/- = 0.029
F_{filter} → 0.11 NS, SEm +/- = 0.0071
$F_{interaction}$ → 0.57 NS, SEm +/- = 0.0094

Month 2

Light quality	Shade level 25	50	75	Mean
Blue	1.14	1.23	1.17	1.18
Green	1.11	1.18	1.11	1.13
Red	1.18	1.17	1.14	1.16
Mean	1.15	1.19	1.14	1.15 (control)

$F_{control}$ → 1.72 NS, SEm +/- = 0.05
F_{shade} → 2.41 NS, SEm +/- = 0.048
F_{filter} → 1.90 NS, SEm +/- = 0.043
$F_{interaction}$ → 0.86 NS, SEm +/- = 0.0167

Month 3

Light quality	Shade level 25	50	75	Mean
Blue	1.32	1.42	1.38	1.37
Green	1.34	1.36	1.33	1.35
Red	1.36	1.34	1.37	1.36
Mean	1.34	1.37	1.36	1.32 (control)

$F_{control}$ → 0.95 NS, SEm +/- = 0.032
F_{shade} → 0.95 NS, SEm +/- = 0.026
F_{filter} → 0.71 NS, SEm +/- = 0.022
$F_{interaction}$ → 1.55 NS, SEm +/- = 0.019

* - significant at 5 %, ** - significant at 1 %, NS – non-significant
Values with the similar alphabets do not differ significantly.
Control – Full-sunlight

Table 2 (b): Two-way tables showing combined effects of shade and light quality on collar diameter (mm) in sandal seedlings

Month 4

Light quality	Shade level 25	50	75	Mean
Blue	1.53	1.58	1.54	1.55
Green	1.54	1.58	1.52	1.55
Red	1.51	1.49	1.56	1.52
Mean	1.53	1.55	1.54	1.46 (control)
$F_{control}$ → 8.57*, SEm +/- = 0.095				
F_{shade} → 0.48 NS, SEm +/- = 0.018				
F_{filter} → 1.43 NS, SEm +/- = 0.032				
$F_{interaction}$ → 1.67 NS, SEm +/- = 0.020				

Month 5

Light quality	Shade level 25	50	75	Mean
Blue	1.68	1.75	1.75	1.73[xy]
Green	1.73	1.79	1.76	1.76[x]
Red	1.69	1.69	1.70	1.69[y]
Mean	1.70	1.74	1.74	1.63 (control)
$F_{control}$ → 7.59*, SEm +/- = 0.105				
F_{shade} → 1.55 NS, SEm +/- = 0.039				
F_{filter} → 4.14*, SEm +/- = 0.063				
$F_{interaction}$ → 0.43 NS, SEm +/- = 0.037				

Month 6

Light quality	Shade level 25	50	75	Mean
Blue	1.88	1.93	1.89	1.90
Green	1.90	2.03	1.90	1.94
Red	1.88	1.87	1.86	1.87
Mean	1.89	1.94	1.88	1.81 (control)
$F_{control}$ → 8.29*, SEm +/- = 0.12				
F_{shade} → 3.14 NS, SEm +/- = 0.061				
F_{filter} → 3.29 NS, SEm +/- = 0.062				
$F_{interaction}$ → 1.14 NS, SEm +/- = 0.021				

* - significant at 5 %, ** - significant at 1 %, NS – non-significant
Values with the similar alphabets do not differ significantly.
Control – Full-sunlight

Table 2 (c): **Two-way tables showing combined effects of shade and light quality on collar diameter (mm) in sandal seedlings**

Month 7

Light quality	Shade level 25	Shade level 50	Shade level 75	Mean
Blue	2.13^{bc}	2.18^{b}	2.07^{c}	2.13^{y}
Green	2.17^{bc}	2.30^{a}	2.14^{bc}	2.20^{x}
Red	2.08^{bc}	2.13^{bc}	2.08^{bc}	2.10^{y}
Mean	2.12^{m}	2.21^{l}	2.10^{m}	2.02 (control)
$F_{control}$ → 13.3^{**}, SEm +/- = 0.155				
F_{shade} → 7.92^{**}, SEm +/- = 0.097				
F_{filter} → 7.22^{**}, SEm +/- = 0.093				
$F_{interaction}$ → 0.92 NS, SEm +/- = 0.019				

* - significant at 5 %, ** - significant at 1 %, NS – non-significant

Values with the similar alphabets do not differ significantly.

Control – Full-sunlight

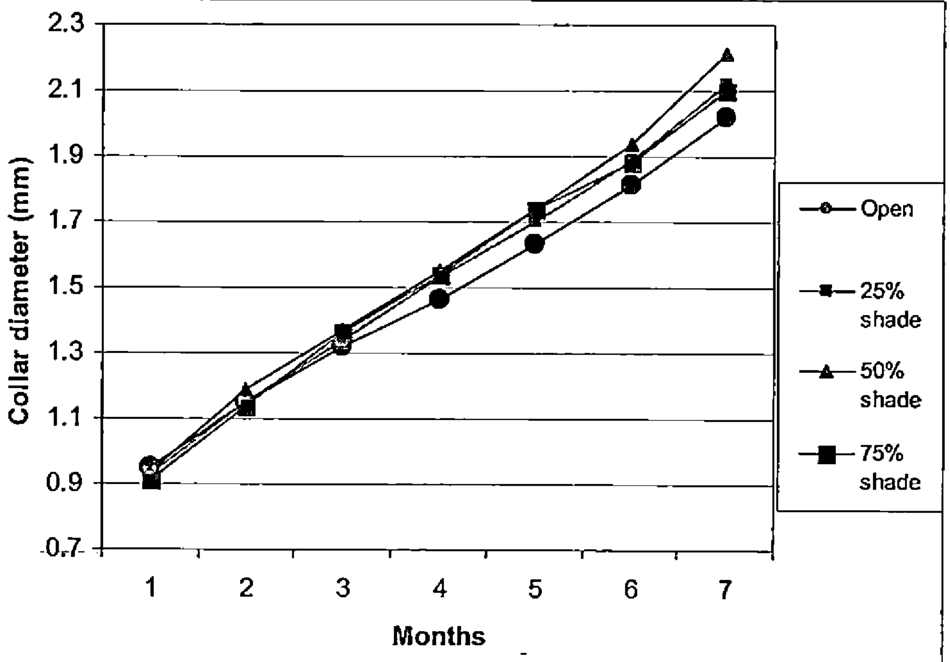

Fig. 2 (a): Effect of shade levels on collar diameter of sandal seedlings

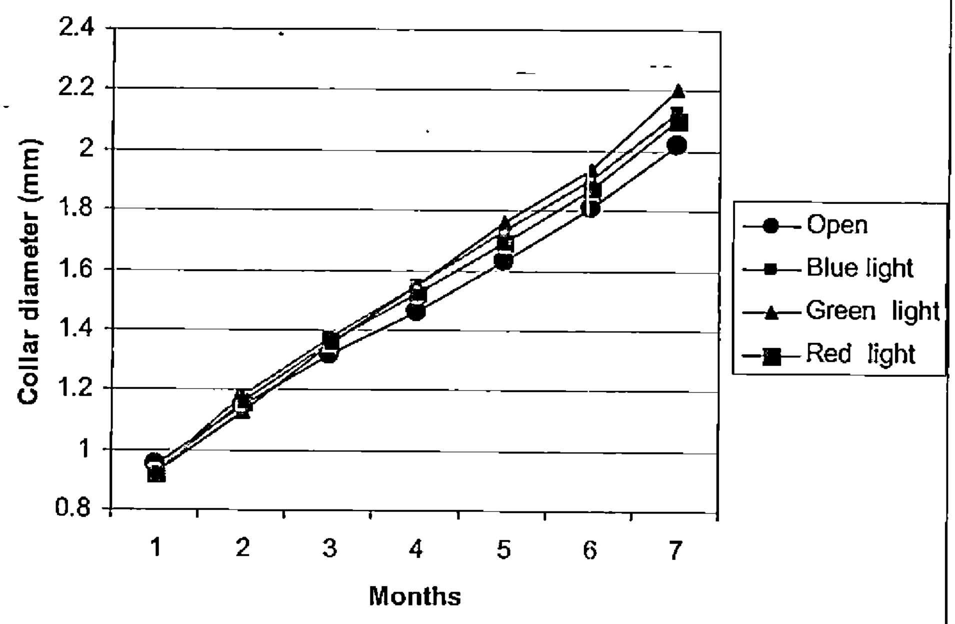

Fig. 2 (b): Effect of light quality on collar diameter of sandal seedlings

collar diameter. On the other hand, control gave a significantly different value at this stage.

In the seventh month the light quality and shade levels showed significant differences with respect to of collar diameter. Control also gave a significant mean value of 2.02 mm. Among the different light qualities, seedlings grown under green light quality gave the best result in the growth of sandal seedlings with a recorded value of 2.20 mm. On the other hand, seedlings under blue and red light qualities did not differ from each other significantly in the development of collar diameter with values of 2.13 mm and 2.10 mm respectively. When seedlings grown under different shades were considered, the maximum growth value was given by 50 per cent shade with a mean value of 2.21 mm. However, 25 per cent and 75 per cent shades did not provide any significant difference in the development of collar diameter with mean values of 2.12 mm and 2.10 mm respectively. Overall increase in the collar diameter of sandal seedlings in the seven months was found to be the best under 50 per cent shade level with an increase of 134.61 %, while use of green light quality showed the highest increase of 139.13 % in collar diameter.

4.1.3 Number of leaves

The effect of different levels of shades and light qualities on the number of leaves of the sandal seedlings are furnished in Table 3 (a to c) and Fig. 3 (a, b). From the tables it can be concluded that use of different shades and light qualities do not affect the production of leaves till the fifth month as the mean values were not significantly different from each other. But light qualities significantly influenced the production of number of leaves in the sixth and seventh months. At the seventh month, the highest number of leaves was found in seedlings grown under green light quality with a recorded value of 20.22. Different levels of shades did not give any significant impact on number of leaves from the first month till the end of the study period. However, control had significant impacts on the number of leaves starting from second month till the end of the study

Table 3 (a): Two-way tables showing combined effects of shade and light quality on number of leaves in sandal seedlings

Month 1

Light quality	Shade level 25	Shade level 50	Shade level 75	Mean
Blue	5.00	4.00	4.00	4.33
Green	3.67	4.00	4.00	3.89
Red	4.33	4.67	4.33	4.44
Mean	4.33	4.22	4.11	4.00 (control)

$F_{control}$ → 0.104 NS, SEm +/- = 0.255
F_{shade} → 0.089 NS, SEm +/- = 0.192
F_{filter} → 0.623 NS, SEm +/- = 0.509
$F_{interaction}$ → 0.445 NS, SEm +/- = 0.248

Month 2

Light quality	Shade level 25	Shade level 50	Shade level 75	Mean
Blue	6.33	6.33	6.33	6.33
Green	6.67	7.67	6.00	6.78
Red	7.33	7.67	6.33	7.11
Mean	6.78	7.22	6.22	5.00 (control)

$F_{control}$ → 4.72*, SEm +/- = 2.01
F_{shade} → 1.31 NS, SEm +/- = 0.868
F_{filter} → 0.80 NS, SEm +/- = 0.676
$F_{interaction}$ → 0.38 NS, SEm +/- = 0.268

Month 3

Light quality	Shade level 25	Shade level 50	Shade level 75	Mean
Blue	8.33	8.67	8.00	8.33
Green	8.33	10.67	8.33	9.11
Red	8.67	9.33	9.00	9.00
Mean	8.44	9.56	8.44	6.00 (control)

$F_{control}$ → 7.72*, SEm +/- = 3.27
F_{shade} → 1.34 NS, SEm +/- = 1.11
F_{filter} → 0.57 NS, SEm +/- = 0.73
$F_{interaction}$ → 0.43 NS, SEm +/- = 0.365

* - significant at 5 %, ** - significant at 1 %, NS – non-significant
Values with the similar alphabets do not differ significantly.
Control – Full- sunlight

Table 3 (b): **Two-way tables showing combined effects of shade and light quality on number of leaves in sandal seedlings**

Month 4

Light quality	Shade level 25	50	75	Mean
Blue	10.67	10.67	10.33	10.56
Green	11.33	14.00	11.00	12.11
Red	11.33	11.67	12.33	11.78
Mean	11.11	12.11	11.22	8.00 (control)
$F_{control}$ → 8.45*, SEm +/- = 4.045				
F_{shade} → 0.70 NS, SEm +/- = 0.949				
F_{filter} → 1.56 NS, SEm +/- = 1.42				
$F_{interaction}$ → 0.81 NS, SEm +/- = 0.591				

Month 5

Light quality	Shade level 25	50	75	Mean
Blue	13.00	12.67	13.33	13.00
Green	15.33	17.00	13.00	15.11
Red	14.00	14.00	15.00	14.33
Mean	14.11	14.56	13.78	8.67 (control)
$F_{control}$ → 29.5**, SEm +/- = 6.369				
F_{shade} → 0.498 NS, SEm +/- = 0.676				
F_{filter} → 3.73 NS, SEm +/- = 1.85				
$F_{interaction}$ → 2.2 NS, SEm +/- = 0.819				

Month 6

Light quality	Shade level 25	50	75	Mean
Blue	14.67	15.00	15.00	14.89^{y}
Green	16.33	21.00	16.00	17.78^{x}
Red	16.00	15.67	16.67	16.11^{xy}
Mean	15.67	17.22	15.89	9.67 (control)
$F_{control}$ → 38.48**, SEm +/- = 7.96				
F_{shade} → 2.09 NS, SEm +/- = 2.11				
F_{filter} → 6.21*, SEm +/- = 3.23				
$F_{interaction}$ → 2.94 NS, SEm +/- = 1.15				

* - significant at 5 %, ** - significant at 1 %, NS – non-significant

Values with the similar alphabets do not differ significantly.

Control – Full- sunlight

Table 3 (c): Two-way tables showing combined effects of shade and light quality on number of leaves in sandal seedlings

Month 7

Light quality	Shade level 25	Shade level 50	Shade level 75	Mean
Blue	16.00[b]	17.67[b]	16.00[b]	16.56[y]
Green	18.00[b]	24.00[a]	18.67[b]	20.22[x]
Red	17.67[b]	17.00[b]	18.67[b]	17.78[y]
Mean	17.22	19.56	17.78	11.33 (control)
$F_{control}$ → 34.82**, SEm +/- = 7.96				
F_{shade} → 3.67 NS, SEm +/- = 2.11				
F_{filter} → 8.62**, SEm +/- = 3.23				
$F_{interaction}$ → 3.29*, SEm +/- = 1.15				

* - significant at 5 %, ** - significant at 1 %, NS – non-significant

Values with the similar alphabets do not differ significantly.

Control – Full- sunlight

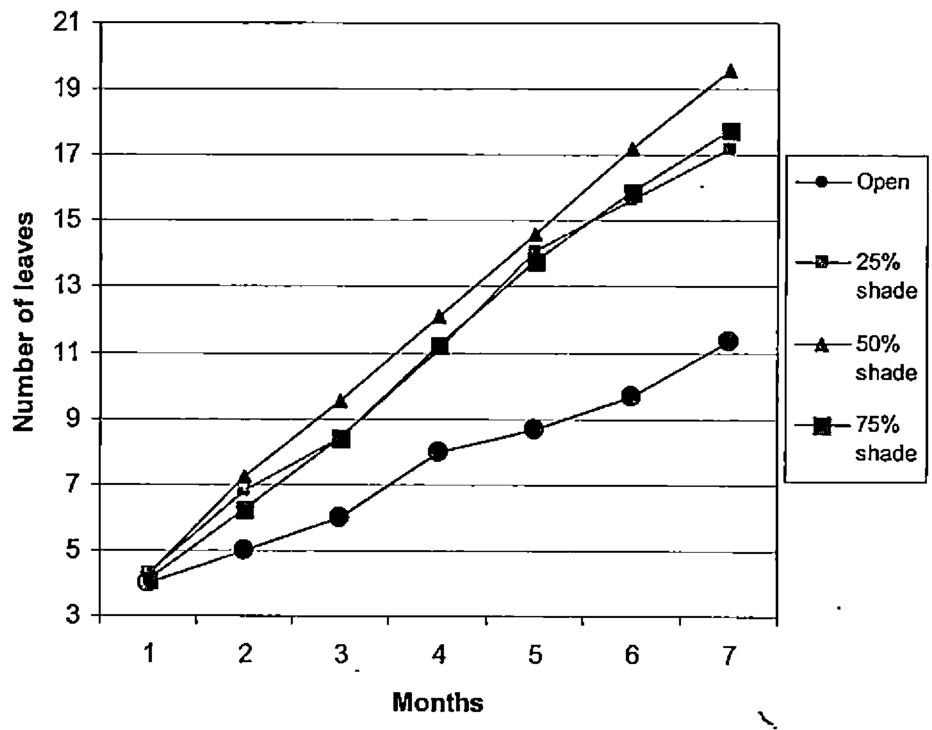

Fig. 3 (a): Effect of shade levels on leaf number in sandal seedlings

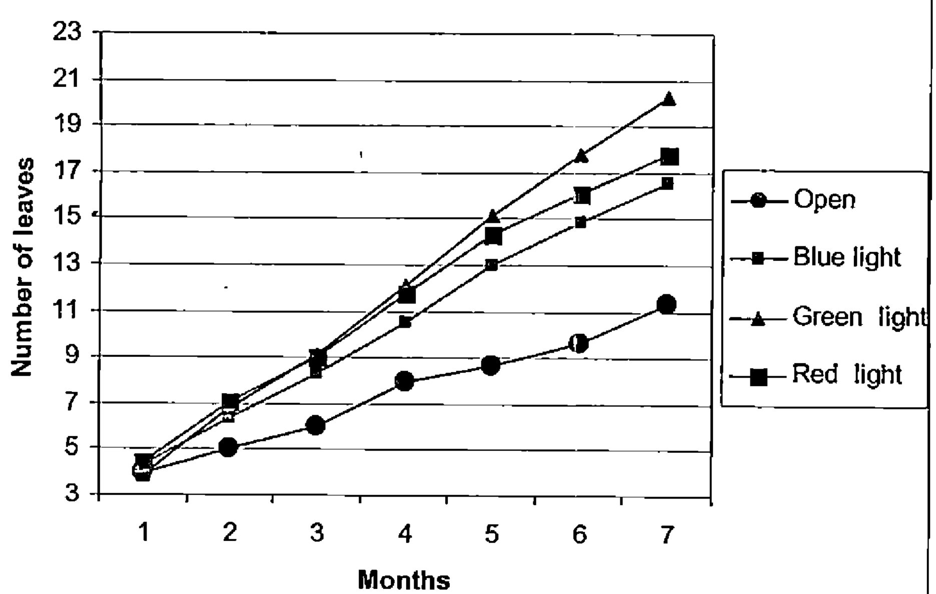

Fig. 3 (b): Effect of light quality on leaf number in sandal seedlings

period. The maximum value of number of leaves under different levels of shades was given by seedlings grown under 50 per cent shade with a mean value of 19.56. Interaction between the factors had significant impact on the number of leaves only in the seventh month. The highest number of leaves among the interactions was found in seedlings under the combination 50 per cent shade and green light quality in the seventh month.

In the sixth month (Table 3b), use of different light qualities gave significant effect on the production of number of leaves and use of green light quality provided the maximum value of 17.78. This was followed by seedlings grown under red and blue light qualities. Red light quality produced a mean value of 16.11 which was higher than the mean value of seedlings grown under blue light quality (14.89). The use of different levels of shades did not make any significant differences. The maximum number of leaf was however found in seedlings grown under 50 per cent shade level with a recorded value of 17.22. Seedlings grown in control gave the minimum value of 9.67 when the value is compared with seedlings grown under different shades and light qualities.

In the seventh month (Table 3c), providing varying light quality resulted in significantly different number of leaves in sandal seedlings. The maximum number of leaf was seen in seedlings grown under green light quality (20.22). The use of blue and red light qualities did not give any significantly different values as they were at par with each other and their respective recorded values were 16.56 and 17.78. On the other hand, shade levels did not influence number of leaves significantly. The maximum value was found to be in seedlings grown under 50 per cent shade level with a mean value of 19.56. Control gave the lowest value with a mean reading of 11.33, and was significantly different from the rest.

4.2 Root growth parameters

The various root growth parameters like length of the main root and the number of secondary roots as affected by different treatments are presented here.

The root growth parameters were found to be significantly influenced by the different levels of shades and light qualities.

4.2.1 Length of main root

The effect of the application of different levels of shades and light qualities in the development of length of the main root is given in Table 4 (a to c) and illustrated in Fig. 4 (a, b). Light quality did not affect the development of main root length throughout the study period. Different levels of shades also did not give any significant difference till the fifth month, but its application started to produce significant impacts from the sixth month till the end of the study period. Control was observed to be significantly different compared to others from the second month itself till the end of the study period. At the seventh month stage, the longest root was observed in seedlings grown under 50 per cent shade with a recorded value of 7.16 cm as far as the use of different levels of shade is considered. Although light qualities did not have a significant influence, the longest root was observed in green light quality with a mean value of 6.83 cm. Interaction was significant only in the sixth and seventh months. At the end of the study period, the maximum length of main root due to interaction of factors was observed in seedlings under the combination of 50 per cent shade and green light quality (7.70 cm). However, the lowest value in interaction was recorded in seedlings under 25 per cent shade and green light quality (6.10 cm) and 25 per cent shade and red light quality (6.10 cm) and they were at par with each other.

In the sixth month (Table 4b), different levels of shades differed significantly with regard to the development of main root length. The longest root was found in seedlings grown under 50 per cent shade level with a mean value of 6.38 cm. The seedlings grown under 25 and 75 per cent shade levels did not differ significantly and they were at par with each other with the recorded mean root lengths of 5.67 cm and 5.87 cm respectively. Seedlings grown under open condition gave the lowest value with a mean value of 5.00 cm at this stage and differed significantly from other treatments.

Table 4 (a): Two-way tables showing combined effects of shade and light quality on root length (cm) in sandal seedlings

Month 1

Light quality	Shade level 25	Shade level 50	Shade level 75	Mean
Blue	2.50	2.57	2.47	2.51
Green	2.50	2.60	2.53	2.54
Red	2.53	2.43	2.33	2.43
Mean	2.51	2.53	2.44	2.37 (control)

$F_{control}$ → 1.65 NS, SEm +/- = 0.140
F_{shade} → 0.83 NS, SEm +/- = 0.081
F_{filter} → 1.25 NS, SEm +/- = 0.099
$F_{interaction}$ → 0.56 NS, SEm +/- = 0.038

Month 2

Light quality	Shade level 25	Shade level 50	Shade level 75	Mean
Blue	3.23	3.20	3.10	3.18
Green	2.97	3.47	3.23	3.22
Red	3.20	3.17	3.00	3.12
Mean	3.13	3.28	3.11	2.90 (control)

$F_{control}$ → 3.58 NS, SEm +/- = 0.318
F_{shade} → 1.30 NS, SEm +/- = 0.157
F_{filter} → 0.40 NS, SEm +/- = 0.087
$F_{interaction}$ → 1.45 NS, SEm +/- = 0.095

Month 3

Light quality	Shade level 25	Shade level 50	Shade level 75	Mean
Blue	3.90	3.87	3.80	3.86
Green	3.53	4.23	3.93	3.90
Red	3.77	3.90	3.67	3.78
Mean	3.73	4.00	3.80	3.43 (control)

$F_{control}$ → 4.73*, SEm +/- = 0.476
F_{shade} → 1.81 NS, SEm +/- = 0.240
F_{filter} → 0.36 NS, SEm +/- = 0.107
$F_{interaction}$ → 1.28 NS, SEm +/- = 0.117

* - significant at 5 %, ** - significant at 1 %, NS – non-significant
Values with the similar alphabets do not differ significantly.
Control – Full-sunlight

Table 4 (b): **Two-way tables showing combined effects of shade and light quality on root length (cm) in sandal seedlings**

Month 4

Light quality	Shade level			Mean
	25	50	75	
Blue	4.77	4.60	4.50	4.62
Green	4.20	5.03	4.57	4.60
Red	4.37	4.67	4.37	4.47
Mean	4.44	4.77	4.48	4.03 (control)
$F_{control}$ → 6.02*, SEm +/- = 0.616				
F_{shade} → 2.24 NS, SEm +/- = 0.307				
F_{filter} → 0.50 NS, SEm +/- = 0.145				
$F_{interaction}$ → 1.53 NS, SEm +/- = 0.146				

Month 5

Light quality	Shade level			Mean
	25	50	75	
Blue	5.43	5.27	5.17	5.29
Green	4.90	5.87	5.30	5.36
Red	4.97	5.40	5.07	5.14
Mean	5.10	5.51	5.18	4.50 (control)
$F_{control}$ → 12.82**, SEm +/- = 0.882				
F_{shade} → 0.31 NS, SEm +/- = 0.378				
F_{filter} → 0.86 NS, SEm +/- = 0.187				
$F_{interaction}$ → 2.01 NS, SEm +/- = 0.165				

Month 6

Light quality	Shade level			Mean
	25	50	75	
Blue	6.00^{bc}	5.90^{bc}	5.77^{c}	5.89
Green	5.50^{c}	6.80^{a}	6.03^{bc}	6.11
Red	5.50^{c}	6.43^{ab}	5.80^{bc}	5.91
Mean	5.67^{m}	6.38^{l}	5.87^{m}	5.00 (control)
$F_{control}$ → 21.92**, SEm +/- = 1.128				
F_{shade} → 10.44**, SEm +/- = 0.635				
F_{filter} → 1.16 NS, SEm +/- = 0.212				
$F_{interaction}$ → 3.42*, SEm +/- = 0.210				

* - significant at 5 %, ** - significant at 1 %, NS – non-significant
Values with the similar alphabets do not differ significantly.
Control – Full-sunlight

Table 4 (c): Two-way tables showing combined effects of shade and light quality on root length (cm) in sandal seedlings

Month 7

Light quality	Shade level			Mean
	25	50	75	
Blue	6.60^{cd}	6.60^{cd}	6.37^{cd}	6.52
Green	6.10^{d}	7.70^{a}	6.70^{bc}	6.83
Red	6.10^{d}	7.17^{b}	6.43^{cd}	6.57
Mean	6.27^{m}	7.16^{l}	6.50^{m}	5.40 (control)
$F_{control} \rightarrow$ 46.16**, SEm +/- = 1.441				
$F_{shade} \rightarrow$ 21.24**, SEm +/- = 0.798				
$F_{filter} \rightarrow$ 2.83 NS, SEm +/- = 0.292				
$F_{interaction} \rightarrow$ 5.53**, SEm +/- = 0.235				

* - significant at 5 %, ** - significant at 1 %, NS – non-significant

Values with the similar alphabets do not differ significantly.

Control – Full-sunlight

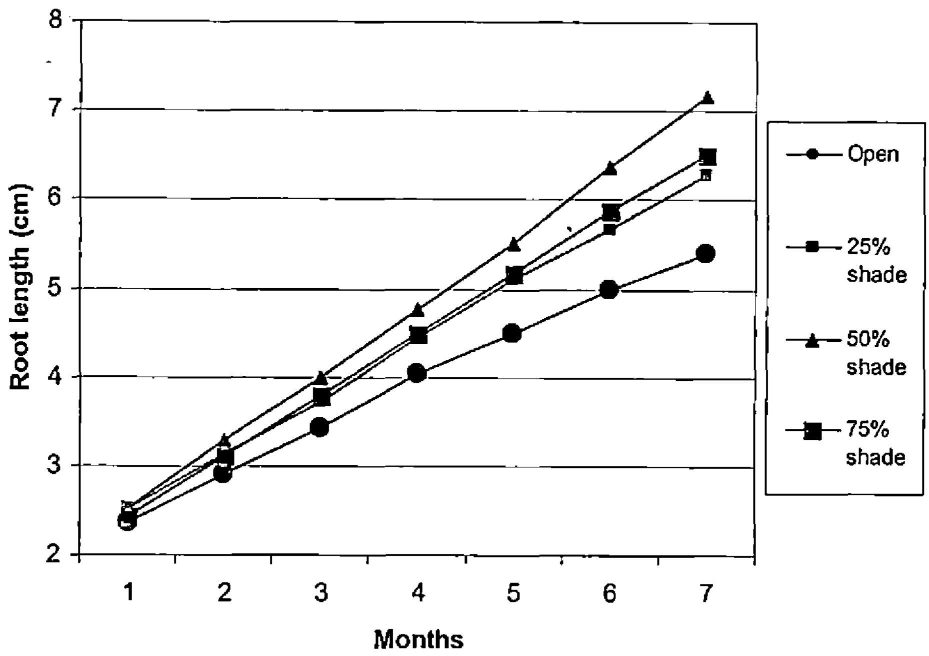

Fig. 4 (a): Effect of shade levels on root length of sandal seedlings

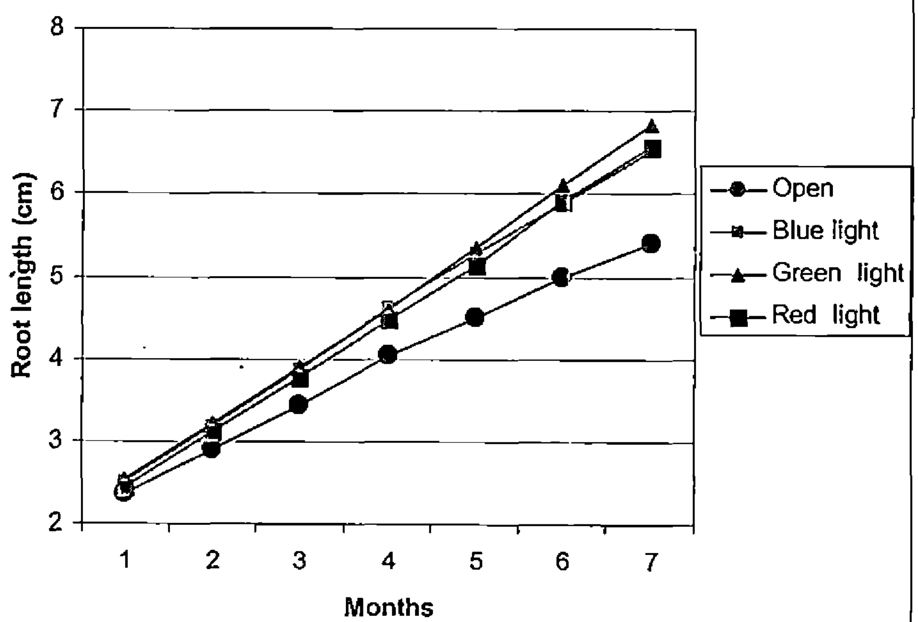

Fig. 4 (b): Effect of light quality on root length of sandal seedlings

When the growth of main root was considered in the seventh month, providing different levels of shades showed a significant difference and it was not the case with regard to the use of different light qualities as they were not significantly different in the same month. Seedlings grown under 50 per cent shade had the longest roots with a mean value of 7.16 cm. However, seedlings grown under 25 and 75 per cent shade levels were at par with each other when the growth of main root was considered with recorded mean values of 6.27 cm and 6.50 cm respectively. Different light qualities did not affect root length at this stage. The maximum was recorded from seedlings grown under green light quality with a mean value of 6.83 cm. Control had a significant influence and recorded the lowest with a mean value of 5.40 cm.

4.2.2 Number of secondary roots

The influence of treatments on the number of secondary roots produced by the plants is depicted in Table 5 (a to c) and Fig. 5 (a, b). The use of different shade levels did not bring any significance difference from the start till the end of the study period. However, the application of different light qualities produced statistically significant values starting from the third month till the end of the study period. Control had significant impacts on number of secondary roots starting from the fourth to the seventh months. At the seventh month stage, the maximum number of secondary roots was found in the seedlings grown under green light quality with a recorded value of 17.11 (Table 5c). As far as different levels of shades are considered, the maximum numbers of secondary roots were produced by seedlings grown under 75 per cent shade level with a value of 15.33 whereas control gave the minimum value of 11 in the same month. Interactions between the two different factors were insignificant from the first month till the end of the study period with respect to number of secondary roots.

In the third month from the application of the treatments, light quality produced significant difference in the development of secondary roots (Table 5a). From the table it is clear that the maximum number of secondary roots was

Table 5 (a): Two-way tables showing combined effects of shade and light quality on number of secondary roots in sandal seedlings

Month 1

Light quality	Shade level			Mean
	25	50	75	
Blue	4.67	3.67	3.67	4.00
Green	4.33	4.33	4.00	4.22
Red	4.00	4.00	3.67	3.89
Mean	4.33	4.00	3.78	4.33 (control)
$F_{control}$ → 0.98 NS, SEm +/- = 0.344				
F_{shade} → 2.90 NS, SEm +/- = 0.484				
F_{filter} → 1.07 NS, SEm +/- = 0.294				
$F_{interaction}$ → 1.07 NS, SEm +/- = 0.1697				

Month 2

Light quality	Shade level			Mean
	25	50	75	
Blue	6.00	5.00	5.67	5.56
Green	6.00	7.00	6.00	6.33
Red	5.67	5.00	5.33	5.33
Mean	5.89	5.67	5.67	5.33 (control)
$F_{control}$ → 0.32 NS, SEm +/- = 0.472				
F_{shade} → 0.11 NS, SEm +/- = 0.222				
F_{filter} → 1.80 NS, SEm +/- = 0.910				
$F_{interaction}$ → 0.71 NS, SEm +/- = 0.330				

Month 3

Light quality	Shade level			Mean
	25	50	75	
Blue	7.67	7.00	8.33	7.67^{xy}
Green	8.67	8.67	8.33	8.56^{x}
Red	7.00	6.67	7.33	7.00^{y}
Mean	7.78	7.44	8.00	6.33 (control)
$F_{control}$ → 4.48 NS, SEm +/- = 1.636				
F_{shade} → 0.59 NS, SEm +/- = 0.484				
F_{filter} → 4.59*, SEm +/- = 1.352				
$F_{interaction}$ → 0.45 NS, SEm +/- = 0.244				

* - significant at 5 %, ** - significant at 1 %, NS – non-significant
Values with the similar alphabets do not differ significantly.
Control – Full-sunlight

Table 5 (b): **Two-way tables showing combined effects of shade and light quality on number of secondary roots in sandal seedlings**

Month 4

Light quality	Shade level 25	Shade level 50	Shade level 75	Mean
Blue	10.33	8.33	10.00	9.56[y]
Green	12.00	11.67	10.33	11.33[x]
Red	8.67	8.33	9.00	8.67[y]
Mean	10.33	9.44	9.78	7.33 (control)

$F_{control}$ → 10.67**, SEm +/- = 2.926
F_{shade} → 1.13 NS, SEm +/- = 0.778
F_{filter} → 10.34**, SEm +/- = 2.352
$F_{interaction}$ → 1.34 NS, SEm +/- = 0.489

Month 5

Light quality	Shade level 25	Shade level 50	Shade level 75	Mean
Blue	11.67	10.33	12.00	11.33[y]
Green	13.67	14.00	13.33	13.67[x]
Red	10.67	9.67	10.33	10.22[y]
Mean	12.00	11.33	11.89	8.33 (control)

$F_{control}$ → 14.10**, SEm +/- = 3.959
F_{shade} → 0.52 NS, SEm +/- = 0.619
F_{filter} → 12.51**, SEm +/- = 3.045
$F_{interaction}$ → 0.52 NS, SEm +/- = 0.357

Month 6

Light quality	Shade level 25	Shade level 50	Shade level 75	Mean
Blue	13.00	12.00	14.00	13.00[y]
Green	15.67	15.33	15.00	15.33[x]
Red	12.00	11.00	12.33	11.78[y]
Mean	13.56	12.78	13.78	9.67 (control)

$F_{control}$ → 15.21**, SEm +/- = 4.303
F_{shade} → 1.02 NS, SEm +/- = 0.910
F_{filter} → 12.07**, SEm +/- = 3.129
$F_{interaction}$ → 0.47 NS, SEm +/- = 0.357

* - significant at 5 %, ** - significant at 1 %, NS – non-significant
Values with the similar alphabets do not differ significantly.
Control – Full-sunlight

Table 5 (c): **Two-way tables showing combined effects of shade and light quality on number of secondary roots in sandal seedlings**

Month 7

Light quality	Shade level			Mean
	25	50	75	
Blue	13.67	12.67	15.67	14.00[y]
Green	17.33	17.33	16.67	17.11[x]
Red	12.67	12.33	13.67	12.89[y]
Mean	14.56	14.11	15.33	11.00 (control)
$F_{control}$ → 18.42**, SEm +/- = 4.26				
F_{shade} → 1.75 NS, SEm +/- = 1.072				
F_{filter} → 21.87**, SEm +/- = 3.79				
$F_{interaction}$ → 1.38 NS, SEm +/- = 0.550				

* - significant at 5 %, ** - significant at 1 %, NS – non-significant
Values with the similar alphabets do not differ significantly.
Control – Full-sunlight

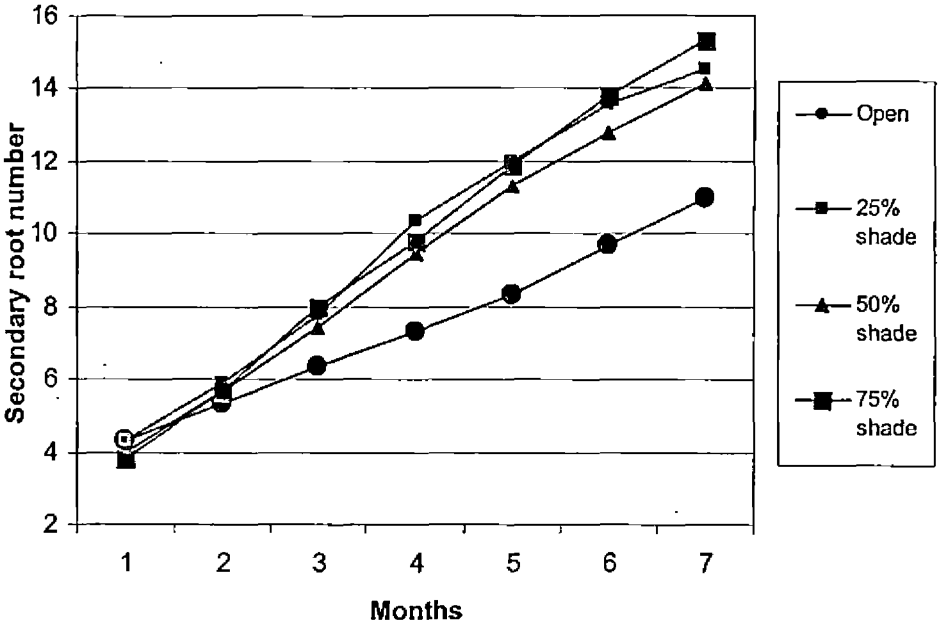

Fig. 5 (a): Effect of shade levels on secondary root number in sandal seedlings

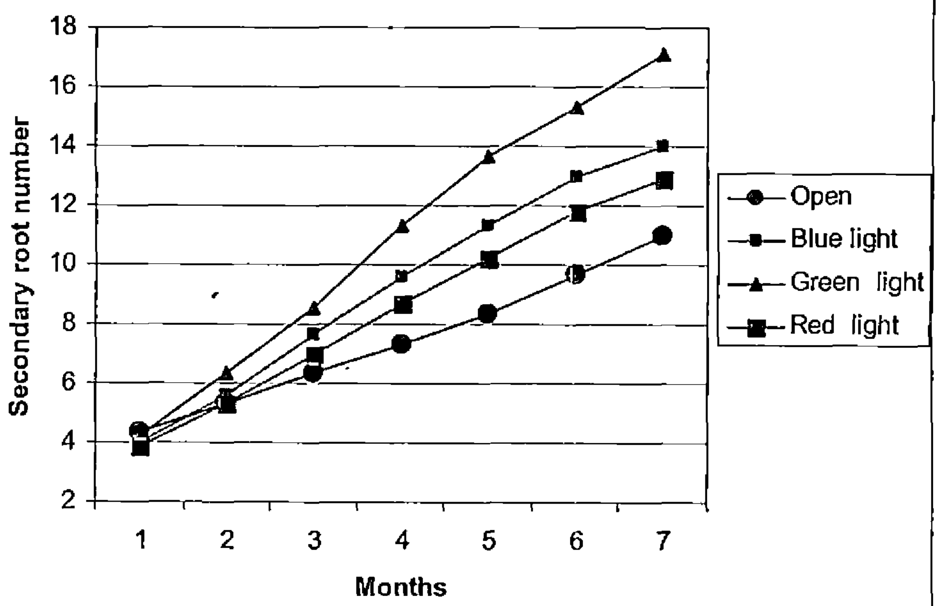

Fig. 5 (b): Effect of light quality on secondary root number of sandal seedlings

obtained when the seedlings were grown under green light quality (8.56). It was closely followed by the seedlings grown under blue light quality with a recorded value of 7.67 and this value was statistically different from number of secondary roots under green light quality. The minimum value (7.00) was given by the seedlings grown under red light quality. Open condition had the least number of secondary roots (6.33). At this stage different levels of shades did not show any significant impact on the number of secondary roots.

In the fourth month, light qualities once again gave the significance impact on the number of secondary roots. The seedlings under green light quality had the highest number of roots (11.33). This was followed by the seedlings under blue and red light qualities with values of 9.56 and 8.67 respectively and these values were at par. The control also provided a significant difference during the same month with a value of 7.33. However different levels of shades had no impact on the production of secondary roots during this stage of seedling growth. The maximum value was found in seedlings grown under 25 per cent shade (10.33).

The seedlings once again performed better under the green light quality (13.67) which showed a significant difference from other light qualities in the fifth month as tabulated in Table 5 (b). However, the seedlings under blue and red light qualities did not differ in number of roots in the same month. Control gave a significance difference in five months old seedling with a recorded mean value of 8.33. But the use of different levels of shades had no significant effect on the production of secondary roots and maximum value was given by seedlings grown under 25 per cent shade (12.00).

In the sixth month, the control and light qualities provided significantly different values whereas the use of varying levels of shades had no impact on the production of secondary roots (Table 5b). The application of green light quality was the best with the production of more number of secondary roots (15.33). Use of blue and red light qualities provided no significant difference in the same month with the recorded mean values of 13.00 and 11.78. However, the use of different shade levels was found to be insignificant in influencing number of secondary roots. The maximum value was observed in 75 per cent shade level (13.78).

Both the light qualities and control showed significant differences in the development of secondary roots in the seventh month (Table 5c). The maximum number of secondary roots was found to be in seedlings grown under green light quality (17.11) in this month. The blue and red light qualities did not give any significant effect as they were at par with each other with mean values of 14.00 and 12.89 respectively. Although the different levels of shades did not show any significant difference in the production of secondary roots, the highest value was observed in 75 per cent shade level (15.33). Control gave a mean value of only 11.00 in the same month, and differed significantly from the rest.

4.3 Dry matter of seedlings

The influence of different levels of shades and light qualities on the fresh and dry weights of the shoot and root portions of the seedlings are clearly evident from the data tabulated in Tables 6, 7, 8 and 9. The various treatments significantly influenced dry as well as fresh weights of shoot and root portions.

4.3.1 Fresh weight of shoot

The influence of various treatments on fresh weight of shoot is given in Table 6 (a to c). The effects of different levels of shades and light qualities started to give significant values from the second month till the end of the study period except in the fourth month, when different shade level had no significant impact. At the end of the observations, the maximum value of fresh weight of shoot was recorded in seedlings grown in 50 per cent shade level (0.818 g) and 75 per cent shade level (0.789 g), and they were at par. Seedlings under green light quality (0.838 g) had the highest value of fresh weight of shoot with regard to different light qualities in the seventh month. Interactions had significant impact on the

Table 6 (a): Two-way tables showing combined effects of shade and light quality on fresh weight of shoot (g) in sandal seedlings

Month 1

Light quality	Shade levels			Mean
	25	50	75	
Blue	0.140	0.150	0.110	0.133
Green	0.140	0.163	0.150	0.151
Red	0.150	0.157	0.137	0.148
Mean	0.143	0.157	0.132	0.147 (control)

$F_{control}$ → 2.80 NS, SEm +/- = 0.045
F_{shade} → 1.05 NS, SEm +/- = 0.022
F_{filter} → 0.70 NS, SEm +/- = 0.018
$F_{interaction}$ → 1.75 NS, SEm +/- = 0.005

Month 2

Light quality	Shade levels			Mean
	25	50	75	
Blue	0.220	0.240	0.260	0.240^{y}
Green	0.227	0.297	0.280	0.268^{x}
Red	0.220	0.233	0.213	0.222^{y}
Mean	0.222^{m}	0.257^{l}	0.251^{l}	0.197 (control)

$F_{control}$ → 1.40 NS , SEm +/- = 0.071
F_{shade} → 4.20*, SEm +/- = 0.032
F_{filter} → 6.30*, SEm +/- = 0.039
$F_{interaction}$ → 1.70 NS, SEm +/- = 0.012

Month 3

Light quality	Shade levels			Mean
	25	50	75	
Blue	0.323^{c}	0.323^{c}	0.367^{bc}	0.338^{y}
Green	0.337^{bc}	0.427^{a}	0.387^{ab}	0.383^{x}
Red	0.327^{c}	0.333^{c}	0.327^{c}	0.329^{y}
Mean	0.329^{m}	0.361^{l}	0.360^{l}	0.267 (control)

$F_{control}$ → 26.60**, SEm +/- = 0.097
F_{shade} → 4.20*, SEm +/- = 0.032
F_{filter} → 10.50**, SEm +/- = 0.05
$F_{interaction}$ → 3.50*, SEm +/- = 0.017

* - significant at 5 %, ** - significant at 1 %, NS – non-significant
Values with the similar alphabets do not differ significantly.
Control – Full-sunlight

Table 6 (b): Two-way tables showing combined effects of shade and light quality on fresh weight of shoot (g) in sandal seedlings

Month 4

Light quality	Shade levels			Mean
	25	50	75	
Blue	0.430[bc]	0.413[c]	0.470[bc]	0.438[y]
Green	0.453[bc]	0.563[a]	0.490[b]	0.502[x]
Red	0.423[c]	0.420[c]	0.447[bc]	0.430[y]
Mean	0.436	0.466	0.469	0.360 (control)

$F_{control}$ → 18.89**, SEm +/- = 0.116
F_{shade} → 2.10 NS, SEm +/- = 0.032
F_{filter} → 6.65**, SEm +/- = 0.056
$F_{interaction}$ → 4.90*, SEm +/- = 0.028

Month 5

Light quality	Shade levels			Mean
	25	50	75	
Blue	0.527[c]	0.520[c]	0.553[bc]	0.533[y]
Green	0.573[bc]	0.690[a]	0.600[b]	0.621[x]
Red	0.510[c]	0.543[bc]	0.557[bc]	0.537[y]
Mean	0.537[m]	0.584[l]	0.570[lm]	0.477 (control)

$F_{control}$ → 11.90**, SEm +/- = 0.092
F_{shade} → 3.85*, SEm +/- = 0.043
F_{filter} → 5.95*, SEm +/- = 0.053
$F_{interaction}$ → 7.70**, SEm +/- = 0.035

Month 6

Light quality	Shade levels			Mean
	25	50	75	
Blue	0.617[c]	0.623[c]	0.647[bc]	0.629[y]
Green	0.657[bc]	0.810[a]	0.700[b]	0.722[x]
Red	0.613[c]	0.647[bc]	0.657[bc]	0.639[y]
Mean	0.629[m]	0.693[l]	0.668[l]	0.577 (control)

$F_{control}$ → 14.70**, SEm +/- = 0.102
F_{shade} → 6.65**, SEm +/- = 0.056
F_{filter} → 16.45**, SEm +/- = 0.089
$F_{interaction}$ → 4.02*, SEm +/- = 0.025

* - significant at 5 %, ** - significant at 1 %, NS – non-significant
Values with the similar alphabets do not differ significantly.
Control – Full-sunlight

Table 6 (c): **Two-way tables showing combined effects of shade and light quality on fresh weight of shoot (g) in sandal seedlings**

Month 7

Light quality	Shade levels			Mean
	25	50	75	
Blue	0.707^{de}	0.747^{cde}	0.780^{bc}	0.744^{y}
Green	0.763^{cd}	0.933^{a}	0.817^{b}	0.838^{x}
Red	0.703^{e}	0.773^{bc}	0.770^{bc}	0.749^{y}
Mean	0.724^{m}	0.818^{l}	0.789^{l}	0.663 (control)
$F_{control}$ → 25.89**, SEm +/- = 0.136				
F_{shade} → 14.35**, SEm +/- = 0.083				
F_{filter} → 17.49**, SEm +/- = 0.091				
$F_{interaction}$ → 3.85*, SEm +/- = 0.025				

* - significant at 5 %, ** - significant at 1 %, NS – non-significant
Values with the similar alphabets do not differ significantly.
Control – Full-sunlight

fresh weight of shoot starting from the third month till the end of the study period. The maximum fresh weight of shoot due to interaction in the seventh month was observed in seedlings under the combination of 50 per cent shade and green light quality (0.933 g). However, the minimum fresh weight of shoot due to interaction effect was observed in seedlings under the combination of 25 per cent shade and red light quality (0.703 g) in the same month. Control had significant effects on the fresh weight of shoot from the third month till the end of the study period.

In the second month, both the different levels of shades and light qualities had significant impacts on the fresh weight of shoot (Table 6a). The maximum fresh weight of shoot was observed in seedlings under 50 per cent shade (0.257 g) and 75 per cent (0.251 g). The minimum fresh weight of shoot was, however, recorded in 25 per cent shade level (0.222 g). The maximum value of fresh weight of shoot was observed in green light quality (0.268 g) when comparison is done for light qualities in the same month. This was followed by seedlings grown under blue (0.240 g) and red light qualities (0.222 g) and they were at par with each other. Control had insignificant impact on the fresh weight of root in the second month.

The maximum fresh weight of shoot was found in seedlings grown under 50 (0.361 g) and 75 per cent shade level (0.360 g) in the third month (Table 6a). 25 per cent shade level also gave significant impact on the production of fresh weight of shoot with a mean value of 0.329 g. Use of different light qualities also gave significant impact on the fresh weight of shoot. The maximum fresh weight of shoot was obtained in green light quality (0.383 g) among the different types of light qualities, which was followed by seedlings grown under blue (0.338 g) and red light qualities (0.329 g). However, seedlings under the blue and red light qualities did not vary significantly with regard to fresh weight of shoot. Control also had significant impact on the fresh weight of shoot in the same month with a mean value of 0.267 g.

In the fourth month use of different levels of shades did not have any significant impact on the fresh weight of shoot while varying levels of light qualities had significant impact on the fresh weight of shoot (Table 6b). The maximum fresh weight of shoot was observed in seedlings under green light quality (0.502 g). It was followed by seedlings under blue and green light qualities with recorded mean values of 0.438 g and 0.430 g and they were at par with each other. Control had a significant impact on the fresh weight of shoot in the same month.

The fifth month showed significant effects on the fresh weight of shoot due to use of different levels of shades and light qualities. The maximum value of fresh weight of shoot was observed in seedlings under 50 per cent shade (0.584 g). The minimum value was given by the seedlings under 25 per cent shade with a mean value of 0.537 g. As far as light qualities are concerned, the best performance was observed in the seedlings grown under green light quality (0.621 g) which was followed by seedlings developed under blue (0.533 g) and red light qualities (0.537 g) and they were par with each other. Control had significant effect on the fresh weight of sandal seedlings.

In the sixth month, both the different types of light qualities and shades provided significant impacts on the fresh weight of shoot (Table 6b). Control had a significant impact on the fresh weight of shoot (0.577 g). The maximum fresh weight of shoot was observed in seedlings under 50 (0.693 g) and 75 per cent shade levels (0.668 g), and they were at par with each other. The least value was recorded in seedlings under 25 per cent shade level (0.629 g). Seedlings under green light quality had the maximum fresh weight of shoot with a mean value of 0.772 g with which was significantly different from values obtained in seedlings under blue (0.629 g) and red light qualities (0.639 g). However, the fresh weights of shoots of sandal seedlings under blue and red light qualities were at par with each other for the same month.

At the end of the study period *i.e.* in the seventh month, different light qualities as well as shades had significant impact on the fresh weight of shoot (Table 6c). The maximum fresh weight of shoot was observed in seedlings under 50 and 75 per cent shade levels with mean values of 0.818 g and 0.789 g respectively, and they did not vary significantly from each other. It was followed by seedlings under 25 per cent shade level (0.724 g). The maximum fresh weight of shoot of sandal seedlings was observed under green light quality (0.838 g). Seedlings grown under blue and red light qualities had mean values of fresh weight of shoot as 0.744 g and 0.749 g respectively. However, they were at par with each other. Open condition had also a significant impact on the fresh weight of shoot in the same month.

4.3.2 Fresh weight of root

The effect of different treatments on fresh weight of root is furnished in Table 7 (a to c) and Fig. 6 (a, b). The different treatments had significant influence on the fresh weight of root starting from the third month of the application of the treatments till the end of the study period except in the fourth month when the different levels of shades and light qualities did not give significantly different values. However, shades affected the sandal seedlings significantly in the second month. In the last month (*i.e.* seventh month) the maximum fresh weight of root among the different levels of shades was given by the seedlings grown under 50 per cent shade which gave significantly different mean value of 0.695 g. However, the maximum value was seen in green light quality (0.684 g) with regard to the use of different light qualities at the end of the study period. Interactions between the factors had significant effects on the fresh weight of root only in the third, sixth and seventh months. In the seventh month, the highest fresh weight of root due to interaction of factors was observed in seedlings under the combination of 50 per cent shade and green light quality (0.779 g) and the least fresh weight of root under 75 per cent shade and red light quality (0.576 g). Control had significant impacts on the fresh weight of root throughout the study period.

Table 7 (a): Two-way tables showing combined effects of shade and light quality on fresh weight of root (g) in sandal seedlings

Month 1

Light quality	Shade level			Mean
	25	50	75	
Blue	0.109	0.123	0.110	0.114
Green	0.102	0.110	0.117	0.110
Red	0.106	0.122	0.117	0.115
Mean	0.105	0.118	0.115	0.102 (control)
$F_{control}$ → 25.64**, SEm +/- = 0.045				
F_{shade} → 3.21 NS, SEm +/- = 0.013				
F_{filter} → 0.32NS, SEm +/- = 0.004				
$F_{interaction}$ → 0.16 NS, SEm +/- = 0.000005				

Month 2

Light quality	Shade level			Mean
	25	50	75	
Blue	0.184	0.208	0.179	0.190
Green	0.184	0.193	0.162	0.180
Red	0.193	0.183	0.168	0.181
Mean	0.187^{l}	0.195^{l}	0.170^{m}	0.154 (control)
$F_{control}$ → 35.97**, SEm +/- = 0.071				
F_{shade} → 5.40*, SEm +/- = 0.022				
F_{filter} → 1.80, SEm +/- = 0.013				
$F_{interaction}$ → 0.90 NS, SEm +/- = 0.005				

Month 3

Light quality	Shade level			Mean
	25	50	75	
Blue	0.234^{c}	0.302^{a}	0.244^{c}	0.260^{x}
Green	0.238^{c}	0.296^{a}	0.227^{c}	0.254^{x}
Red	0.244^{c}	0.225^{c}	0.257^{b}	0.242^{y}
Mean	0.239^{m}	0.274^{l}	0.242^{m}	0.216 (control)
$F_{control}$ → 359.71**, SEm +/- = 0.100				
F_{shade} → 62.95**, SEm +/- = 0.034				
F_{filter} → 8.99**, SEm +/- = 0.013				
$F_{interaction}$ → 49.46**, SEm +/- = 0.017				

* - significant at 5 %, ** - significant at 1 %, NS – non-significant

Values with the similar alphabets do not differ significantly.

Control – Full-sunlight

Table 7 (b): Two-way tables showing combined effects of shade and light quality on fresh weight of root (g) in sandal seedlings

Month 4

Light quality	Shade level 25	Shade level 50	Shade level 75	Mean
Blue	0.315	0.412	0.370	0.366
Green	0.378	0.365	0.361	0.368
Red	0.350	0.386	0.345	0.360
Mean	0.348	0.388	0.359	0.285 (control)

$F_{control}$ → 18.02**, SEm +/- = 0.141
F_{shade} → 1.80 NS, SEm +/- = 0.037
F_{filter} → 0.023, SEm +/- = 0.004
$F_{interaction}$ → 1.13, SEm +/- = 0.017

Month 5

Light quality	Shade level 25	Shade level 50	Shade level 75	Mean
Blue	0.391	0.485	0.446	0.441^{y}
Green	0.470	0.519	0.454	0.481^{x}
Red	0.420	0.430	0.448	0.433^{y}
Mean	0.427^{n}	0.478^{l}	0.449^{m}	0.372 (control)

$F_{control}$ → 56.24**, SEm +/- = 0.158
F_{shade} → 6.75**, SEm +/- = 0.045
F_{filter} → 6.75**, SEm +/- = 0.045
$F_{interaction}$ → 2.81, SEm +/- = 0.017

Month 6

Light quality	Shade level 25	Shade level 50	Shade level 75	Mean
Blue	0.531^{b}	0.526^{b}	0.526^{b}	0.528^{y}
Green	0.536^{b}	0.687^{a}	0.527^{b}	0.583^{x}
Red	0.525^{b}	0.537^{b}	0.485^{b}	0.515^{y}
Mean	0.530^{m}	0.583^{l}	0.512^{m}	0.474 (control)

$F_{control}$ → 134.93**, SEm +/- = 0.212
F_{shade} → 18.74**, SEm +/- = 0.065
F_{filter} → 17.99**, SEm +/- = 0.063
$F_{interaction}$ → 10.87**, SEm +/- = 0.028

* - significant at 5 %, ** - significant at 1 %, NS – non-significant
Values with the similar alphabets do not differ significantly.
Control – Full-sunlight

Table 7 (c): **Two-way tables showing combined effects of shade and light quality on fresh weight of root (g) in sandal seedlings**

Month 7

Light quality	Shade level			Mean
	25	50	75	
Blue	0.631[bc]	0.633[bc]	0.636[bc]	0.633[y]
Green	0.641[bc]	0.779[a]	0.632[bc]	0.684[x]
Red	0.643[bc]	0.673[b]	0.576[c]	0.631[y]
Mean	0.639[m]	0.695[l]	0.615[n]	0.578 (control)
$F_{control}$ → 90**, SEm +/- = 0.212				
F_{shade} → 15.5**, SEm +/- = 0.072				
F_{filter} → 8**, SEm +/- = 0.052				
$F_{interaction}$ → 6.25**, SEm +/- = 0.026				

* - significant at 5 %, ** - significant at 1 %, NS – non-significant
Values with the similar alphabets do not differ significantly.
Control – Full-sunlight

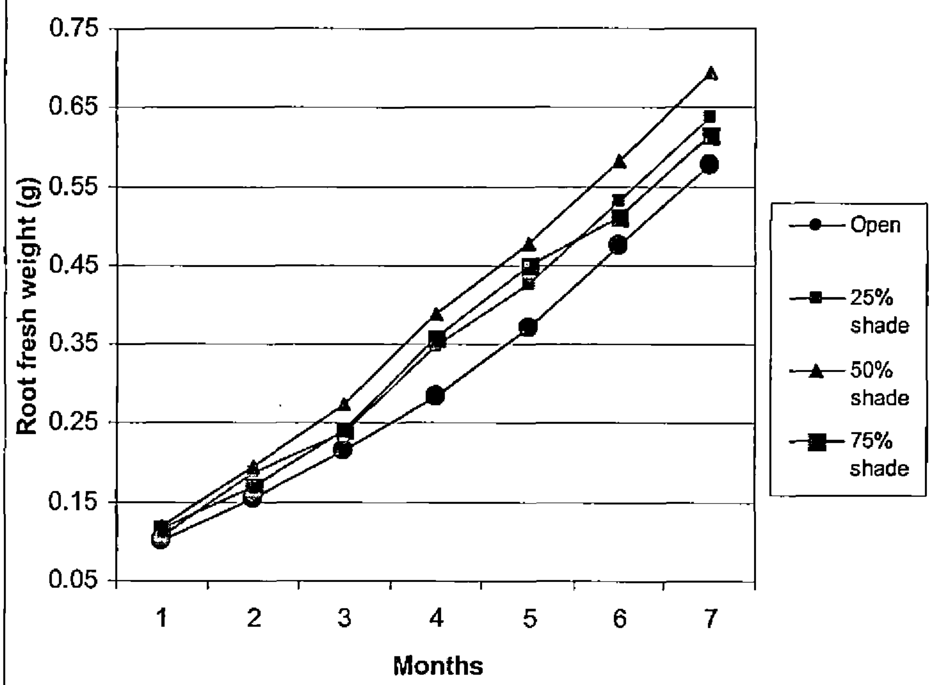

Fig. 6 (a): Effect of shade levels on root fresh weight in sandal seedlings

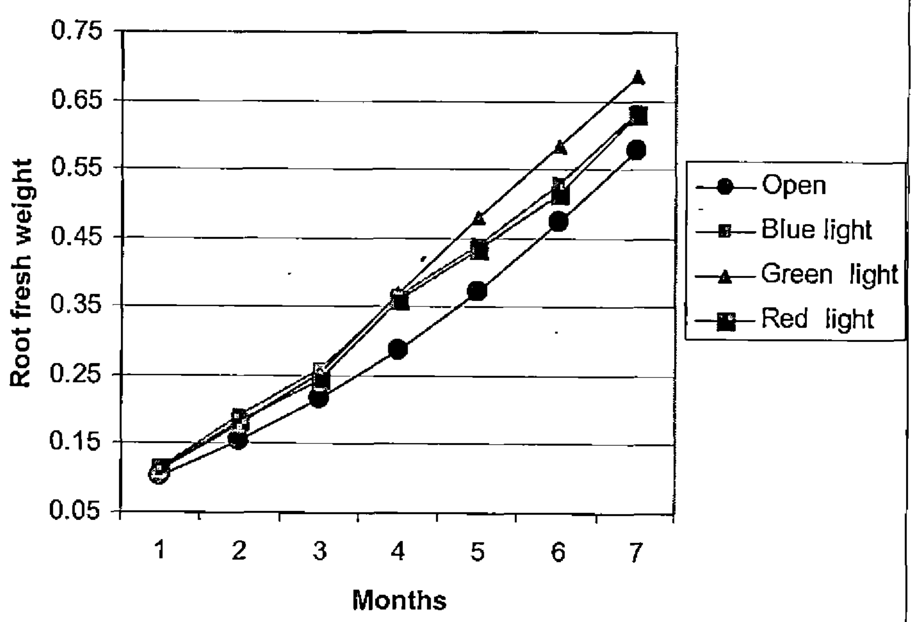

Fig. 6 (b): Effect of light quality on root fresh weight in sandal seedlings

In the second month, the maximum fresh weight of root was observed in the seedlings grown under 25 and 50 per cent shades with mean values of 0.187 g and 0.195 g and they were insignificantly different (Table 7a). The minimum value was obtained in seedlings under 75 per cent shade level (0.170 g) at that stage of seedling growth. Light qualities did not give any significant effect on the fresh weight of root in the same month.

The highest fresh weight of root was observed in seedlings grown under 50 per cent shade level among the different levels of shades in the third month (0.274 g) as shown in Table 7 (a). This was followed by seedlings under 25 and 75 per cent shade levels with respective mean values of 0.239 g and 0.242 g and they were at par with each other. As far as different light qualities were considered in the same month, the maximum fresh weight of root was observed in seedlings under blue and green light qualities with mean values of 0.260 g and 0.254 g respectively without any significant differences. This was trailed by seedlings under red light quality with a mean value of 0.242 g. Control had a significant influence and recorded the lowest value of 0.216 g.

In the fourth month the different levels of shades and light qualities had no effect on the fresh weight of root (Table 7b). However the maximum value was recorded in seedlings grown under 50 per cent shade level with a mean value of 0.388 g as far as different light qualities were concerned and the highest fresh weight of root was observed in seedlings under green light quality (0.368 g) when light qualities were taken into consideration. Control had a significant effect on the fresh weight of root with a mean value of 0.285 g.

In the fifth month, the maximum fresh weight of root under varying levels of shades was observed in seedlings under 50 per cent shade (0.478 g) which was followed by seedlings under 75 per cent shade with mean of 0.449 g and they were significantly different from each other (Table 7b). The least value was recorded in seedlings under 25 per cent shade level with a recorded mean value of 0.427 g. Among the different light qualities used, the highest fresh weight of root was observed in seedlings under green light quality (0.481 g). This was followed by blue and red light qualities where the seedlings had recorded mean values of 0.441 g and 0.433 g, and they were found to be insignificantly different from each other. The control also had significant impact on the fresh weight of the root at the same stage of growth with a mean value of 0.372 g.

When comparison is done in the sixth month, the light qualities and different levels of shades also affected the production of fresh weight of root significantly (Table 7 b). The highest fresh weight of root was observed in seedlings under 50 per cent shade (0.583 g). The minimum value was observed in seedlings under 25 per cent shade level (0.530 g) and 75 per cent shade (0.512 g) and they were found to be non-significantly different from each other. The highest fresh weight of root was recorded in seedlings under green light quality (0.583 g). This was trailed by the seedlings under blue and red light qualities where their mean values were 0.528 g and 0.515 g respectively, and they did not vary significantly. Control had also a significant impact on the fresh weight of root in the same month with lowest mean value of 0.474 g.

Different light qualities and light quantities also showed significant effects on the fresh weight of root at the end of the study period (Table 7c). The highest value of fresh weight of root was recorded in seedlings under 50 per cent shade level with a mean value of 0.695 g. This was trailed by seedlings under 25 per cent shade level (0.639 g). The minimum fresh weight of root was recorded in seedlings under 75 per cent shade level with a mean value of 0.615 g. The maximum fresh weight of root was observed in seedlings under green light quality (0.684 g) among different light qualities. This was trailed by seedlings under blue (0.633 g) and red light qualities (0.631 g) where their mean values were not significantly different from each other. Control had also shown some significant effect on the fresh weight of root in the same month with a mean value of 0.578 g.

4.3.3 Dry weight of shoot

The effects of various levels of shades and light qualities in sandal seedlings during the course of seven months are given in Table 8 (a to c) and Fig. 7 (a, b). It can be seen that different light qualities did not show any significant effect on the dry weight of shoot till the third month. But it started to give influence on the sandal seedlings from the fourth month up to the end of the study period. The different levels of shades showed significant effects in the second, fifth and seventh months. At the end of the study period the best performance was seen in the sandal seedlings under 50 per cent shade level (0.171 g) and green light quality (0.173 g) when different levels of shades and light qualities were taken into consideration separately. Interactions between the factors had significant effect only in the seventh month of the study period. The maximum dry weight of shoot due to interaction was observed in seedlings under the combination 50 per cent shade and green light quality (0.178 g) in the seventh month. However, the minimum value of dry weight of shoot due to interaction for the same month was observed in seedlings under the combination of 25 per cent shade and red light quality (0.162 g). Control had significant impacts on the dry weight of shoot throughout the study period except in the first month.

In the second month the different levels of shades and control showed significant effects on the dry weight of shoot (Table 8 a). Light qualities, however, had no influence on the dry weight of shoot at the same stage of growth. Among the levels of shades, the maximum dry weight of shoot was seen in seedlings grown under 50 per cent shade level (0.104 g). 25 and 75 per cent shade levels also showed significant differences in their performances with 75 per cent shade recording a better mean value (0.102 g) as compared to 25 per cent shade (0.099 g). The maximum dry weight of shoot was observed in seedlings under green light quality (0.104 g).

In the third month, the application of various types of light qualities and shades provided no significantly different results except the control (Table 8a). However, in the fourth month of the study period the use of different light qualities and control showed significant effects. The highest dry weight of shoot

Table 8 (a): **Two-way tables showing combined effects of shade and light quality on dry weight of shoot (g) in sandal seedlings**

Month 1

Light quality	Shade level 25	50	75	Mean
Blue	0.060	0.065	0.071	0.065
Green	0.063	0.074	0.066	0.067
Red	0.065	0.068	0.066	0.066
Mean	0.063	0.069	0.068	0.065 (control)

$F_{control}$ → 0.04 NS, SEm +/- = 0.004
F_{shade} → 1.22 NS, SEm +/- = 0.018
F_{filter} → 0.11 NS, SEm +/- = 0.005
$F_{interaction}$ → 0.53 NS, SEm +/- = 0.007

Month 2

Light quality	Shade level 25	50	75	Mean
Blue	0.099	0.104	0.104	0.102
Green	0.100	0.106	0.104	0.104
Red	0.098	0.102	0.097	0.099
Mean	0.099^{n}	0.104^{l}	0.102^{ln}	0.094 (control)

$F_{control}$ → 12.76**, SEm +/- = 0.028
F_{shade} → 4.25*, SEm +/- = 0.013
F_{filter} → 3.60 NS, SEm +/- = 0.0123
$F_{interaction}$ → 0.65 NS, SEm +/- = 0.003

Month 3

Light quality	Shade level 25	50	75	Mean
Blue	0.118	0.111	0.122	0.117
Green	0.121	0.129	0.124	0.125
Red	0.120	0.117	0.116	0.118
Mean	0.107	0.119	0.121	0.106 (contro

$F_{control}$ → 8.81*, SEm +/- = 0.052
F_{shade} → 0.12 NS, SEm +/- = 0.005
F_{filter} → 2.71 NS, SEm +/- = 0.0236
$F_{interaction}$ → 1.08 NS, SEm +/- = 0.009

* - significant at 5 %, ** - significant at 1 %, NS – non-significant
Values with the similar alphabets do not differ significantly.
Control – Full-sunlight

Table 8 (b): Two-way tables showing combined effects of shade and light quality on dry weight of shoot (g) in sandal seedlings

Month 4

Light quality	Shade level 25	Shade level 50	Shade level 75	Mean
Blue	0.135	0.129	0.134	0.133^{y}
Green	0.136	0.139	0.136	0.137^{x}
Red	0.131	0.131	0.127	0.130^{y}
Mean	0.134	0.133	0.132	0.121 (control)

$F_{control}$ → 16.46**, SEm +/- = 0.044
F_{shade} → 0.27 NS, SEm +/- = 0.005
F_{filter} → 5.14*, SEm +/- = 0.02
$F_{interaction}$ → 1.21 NS, SEm +/- = 0.006

Month 5

Light quality	Shade level 25	Shade level 50	Shade level 75	Mean
Blue	0.141	0.142	0.145	0.143^{y}
Green	0.149	0.149	0.148	0.148^{x}
Red	0.142	0.145	0.143	0.143^{y}
Mean	0.144^{m}	0.145^{l}	0.145^{l}	0.137 (control)

$F_{control}$ → 11.49**, SEm +/- = 0.027
F_{shade} → 0.30 NS, SEm +/- = 0.004
F_{filter} → 7.22**, SEm +/- = 0.018
$F_{interaction}$ → 0.57 NS, SEm +/- = 0.003

Month 6

Light quality	Shade level 25	Shade level 50	Shade level 75	Mean
Blue	0.154	0.151	0.153	0.153^{y}
Green	0.158	0.159	0.154	0.157^{x}
Red	0.154	0.153	0.152	0.153^{y}
Mean	0.155	0.154	0.153	0.150 (control)

$F_{control}$ → 7.12*, SEm +/- = 0.016
F_{shade} → 1.20 NS, SEm +/- = 0.005
F_{filter} → 7.98**, SEm +/- = 0.014
$F_{interaction}$ → 1.22 NS, SEm +/- = 0.003

* - significant at 5 %, ** - significant at 1 %, NS – non-significant
Values with the similar alphabets do not differ significantly.
Control – Full-sunlight

Table 8 (c): **Two-way tables showing combined effects of shade and light quality on dry weight of shoot (g) in sandal seedlings**

Month 7

Light quality	Shade level			Mean
	25	**50**	**75**	
Blue	0.167^{ab}	0.165^{ab}	0.170^{ab}	0.167^{y}
Green	0.168^{ab}	0.178^{a}	0.171^{ab}	0.173^{x}
Red	0.162^{b}	0.170^{ab}	0.168^{ab}	0.166^{y}
Mean	0.166^{n}	0.171^{l}	0.169^{m}	0.159 (control)

$F_{control}$ → 26.87**, SEm +/- = 0.0357

F_{shade} → 7.73**, SEm +/- = 0.0156

F_{filter} → 10.77**, SEm +/- = 0.018

$F_{interaction}$ → 3.92*, SEm +/- = 0.006

* - significant at 5 %, ** - significant at 1 %, NS – non-significant

Values with the similar alphabets do not differ significantly.

Control – Full-sunlight

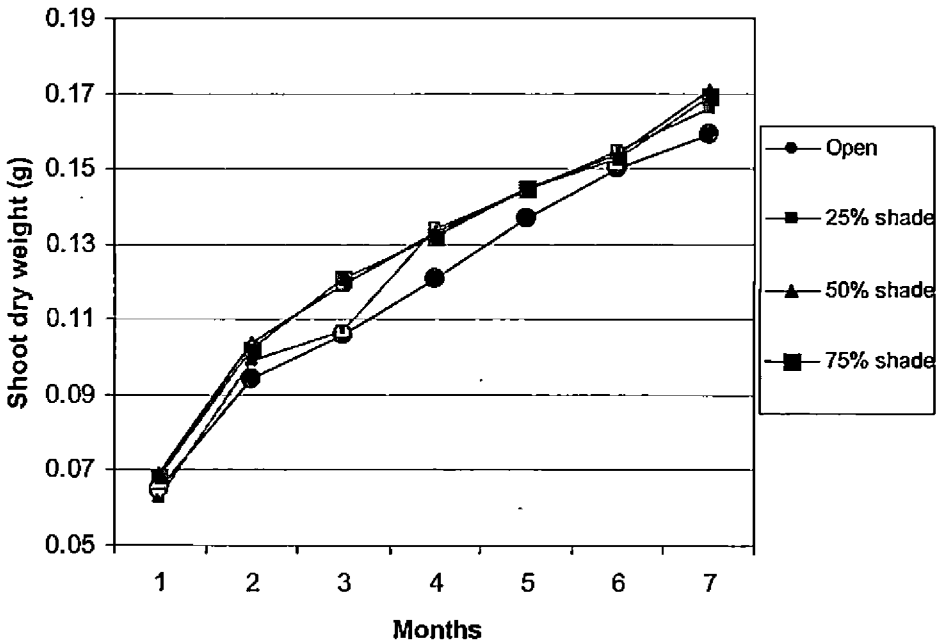

Fig. 7 (a): Effect of shade levels on shoot dry weight in sandal seedlings

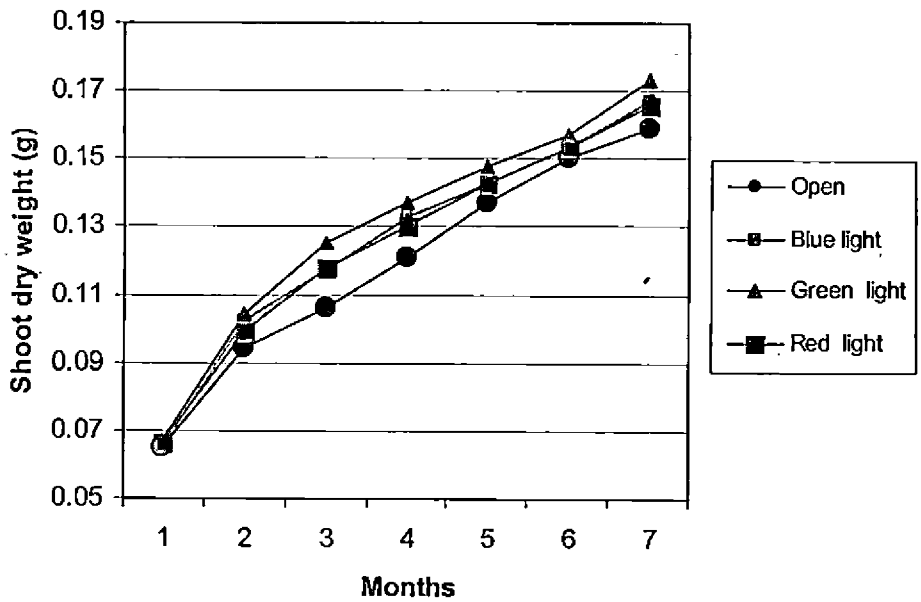

Fig. 7 (b): Effect of light quality on shoot dry weight of sandal seedlings

was observed in seedlings under green light quality (0.137 g). There was no significant difference between seedlings under blue and red light qualities with recorded mean values of 0.133 g and 0.130 g respectively.

Use of varying light qualities and quantities, and control gave significant difference in the fifth month (Table 8b). The maximum dry weight of shoot among the different levels of shades was observed in seedlings under 50 and 75 per cent levels of shades with mean values of 0.145 g each with no significant difference as they were at par with each other. The minimum mean value was observed in seedlings under 25 per cent shade level (0.144 g). On the other hand, seedlings under green light quality had the maximum dry weight of shoot among the different light qualities with a mean of 0.148 g. Seedlings under blue and red light qualities performed at par with each other with mean values of 0.143 g each.

In the sixth month both the light qualities and control showed significant effects on the dry weight of shoot (Table 8b). Seedlings under green light quality recorded the maximum dry weight of shoot (0.157 g). Seedlings under blue and red light qualities recorded mean values of 0.153 g each and they were at par with each other. However, different levels of shades had no significant impact on the dry weight of shoot in the same month. Control had significant effect with a mean value of 0.150 g.

In the seventh month all the factors *viz.* light qualities, different levels of shades and control gave significant impacts on the dry weight of shoot (Table 8c). Among the different levels of shades, the maximum dry weight of shoot was observed in seedlings under 50 per cent shade level (0.171 g). This was followed by seedlings under 25 and 75 per cent shade levels which showed significant differences with mean values of 0.166 g and 0.169 g respectively. When different light qualities were taken into consideration, the maximum dry weight of shoot was observed in seedlings under green light quality (0.173 g). This was trailed by seedlings under blue (0.167 g) and red light qualities (0.168 g), and they were at par with each other. Hence, the overall performance of the sandal seedlings under varying levels of shades and light qualities was the best in 50 per cent shade level and green light quality when these two factors were taken into consideration separately. The best combination of factors was found to be 50 per cent and green light quality.

4.3.4 Dry weight of root

The dry weight of root was found to be significantly influenced by the different levels of shades and light qualities as evident from Table 9 (a to c) and Fig. 8 (a, b).

Different levels of shades showed significant differences in the second, fourth, sixth and seven months with regard to dry weight of root. The use of different light qualities started to give significant differences from the third month till the end of the study period. Control also showed significant impacts on dry weight of root from the second month till the seventh month. At the end of the study period, the best performance was shown by the seedlings grown under 50 per cent shade level and green light quality when these two factors were taken into consideration separately with recorded mean values of 0.074 g and 0.075 g respectively. Interaction between the factors had significant impact on the dry weight of root throughout the study period except in the first month. The maximum dry weight of root due to interaction was observed in seedlings under the combination of 50 per cent shade and green light quality (0.084 g). However, the least dry weight of root due to interaction was observed in seedlings under the combination of 25 per cent shade and blue light quality (0.064 g).

In the second month the application of both the control and different levels of shades showed significant differences in their performances (Table 9a). The best performance was given by seedlings under 50 and 75 per cent levels of shades as they performed at par with each other with mean values of 0.041 g each. In the same month the different light qualities did not show any significant effect on the dry weight of root.

Table 9 (a): Two-way tables showing combined effects of shade and light quality on dry weight of root (g) in sandal seedlings

Month 1

Light quality	Shade level			Mean
	25	50	75	
Blue	0.027	0.027	0.029	0.028
Green	0.027	0.026	0.027	0.027
Red	0.030	0.027	0.027	0.028
Mean	0.028	0.027	0.028	0.029 (control)
$F_{control}$ → 0.54 NS, SEm +/- = 0.0215				
F_{shade} → 0.29 NS, SEm +/- = 0.0128				
F_{filter} → 0.15 NS, SEm +/- = 0.009				
$F_{interaction}$ → 0.28 NS, SEm +/- = 0.007				

Month 2

Light quality	Shade level			Mean
	25	50	75	
Blue	0.038^{e}	0.040^{c}	0.041^{b}	0.040
Green	0.036^{f}	0.043^{a}	0.043^{a}	0.041
Red	0.038^{e}	0.039^{d}	0.038^{e}	0.038
Mean	0.037^{m}	0.041^{l}	0.041^{l}	0.034 (control)
$F_{control}$ → 17.05**, SEm +/- = 0.019				
F_{shade} → 8.89**, SEm +/- = 0.011				
F_{filter} → 3.57 NS, SEm +/- = 0.007				
$F_{interaction}$ → 3.16*, SEm +/- = 0.002				

Month 3

Light quality	Shade level			Mean
	25	50	75	
Blue	0.045^{c}	0.044^{d}	0.047^{b}	0.045^{y}
Green	0.044^{d}	0.052^{a}	0.047^{b}	0.047^{x}
Red	0.045^{c}	0.043^{e}	0.043^{e}	0.043^{z}
Mean	0.045	0.046	0.045	0.041 (control)
$F_{control}$ → 14.36**, SEm +/- = 0.016				
F_{shade} → 1.96 NS, SEm +/- = 0.005				
F_{filter} → 9.87**, SEm +/- = 0.011				
$F_{interaction}$ → 6.31**, SEm +/- = 0.005				

* - significant at 5 %, ** - significant at 1 %, NS – non-significant
Values with the similar alphabets do not differ significantly.
Control – Full-sunlight

Table 9 (b): Two-way tables showing combined effects of shade and light quality on dry weight of root (g) in sandal seedlings

Month 4

Light quality	Shade level			Mean
	25	50	75	
Blue	0.052^{c}	0.050^{c}	0.051^{d}	0.051^{y}
Green	0.054^{b}	0.059^{a}	0.051^{d}	0.055^{x}
Red	0.051^{d}	0.052^{c}	0.048^{f}	0.050^{y}
Mean	0.052^{m}	0.054^{l}	0.050^{n}	0.047 (control)

$F_{control}$ → 19.49**, SEm +/- = 0.0197
F_{shade} → 8.19**, SEm +/- = 0.0104
F_{filter} → 10.97**, SEm +/- = 0.012
$F_{interaction}$ → 4.71*, SEm +/- = 0.005

Month 5

Light quality	Shade level			Mean
	25	50	75	
Blue	0.055^{f}	0.056^{e}	0.056^{e}	0.055^{y}
Green	0.061^{b}	0.064^{a}	0.059^{c}	0.061^{x}
Red	0.057^{d}	0.054^{g}	0.055^{f}	0.056^{y}
Mean	0.058	0.058	0.057	0.051 (control)

$F_{control}$ → 33.30**, SEm +/- = 0.024
F_{shade} → 1.48 NS, SEm +/- = 0.004
F_{filter} → 31.29**, SEm +/- = 0.019
$F_{interaction}$ → 3.88*, SEm +/- = 0.004

Month 6

Light quality	Shade level			Mean
	25	50	75	
Blue	0.057^{f}	0.062^{e}	0.062^{e}	0.061^{z}
Green	0.064^{c}	0.073^{a}	0.063^{d}	0.067^{x}
Red	0.062^{e}	0.062^{e}	0.065^{b}	0.063^{y}
Mean	0.061^{n}	0.066^{l}	0.064^{m}	0.056 (control)

$F_{control}$ → 44.70**, SEm +/- = 0.026
F_{shade} → 17.44**, SEm +/- = 0.013
F_{filter} → 26.55**, SEm +/- = 0.017
$F_{interaction}$ → 11.28**, SEm +/- = 0.006

* - significant at 5 %, ** - significant at 1 %, NS – non-significant
Values with the similar alphabets do not differ significantly.
Control – Full-sunlight

Table 9 (c): **Two-way tables showing combined effects of shade and light quality on dry weight of root (g) in sandal seedlings**

Month 7

Light quality	Shade level 25	Shade level 50	Shade level 75	Mean
Blue	0.064^{g}	0.067^{e}	0.071^{c}	0.067^{z}
Green	0.067^{e}	0.084^{a}	0.073^{b}	0.075^{x}
Red	0.065^{f}	0.071^{c}	0.070^{d}	0.069^{y}
Mean	0.065^{n}	0.074^{l}	0.071^{m}	0.062 (control)

$F_{control} \rightarrow$ 34.34**, SEm +/- = 0.031
$F_{shade} \rightarrow$ 29.88**, SEm +/- = 0.024
$F_{filter} \rightarrow$ 24.86**, SEm +/- = 0.022
$F_{interaction} \rightarrow$ 10.20**, SEm +/- = 0.008

* - significant at 5 %, ** - significant at 1 %, NS – non-significant
Values with the similar alphabets do not differ significantly.
Control – Full-sunlight

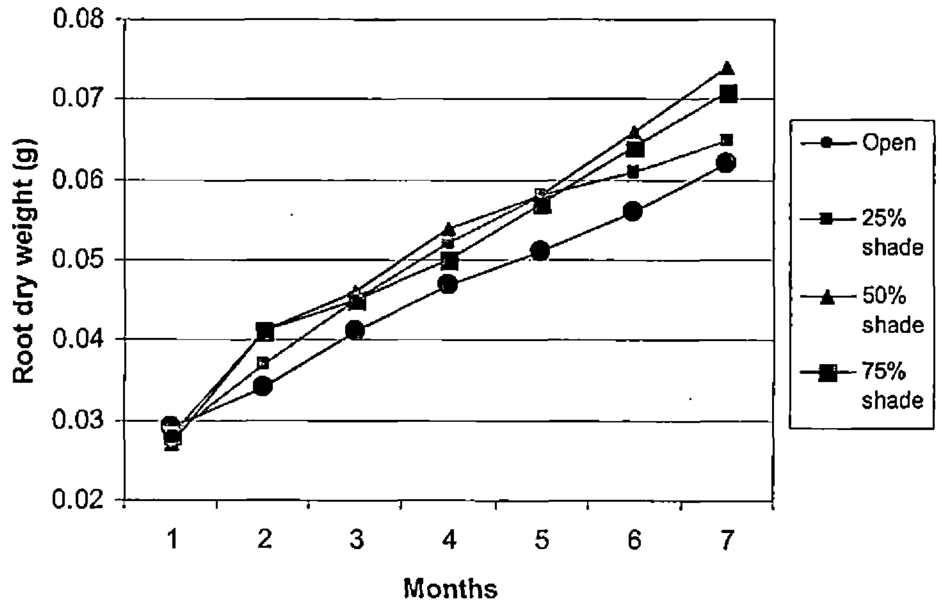

Fig. 8 (a): Effect of shade levels on root dry weight in sandal seedlings

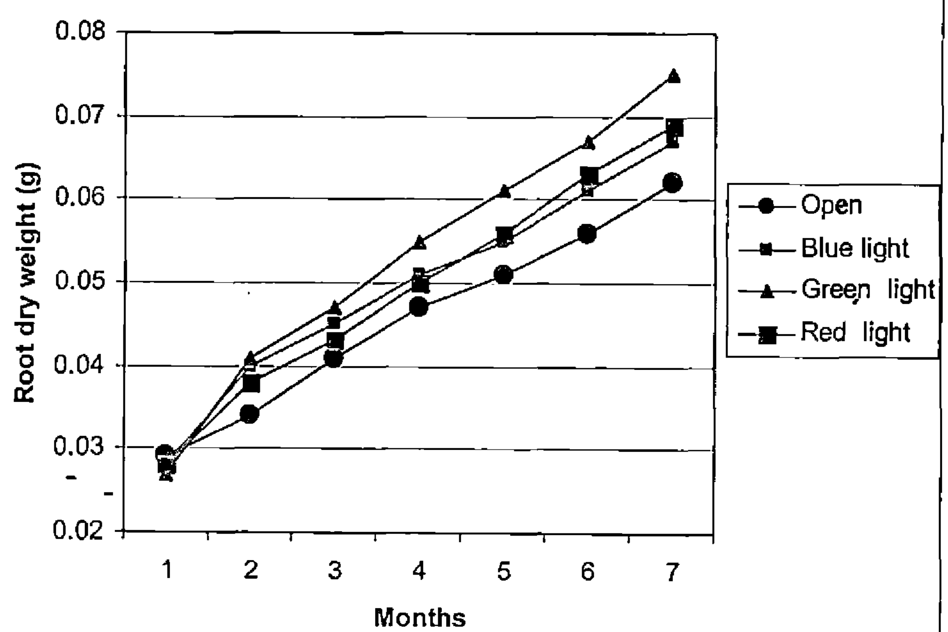

Fig. 8 (b): Effect of light quality on root dry weight in sandal seedlings

Dry weight of roots were influenced significantly due to the use of different light qualities and control, whereas varying levels of shades did not show any significant effect in the third month. Among the light qualities, the highest dry weight of root was recorded in seedlings under green light quality (0.047 g). This was followed by the seedlings grown under blue and red light qualities with significant differences and mean values of 0.045 g and 0.043 g respectively. Control had a mean value of 0.041 g.

In the fourth month the application of various types of light qualities and shades showed significant differences in the performances of the seedlings (Table 9 b). The best performance among different levels of shades was given by 50 per cent shade level where seedlings gave a mean reading of 0.054 g. This was trailed by seedlings under 25 and 75 per cent shade levels which showed significant differences with mean values of 0.050 g and 0.052 g respectively. Among the different types of light qualities used, the best result was found in the seedlings under green light quality (0.055 g). This was followed by seedlings under blue and red light qualities which were not significantly different with recorded mean values of 0.051 g and 0.050 g respectively.

Light qualities and control showed significantly different impact on the dry weight of root in the fifth month. Different levels of shades had no effect in this month on the dry weight of root. Among the light qualities used, the best performance was observed in the seedlings under green light quality (0.061 g). This was followed by seedlings under blue and red light qualities where their performances were at par with each other with recorded mean values of 0.055 g and 0.056 g respectively.

The various levels of shades and light qualities showed significant differences with regard to dry weight of root in the sixth month. Seedlings under 50 per cent shade level showed the highest dry weight of root (0.066 g) followed by seedlings under 25 (0.061 g) and 75 per cent levels of shades (0.064 g). But the performances of the seedlings under blue and red light qualities were not significantly different from each other. Among the different types of light qualities used, the green light quality resulted in the production of highest dry weight of root with a mean value of 0.067 g. At the same time, the seedlings under blue and red light qualities also showed significantly different values of 0.061 g and 0.063 g respectively. Control also had significant influence on the dry weight of root in the same month with mean value of 0.056 g.

The use of different shade levels and light qualities also proved to be significantly influencing the dry matter production of root in the seventh month of the study period (Table 9c). The best performance was seen in seedlings under 50 per cent shade level (0.074 g) which was followed by seedlings under 75 (0.071 g) and 25 per cent levels of shades (0.065 g). They were all significantly different from each other. The best performance was seen in seedlings under green light quality (0.075 g). This was trailed by seedlings under blue and red light qualities with recorded mean values of 0.067 g and 0.069 g, and they were also found to be significantly different from each other. Control had also shown significant difference with a mean value of 0.062 g in the same month. Thus, the performance of the seedlings was seen to be the best under 50 per cent shade level and green light qualities when both these two factors were taken separately.

4.4 Chlorophyll content

The chlorophyll content of leaves was found to be significantly influenced by varying light qualities and light quantities. The data related to chlorophyll content are tabulated in Tables 10, 11 and 12.

4.4.1 Chlorophyll-a

The data related to the chlorophyll-a content of the leaves are furnished in Table 10 (a to c). The influence of different levels of shades and light qualities on the chlorophyll-a content could be seen in the sandal seedlings starting from the first month of the application of the treatment till the end of the study period. At

Table 10 (a): Two-way tables showing combined effects of shade and light quality on chlorophyll-a content (mg/g) in sandal seedlings

Month 1

Light quality	Shade level			Mean
	25	50	75	
Blue	0.271^{b}	0.220^{de}	0.223^{de}	0.238^{y}
Green	0.291^{a}	0.301^{a}	0.236^{c}	0.276^{x}
Red	0.292^{a}	0.212^{e}	0.233^{cd}	0.246^{y}
Mean	0.285^{l}	0.244^{m}	0.231^{n}	0.248 (control)

$F_{control}$ → 1.43 NS, SEm +/- = 0.022
F_{shade} → 10*, SEm +/- = 0.048
F_{filter} → 5*, SEm +/- = 0.034
$F_{interaction}$ → 2.86 NS, SEm +/- = 0.015

Month 2

Light quality	Shade level			Mean
	25	50	75	
Blue	0.271^{c}	0.208^{e}	0.208^{e}	0.229^{z}
Green	0.289^{b}	0.314^{a}	0.242^{d}	0.281^{x}
Red	0.288^{b}	0.224^{e}	0.214^{e}	0.242^{y}
Mean	0.283^{l}	0.249^{m}	0.221^{n}	0.219 (control)

$F_{control}$ → 1.43 NS, SEm +/- = 0.022
F_{shade} → 12.14*, SEm +/- = 0.053
F_{filter} → 9.29*, SEm +/- = 0.047
$F_{interaction}$ → 3.21*, SEm +/- = 0.016

Month 3

Light quality	Shade level			Mean
	25	50	75	
Blue	0.271^{c}	0.220^{e}	0.233^{de}	0.241^{z}
Green	0.258^{c}	0.323^{a}	0.234^{de}	0.272^{x}
Red	0.285^{b}	0.239^{d}	0.217^{e}	0.247^{y}
Mean	0.272^{l}	0.261^{m}	0.228^{n}	0.208 (control)

$F_{control}$ → 1.43 NS, SEm +/- = 0.022
F_{shade} → 6.43*, SEm +/- = 0.039
F_{filter} → 3.57 NS, SEm +/- = 0.029
$F_{interaction}$ → 5.36*, SEm +/- = 0.020

* - significant at 5 %, ** - significant at 1 %, NS – non-significant
Values with the similar alphabets do not differ significantly.
Control – Full-sunlight

Table 10 (b): Two-way tables showing combined effects of shade and light quality on chlorophyll-a content (mg/g) in sandal seedlings

Month 4

Light quality	Shade level 25	50	75	Mean
Blue	0.272[ab]	0.236[bcd]	0.234[cd]	0.247[xy]
Green	0.243[cd]	0.294[a]	0.239[bcd]	0.259[x]
Red	0.257[bc]	0.242[bcd]	0.221[d]	0.240[y]
Mean	0.257[l]	0.257[l]	0.232[m]	0.195 (control)

$F_{control}$ → 11.43**, SEm +/- = 0.063
F_{shade} → 2.86 NS, SEm +/- = 0.026
F_{filter} → 1.43 NS, SEm +/- = 0.018
$F_{interaction}$ → 2.14 NS, SEm +/- = 0.0088

Month 5

Light quality	Shade level 25	50	75	Mean
Blue	0.277[b]	0.241[d]	0.227[de]	0.248[y]
Green	0.269[bc]	0.332[a]	0.236[d]	0.279[x]
Red	0.284[b]	0.256[c]	0.222[e]	0.254[y]
Mean	0.277[l]	0.276[l]	0.229[m]	0.184 (control)

$F_{control}$ → 1.43 NS, SEm +/- = 0.022
F_{shade} → 10**, SEm +/- = 0.048
F_{filter} → 3.57*, SEm +/- = 0.029
$F_{interaction}$ → 3.57*, SEm +/- = 0.017

Month 6

Light quality	Shade level 25	50	75	Mean
Blue	0.276[b]	0.258[c]	0.227[e]	0.254[y]
Green	0.285[b]	0.337[a]	0.252[cd]	0.291[x]
Red	0.261[c]	0.236[de]	0.251[cd]	0.249[y]
Mean	0.274[l]	0.277[l]	0.243[n]	0.186 (control)

$F_{control}$ → 21.43**, SEm +/- = 0.087
F_{shade} → 4.29*, SEm +/- = 0.032
F_{filter} → 7.14**, SEm +/- = 0.041
$F_{interaction}$ → 0.32 NS, SEm +/- = 0.016

* - significant at 5 %, ** - significant at 1 %, NS – non-significant
Values with the similar alphabets do not differ significantly.
Control – Full-sunlight

Table 10 (c): **Two-way tables showing combined effects of shade and light quality on chlorophyll-a content (mg/g) in sandal seedlings**

Month 7

Light quality	Shade level			Mean
	25	50	75	
Blue	0.274^{c}	0.268^{c}	0.235^{d}	0.259^{y}
Green	0.290^{b}	0.339^{a}	0.251^{d}	0.293^{x}
Red	0.271^{c}	0.248^{d}	0.250^{d}	0.256^{y}
Mean	0.278^{m}	0.285^{l}	0.245^{n}	0.178 (control)
$F_{control} \rightarrow$ 38.57**, SEm +/- = 0.116				
$F_{shade} \rightarrow$ 5.71*, SEm +/- = 0.037				
$F_{filter} \rightarrow$ 5.71*, SEm +/- = 0.037				
$F_{interaction} \rightarrow$ 2.5 NS, SEm +/- = 0.014				

* - significant at 5 %, ** - significant at 1 %, NS – non-significant

Values with the similar alphabets do not differ significantly.

Control – Full-sunlight

the final stage of the observation *i.e.* in the seventh month, the best performance was seen in seedlings under 50 per cent shade level (0.285 mg/g) and green light quality (0.293 mg/g) when the different levels of shades and light qualities were considered individually. Interaction between the factors had significant effect on the chlorophyll-a content of sandal seedlings throughout the study period. The maximum chlorophyll-a content due to interaction at the end of the study period was observed in seedlings under the combination of 50 per cent shade and green light quality (0.339 mg/g). However, the minimum chlorophyll-a content due to interaction was observed in seedlings under the combinations of 75 per cent shade and blue light quality (0.235 mg/g), 75 per cent shade and green light quality (0.251 mg/g), 75 per cent shade and red light quality (0.250 mg/g), 50 per cent and red light quality (0.248 mg/g) and all of them were at par with each other with respect to chlorophyll-a content. Control had significant effects on the chlorophyll-a content in the fourth, sixth and seventh months.

Different light qualities and quantities showed a significant effect on chlorophyll-a content in the first month itself. The maximum value was observed in the seedlings under 25 per cent shade level (0.285 mg/g). This was followed by seedlings under 50 and 75 per cent shade levels with mean values of 0.244 mg/g and 0.231 mg/g showing significant differences between them. The best performance among the different light qualities was shown by seedlings under green light quality (0.276 mg/g). It was followed by seedlings under blue and red light qualities with recorded mean values of 0.238 mg/g and 0.246 mg/g, and they did not vary significantly.

In the second month, the best among the different levels of shades was shown by seedlings under 25 per cent shade level (0.283 mg/g) (Table 10a). It was then followed by seedlings under 50 (0.249 mg/g) and 75 per cent shade levels (0.221 mg/g) which were significantly different. When the comparison was done for the different light qualities in the same month, the best performance was shown by seedlings under green light quality (0.281 mg/g) trailed by seedlings under red (0.242 mg/g) and blue light qualities (0.229 mg/g). They also varied significantly from each other in chlorophyll-a content.

The performances of the sandal seedlings showed significant effects due to the application of varying light qualities and light quantities in the third month (Table 10a). The maximum chlorophyll-a value was seen in seedlings under 25 per cent shade level (0.272 mg/g). 50 and 75 per cent levels of shades also showed significant differences with recorded values of 0.261 mg/g and 0.228 mg/g of chlorophyll-a respectively. Green light quality again showed the best performance with respect to chlorophyll-a in this month with a mean value of 0.272 mg/g. It was trailed by seedlings under blue (0.241 mg/g) and red light qualities (0.247 mg/g), and they were also found to vary significantly from each other.

In the fourth month, the maximum chlorophyll-a was observed in seedlings under 25 and 50 per cent shade levels with recorded mean values of 0.257 mg/g each (Table 10b). This was followed by seedlings under 75 per cent shade level with a mean value of 0.232 mg/g. On the other hand, the best performance was seen in seedlings under green light quality (0.259 mg/g) with regard to the use of different light qualities. This was however comparable with the performance of the seedlings under blue light quality (0.247 mg/g). The minimum value was observed in seedlings grown under red light quality (0.240 mg/g). The values varied significantly from each other.

25 and 50 per cent shade levels did not show any significant difference in the fifth month with mean values of 0.277 mg/g and 0.276 mg/g of chlorophyll-a respectively. The minimum value was seen in seedlings under 75 per cent shade level (0.229 mg/g) which had significantly different value from the previous two shade levels. As far as different types of light qualities were concerned, the best performance was observed in the seedlings under green light quality (0.279 mg/g). This was trailed by the performances of the seedlings under blue and red light qualities with mean values of 0.248 mg/g and 0.254 mg/g of chlorophyll-a

respectively, which however did not show any significant difference between each other.

In the sixth month both the different levels of shades and light qualities showed significant effects on the chlorophyll-a content (Table 10b). Among the different types of light qualities the best performance was shown by seedlings under 25 and 50 per cent shade levels and they were at par with each other with mean values of 0.274 mg/g and 0.277 mg/g. The lowest value was seen in seedlings under 75 per cent shade level (0.243 mg/g). When different light qualities were taken into consideration, the best result was observed in seedlings under green light quality (0.291 mg/g). This was followed by seedlings under blue (0.254 mg/g) and red light qualities (0.249 mg/g) which did not vary significantly from each other in their performances.

In the last month of the study period, the significant effects of different levels of shades and light qualities were seen in the seedlings (Table 10c). The highest value among the different levels of shades was observed in 50 per cent shade level (0.285 mg/g). The second highest value was observed in seedlings under 25 per cent shade level (0.278 mg/g) followed by seedlings under 75 per cent shade level (0.245 mg/g). Among the different light qualities used, the best performance was observed in seedlings under green light quality (0.293 mg/g). This was trailed by seedlings under blue (0.259 mg/g) and red light qualities (0.256 mg/g) without any significant differences.

Thus it can be seen that the green light quality always had the best impact on the chlorophyll-a content of the sandal seedlings right from the first month till the end of the study period. On the other hand, 50 per cent level of shade had a positive effect on the chlorophyll-a content in sandal seedlings in most of the time during the course of study.

4.4.2 Chlorophyll-b

Chlorophyll-b content was also greatly affected by the application of different levels of shades and light qualities in sandal seedlings from the first month till the end of the study period except in the fourth month when the different levels of shades had no significant effect on chlorophyll-b content. Data related to the influence of these factors are furnished in Table 11 (a-c).

In the last month of the study period the best performance was given by the seedlings under 25 per cent level of shade (0.502 mg/g) and green light quality (0.514 mg/g) when the different shade levels and light qualities were separately analyzed. Interaction of different factors had significant impacts on the chlorophyll-b content throughout the study period. The maximum chlorophyll-b content at the end of the study period was found in seedlings under the combination of 25 per cent shade and green light quality (0.550 mg/g) and 50 per cent shade and green light quality (0.561 mg/g), and they were at par with each other with respect to chlorophyll-b content. However, the minimum chlorophyll-b content for the same period of growth due to interaction effect was observed in seedlings under the combination of 75 per cent shade and green light quality (0.432 mg/g). Control had significant impacts on the chlorophyll-b content throughout the study period except in the first month.

In the first month, among the different levels of shades the maximum chlorophyll-b content was given by seedlings under 25 per cent shade level (0.510 mg/g) (Table 11a). It was then followed by seedlings under 50 (0.414 mg/g) and 75 per cent shade levels (0.404 mg/g). When the different light qualities were considered, the maximum chlorophyll-b was seen in seedlings under green light quality (0.491 mg/g). This was trailed by seedlings under blue and red light qualities with mean values of 0.427 mg/g and 0.414 mg/g respectively, and they differed significantly from each other. Control did not vary from the rest.

In the second month the best performance from among the different levels of shades was seen in seedlings under 25 per cent shade level (0.503 mg/g). 50 and 75 per cent shade levels gave mean values of 0.422 mg/g and 0.412 mg/g

Table 11 (a): Two-way tables showing combined effects of shade and light quality on chlorophyll-b content (mg/g) in sandal seedlings

Month 1

Light quality	Shade level 25	50	75	Mean
Blue	0.480[d]	0.384[f]	0.416[e]	0.427[y]
Green	0.548[a]	0.515[b]	0.409[e]	0.491[x]
Red	0.501[c]	0.355[g]	0.386[f]	0.414[z]
Mean	0.510[l]	0.418[m]	0.404[n]	0.448 (control)

$F_{control}$ → 1.43 NS, SEm +/- = 0.022
F_{shade} → 10*, SEm +/- = 0.048
F_{filter} → 5*, SEm +/- = 0.034
$F_{interaction}$ → 2.86 NS, SEm +/- = 0.015

Month 2

Light quality	Shade level 25	50	75	Mean
Blue	0.482[c]	0.369[g]	0.410[e]	0.420[y]
Green	0.548[a]	0.533[b]	0.438[d]	0.506[x]
Red	0.480[c]	0.362[h]	0.390[f]	0.411[y]
Mean	0.503[l]	0.422[m]	0.412[m]	0.402 (control)

$F_{control}$ → 8.57*, SEm +/- = 0.055
F_{shade} → 32.14**, SEm +/- = 0.087
F_{filter} → 35.71**, SEm +/- = 0.091
$F_{interaction}$ → 6.79**, SEm +/- = 0.023

Month 3

Light quality	Shade level 25	50	75	Mean
Blue	0.480[b]	0.386[de]	0.422[c]	0.429[y]
Green	0.497[b]	0.539[a]	0.409[cd]	0.482[x]
Red	0.476[b]	0.375[e]	0.422[c]	0.425[y]
Mean	0.484[l]	0.434[m]	0.418[m]	0.389 (control)

$F_{control}$ → 10**, SEm +/- = 0.059
F_{shade} → 1.43 NS, SEm +/- = 0.018
F_{filter} → 12.86**, SEm +/- = 0.055
$F_{interaction}$ → 11.79**, SEm +/- = 0.030

* - significant at 5 %, ** - significant at 1 %, NS – non-significant
Values with the similar alphabets do not differ significantly.
Control – Full-sunlight

Table 11 (b): Two-way tables showing combined effects of shade and light quality on chlorophyll-b content (mg/g) in sandal seedlings

Month 4

Light quality	Shade level			Mean
	25	50	75	
Blue	0.478^{b}	0.425^{d}	0.464^{bc}	0.456^{x}
Green	0.444^{cd}	0.532^{a}	0.422^{d}	0.466^{x}
Red	0.418^{d}	0.384^{e}	0.423^{d}	0.409^{y}
Mean	0.447	0.447	0.436	0.372 (control)
$F_{control}$ → 21.43**, SEm +/- = 0.087				
F_{shade} → 0.71 NS, SEm +/- = 0.013				
F_{filter} → 12.14**, SEm +/- = 0.053				
$F_{interaction}$ → 9.64**, SEm +/- = 0.027				

Month 5

Light quality	Shade level			Mean
	25	50	75	
Blue	0.484^{b}	0.440^{cd}	0.430^{cd}	0.452^{y}
Green	0.523^{a}	0.536^{a}	0.449^{c}	0.502^{x}
Red	0.488^{b}	0.396^{e}	0.417^{de}	0.434^{z}
Mean	0.498^{l}	0.457^{m}	0.432^{n}	0.358 (control)
$F_{control}$ → 35.71**, SEm +/- = 0.112				
F_{shade} → 14.29**, SEm +/- = 0.058				
F_{filter} → 16.43**, SEm +/- = 0.062				
$F_{interaction}$ → 5.71**, SEm +/- = 0.021				

Month 6

Light quality	Shade level			Mean
	25	50	75	
Blue	0.482^{b}	0.471^{bc}	0.452^{cd}	0.468^{y}
Green	0.559^{a}	0.550^{a}	0.430^{de}	0.513^{x}
Red	0.469^{bc}	0.405^{e}	0.469^{bc}	0.448^{z}
Mean	0.503^{l}	0.475^{m}	0.450^{n}	0.368 (control)
$F_{control}$ → 41.43**, SEm +/- = 0.120				
F_{shade} → 9.29**, SEm +/- = 0.047				
F_{filter} → 14.29**, SEm +/- = 0.058				
$F_{interaction}$ → 10**, SEm +/- = 0.028				

* - significant at 5 %, ** - significant at 1 %, NS – non-significant
Values with the similar alphabets do not differ significantly.
Control – Full-sunlight

Table 11 (c): **Two-way tables showing combined effects of shade and light quality on chlorophyll-b content (mg/g) in sandal seedlings**

Month 7

Light quality	Shade level 25	Shade level 50	Shade level 75	Mean
Blue	0.480[c]	0.498[b]	0.455[d]	0.478[y]
Green	0.550[a]	0.561[a]	0.432[e]	0.514[x]
Red	0.475[c]	0.399[f]	0.468[cd]	0.447[z]
Mean	0.502[l]	0.486[m]	0.452[n]	0.361 (control)
$F_{control}$ → 51.43**, SEm +/- = 0.134				
F_{shade} → 8.57**, SEm +/- = 0.045				
F_{filter} → 14.29**, SEm +/- = 0.058				
$F_{interaction}$ → 11.43**, SEm +/- = 0.030				

* - significant at 5 %, ** - significant at 1 %, NS – non-significant

Values with the similar alphabets do not differ significantly.

Control – Full-sunlight

respectively which were at par with each other. The green light quality gave the highest value (0.506 mg/g) followed by seedlings under blue (0.420 mg/g) and red light qualities (0.411 mg/g). The values obtained from the seedlings from red and blue light qualities did not differ significantly from each other. Control had a mean value of 0.402 mg/g and it was the lowest of all the values among different levels of shades and light qualities.

Seedlings grown under 25 per cent shade level had the highest chlorophyll-b (0.484 mg/g) when light quantity was taken into consideration, which was followed by the seedlings under 50 (0.434 mg/g) and 75 per cent shade levels (0.418 mg/g) in the third month (Table 11a). The performances of the seedlings under 50 and 75 per cent shades were found to be at par. Among the light qualities used, the maximum chlorophyll-b was obtained from the seedlings under green light quality (0.482 mg/g) and it was followed by seedlings under blue (0.429 mg/g) and red light qualities (0.425 mg/g). However the performances of the seedlings under blue and red light qualities were found to be at par with each other. Control had the lowest mean value of chlorophyll-b (0.389) among different levels of shades and light qualities.

In the fourth month, amount of shade did not show any significant effect on chlorophyll-b content of the seedlings (Table 11b). On the other hand, light qualities had a significant impact on it. Blue and green light qualities were found to be at par, with chlorophyll-b content being 0.456 mg/g and 0.466 mg/g followed by red light qualities with the lowest value of 0.409 mg/g of chlorophyll-b. Control had the lowest mean value of 0.372 mg/g among different levels of shades and light qualities.

Seedlings under 25 per cent shade level had the maximum chlorophyll-b content in the fifth month (Table 11b). This was followed by seedlings under 50 and 75 per cent shade levels with mean chlorophyll-b contents of 0.457 mg/g and 0.432 mg/g respectively and they were also found to be significantly different from each other. As far as different light qualities were concerned, seedlings under green light quality had the maximum chlorophyll-b content (0.502 mg/g). Seedlings under blue and red light qualities recorded mean values of 0.452 mg/g and 0.434 mg/g of chlorophyll-b, and they were significantly different from each other. Control had a significant effect on the chlorophyll-b content in the fifth month with a mean value of 0.358 mg/g and it was the lowest of all the mean values.

In the sixth month, the seedlings under green light quality had the maximum chlorophyll-b content (0.513 mg/g) (Table 11 b). This was followed by seedlings under blue (0.468 mg/g) and red light qualities (0.448 mg/g). 25 per cent shade level recorded the maximum chlorophyll-b content (0.503 mg/g) in seedlings at the same stage of growth followed by 50 (0.475 mg/g) and 75 per cent shade levels (0.450 mg/g), and they were found to be significantly different from each other. Control had a significant impact on the chlorophyll-b content in the same month with the lowest mean value of 0.368 mg/g among different levels of shades and light qualities.

The maximum value of chlorophyll-b (0.502 mg/g) was recorded in seedlings under 25 per cent shade level among the different levels of shades in the seventh month followed by seedlings under 50 (0.486 mg/g) and 75 per cent shade levels (0.452 mg/g), and all of them were significantly different from each other (Table 11c). The maximum chlorophyll-b content was found to in seedlings under green light quality (0.514 mg/g) followed by blue (0.478 mg/g) and red light qualities (0.447 mg/g) and they were found to be significantly different from each other. Control had significant impact on chlorophyll-b content with the lowest mean value of 0.361 mg/g.

4.4.3 Total chlorophyll

The varying levels of shades and light qualities had shown considerable impacts on the total chlorophyll content of the sandal seedlings from the first month till the end of the study period and it is presented in Table 12 (a to c) and Fig. 9 (a, b).

In the first month, 25 per cent shade level had the highest total chlorophyll (0.800 mg/g) followed by seedlings under 50 (0.681 mg/g) and 75 per cent shade levels (0.620 mg/g), and all of them gave significantly different values from each other (Table 12a). Among the light qualities the best performance was given by seedlings under green light quality (0.770 mg/g) followed by blue (0.664 mg/g) and red light qualities (0.667 mg/g) and the last two light qualities did not show any significant difference with respect to total chlorophyll content as they were at par with each other. Interactions between the factors had significant impact on the total chlorophyll content starting from the first month up to the end of the study period. The maximum total chlorophyll content due to interaction effect in the seventh month was observed in seedlings under the combination of 25 per cent shade and green light quality (0.858 mg/g) and 50 per cent shade and green light quality (0.901 mg/g), and they were at par with each other. However, the minimum value of total chlorophyll content due to interaction for the same month was observed in seedlings under the combination of 50 per cent shade and red light quality (0.651 mg/g). Control had significant impacts on the total chlorophyll content of sandal seedlings throughout the study period with a mean value of 0.697 mg/g.

The performances of the seedlings under different levels of shades in the second month was the same as that of the previous month with mean readings of 0.793 mg/g, 0.677 mg/g and 0.642 mg/g of total chlorophyll in treatments with 25, 50 and 75 per cent levels of shades respectively. The differences between them were statistically significant. The green light quality was the best from among the different light qualities (0.770 mg/g) trailed by seedlings under red (0.684 mg/g) and blue light qualities (0.658 mg/g). All the readings from the different light qualities had significant effects on the total chlorophyll content. Control had a significant impact on total chlorophyll content with the mean value of 0.633 mg/g among different levels of shades and light qualities.

Table 12 (a): **Two-way tables showing combined effects of shade and light quality on total chlorophyll (mg/g) in sandal seedlings**

Month 1

Light quality	Shade level			Mean
	25	**50**	**75**	
Blue	0.757[c]	0.593[e]	0.643[d]	0.664[y]
Green	0.841[a]	0.822[ab]	0.647[d]	0.770[x]
Red	0.803[b]	0.628[d]	0.570[e]	0.667[y]
Mean	0.800[l]	0.681[m]	0.620[n]	0.697 (control)
$F_{control}$ → 20**, SEm +/- = 0.084				
F_{shade} → 107.86**, SEm +/- = 0.159				
F_{filter} → 46.43**, SEm +/- = 0.104				
$F_{interaction}$ → 17.14**, SEm +/- = 0.0365				

Month 2

Light quality	Shade level			Mean
	25	**50**	**75**	
Blue	0.763[b]	0.586[f]	0.625[d]	0.658[z]
Green	0.843[a]	0.849[a]	0.619[de]	0.770[x]
Red	0.774[b]	0.596[ef]	0.683[c]	0.684[y]
Mean	0.793[l]	0.677[m]	0.642[n]	0.633 (control)
$F_{control}$ → 22.86**, SEm +/- = 0.089				
F_{shade} → 80.71**, SEm +/- = 0.137				
F_{filter} → 44.29**, SEm +/- = 0.102				
$F_{interaction}$ → 31.43**, SEm +/- = 0.049				

Month 3

Light quality	Shade level			Mean
	25	**50**	**75**	
Blue	0.757[b]	0.610[e]	0.660[c]	0.676[y]
Green	0.759[b]	0.867[a]	0.647[cd]	0.758[x]
Red	0.770[b]	0.620[e]	0.625[de]	0.672[y]
Mean	0.762[l]	0.699[m]	0.644[n]	0.614 (control)
$F_{control}$ → 25.71**, SEm +/- = 0.095				
F_{shade} → 44.29**, SEm +/- = 0.102				
F_{filter} → 30.71**, SEm +/- = 0.085				
$F_{interaction}$ → 31.07**, SEm +/- = 0.049				

* - significant at 5 %, ** - significant at 1 %, NS – non-significant
Values with the similar alphabets do not differ significantly.
Control – Full-sunlight

Table 12 (b): **Two-way tables showing combined effects of shade and light quality on total chlorophyll (mg/g) in sandal seedlings**

Month 4

Light quality	Shade level 25	50	75	Mean
Blue	0.763^{b}	0.666^{cd}	0.701^{c}	0.710^{y}
Green	0.695^{c}	0.859^{a}	0.665^{cd}	0.740^{x}
Red	0.682^{cd}	0.629^{e}	0.647^{de}	0.653^{z}
Mean	0.714^{l}	0.718^{l}	0.671^{m}	0.573 (control)

$F_{control}$ → 57.14**, SEm +/- = 0.141
F_{shade} → 8.57**, SEm +/- = 0.045
F_{filter} → 25**, SEm +/- = 0.076
$F_{interaction}$ → 26.07**, SEm +/- = 0.045

Month 5

Light quality	Shade level 25	50	75	Mean
Blue	0.768^{b}	0.682^{c}	0.656^{c}	0.702^{y}
Green	0.800^{b}	0.874^{a}	0.646^{c}	0.773^{x}
Red	0.774^{b}	0.656^{c}	0.690^{c}	0.707^{y}
Mean	0.781^{l}	0.737^{m}	0.664^{n}	0.554 (control)

$F_{control}$ → 110**, SEm +/- = 0.196
F_{shade} → 44.29**, SEm +/- = 0.102
F_{filter} → 20.71**, SEm +/- = 0.070
$F_{interaction}$ → 22.14**, SEm +/- = 0.0415

Month 6

Light quality	Shade level 25	50	75	Mean
Blue	0.765^{b}	0.734^{b}	0.683^{c}	0.727^{y}
Green	0.853^{a}	0.893^{a}	0.666^{c}	0.804^{x}
Red	0.732^{b}	0.658^{c}	0.727^{b}	0.705^{y}
Mean	0.783^{l}	0.761^{l}	0.692^{m}	0.564 (control)

$F_{control}$ → 132.86**, SEm +/- = 0.216
F_{shade} → 29.29**, SEm +/- = 0.083
F_{filter} → 34.29**, SEm +/- = 0.089
$F_{interaction}$ → 24.29**, SEm +/- = 0.043

* - significant at 5 %, ** - significant at 1 %, NS – non-significant
Values with the similar alphabets do not differ significantly.
Control – Full-sunlight

Table 12 (c): **Two-way tables showing combined effects of shade and light quality on total chlorophyll (mg/g) in sandal seedlings**

Month 7

Light quality	Shade level			Mean
	25	50	75	
Blue	0.760^{b}	0.773^{b}	0.709^{cd}	0.747^{y}
Green	0.858^{a}	0.901^{a}	0.671^{de}	0.810^{x}
Red	0.748^{bc}	0.651^{e}	0.727^{bc}	0.708^{z}
Mean	0.789^{l}	0.775^{l}	0.702^{m}	0.542 (control)
$F_{control}$ → 170**, SEm +/- = 0.244				
F_{shade} → 27.86**, SEm +/- = 0.081				
F_{filter} → 34.29**, SEm +/- = 0.089				
$F_{interaction}$ → 26.43**, SEm +/- = 0.043				

* - significant at 5 %, ** - significant at 1 %, NS – non-significant

Values with the similar alphabets do not differ significantly.

Control – Full-sunlight

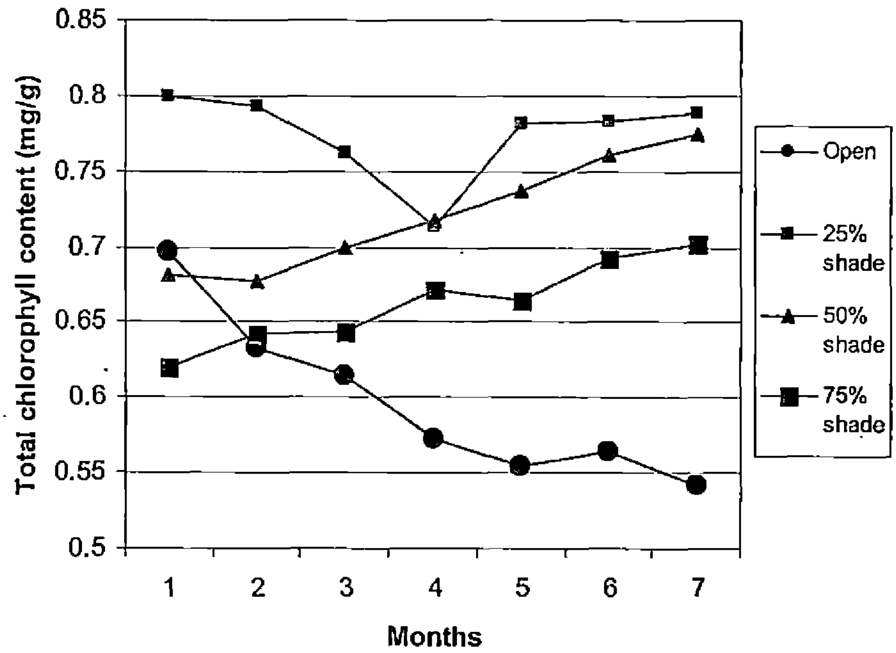

Fig. 9 (a): Effect of shade levels on total chlorophyll content in sandal seedlings

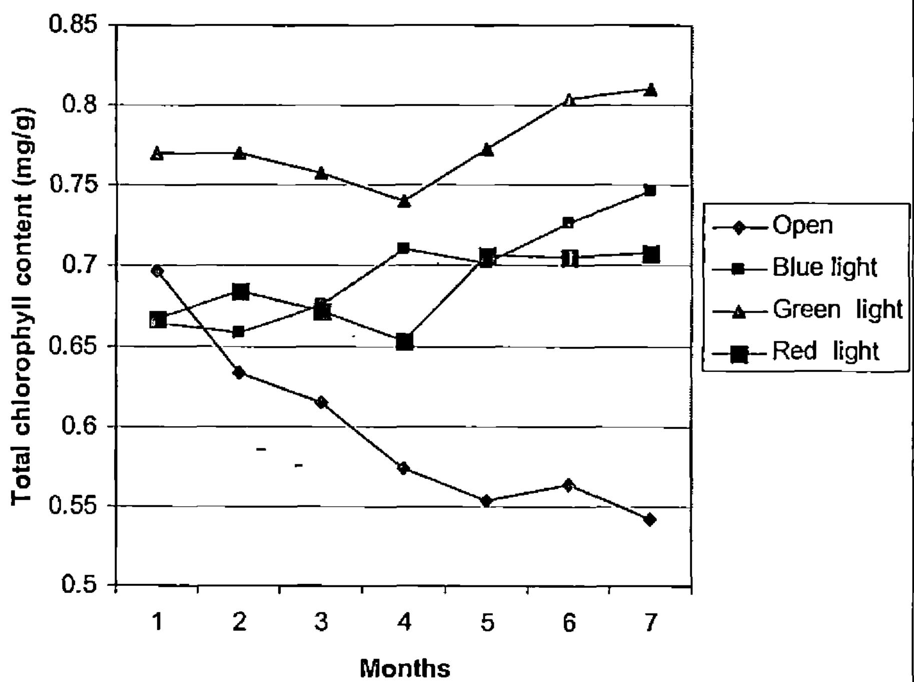

Fig. 9 (b): Effect of light quality on total chlorophyll content in sandal seedlings

25 per cent shade level again performed the best in the third month with a mean value of 0.762 mg/g of total chlorophyll. This was followed by seedlings under 50 and 75 per cent shade levels with recorded mean values of 0.699 mg/g and 0.644 mg/g respectively. All the different levels of light qualities showed significant effect on total chlorophyll content. Among the light qualities the best light quality was found to be green light quality (0.758 mg/g) in the same month. It was trialed by seedlings under blue (0.676 mg/g) and red light qualities (0.672 mg/g). However the performances of the seedlings under blue and red light qualities were at par with each other. Control had a mean value of 0.614 mg/g which was the lowest among different levels of shades and light qualities.

In the fourth month (Table 12 b), performances of the seedlings under 25 and 50 per cent shade levels were not significantly different with mean values of 0.714 mg/g and 0.718 mg/g respectively. The lowest value of total chlorophyll was given by seedlings under 75 per cent shade level (0.671 mg/g). Comparison of different light qualities showed that the best light quality was found to be green light quality which gave a mean value of 0.740 mg/g. Blue and red light qualities, however, gave mean values of 0.710 mg/g and 0.653 mg/g respectively, and they were found to be significantly different. Control had the lowest mean value of 0.573 mg/g among different levels of shades and light qualities.

Among the different light quantities, the maximum total chlorophyll was seen in seedlings under 25 per cent shade (0.781 mg/g) in the fifth month. This was trailed by seedlings under 50 and 75 per cent shade levels with mean values of 0.737 mg/g and 0.664 mg/g respectively showing significant differences. Green light quality had the maximum total chlorophyll with a mean reading of 0.773 mg/g. Seedlings under blue and red light qualities had mean values of 0.702 mg/g and 0.707 mg/g, and both of them performed at par with each other. Control had the lowest mean value of 0.554 mg/g among different levels of shades and light qualities.

In the sixth month, the best result was given by seedlings under 25 and 50 per cent shade levels with mean values of 0.783 mg/g and 0.761 mg/g which showed no significant difference of total chlorophyll (Table 12b). However seedlings under 75 per cent shade gave a mean reading of 0.692 mg/g which was the lowest value in the same month and different from the other treatments. Among the different light qualities, the best light quality was green light quality with a mean value of 0.804 mg/g of total chlorophyll. Blue and red light qualities did not show any significantly different values with mean readings of 0.727 mg/g and 0.705 mg/g respectively. Control had the lowest mean value of 0.564 mg/g among different levels of shades and light qualities.

In the last month of the study period, the maximum total chlorophyll was observed in seedlings under 25 and 50 per cent shade levels with recorded mean values of 0.789 mg/g and 0.775 mg/g respectively and they performed at par with each other (Table 12c). The lowest value was observed in seedlings under 75 per cent shade (0.702 mg/g). Among the different types of light qualities, the best performance was seen in seedlings under green light quality (0.810 mg/g). Blue and red light qualities produced mean values of 0.747 mg/g and 0.708 mg/g and they were also found to be statistically significant. Control had the lowest mean value of 0.542 mg/g among different levels of shades and light qualities.

Hence it can be seen that green light quality was providing the best effect on the total chlorophyll content from among the different light qualities while 25 and 50 per cent levels of shades were the best in influencing the total chlorophyll content when shade level is taken into consideration.

4.5 Rate of photosynthesis

The observations related to the rate of photosynthesis of sandal seedlings for five months are furnished in Table 13 (a to b) and Fig. 10 (a, b). In the first and second months the different levels of shades and light qualities did not show any significant effect on the rate of photosynthesis of the sandal seedlings. The

Table 13 (a): Two-way tables showing combined effects of shade and light quality on rate of photosynthesis (μ mol m^{-2} s^{-1}) in sandal seedlings

Month 1

Light quality	Shade level 25	Shade level 50	Shade level 75	Mean
Blue	17.417^{ab}	15.517^{bc}	11.710^{cd}	14.881
Green	10.190^{d}	15.143^{bc}	21.873^{a}	15.736
Red	21.277^{a}	20.487^{a}	13.960^{bcd}	18.574
Mean	16.294	17.049	15.848	5.917 (control)

$F_{control}$ → 32.7**, SEm +/- = 4.04

F_{shade} → 0.366 NS, SEm +/- = 0.349

F_{filter} → 3.71 NS, SEm +/- = 1.11

$F_{interaction}$ → 9.57**, SEm +/- = 1.031

Month 2

Light quality	Shade level 25	Shade level 50	Shade level 75	Mean
Blue	20.627^{ab}	14.913^{bc}	11.733^{c}	15.758
Green	15.327^{bc}	20.153^{ab}	23.910^{a}	19.797
Red	21.650^{ab}	16.733^{abc}	17.943^{abc}	18.776
Mean	19.201	17.267	17.862	8.837 (control)

$F_{control}$ → 13.41**, SEm +/- = 2.59

F_{shade} → 0.51 NS, SEm +/- = 0.412

F_{filter} → 2.29 NS, SEm +/- = 0.874

$F_{interaction}$ → 3.68*, SEm +/- = 0.639

Month 3

Light quality	Shade level 25	Shade level 50	Shade level 75	Mean
Blue	22.093	15.373	14.000	17.156^{z}
Green	26.727	28.500	25.517	26.914^{x}
Red	24.483	22.037	21.987	22.836^{y}
Mean	24.434	21.970	20.501	6.500 (control)

$F_{control}$ → 56.32**, SEm +/- = 5.307

F_{shade} → 2.97 NS, SEm +/- = 0.995

F_{filter} → 18.06**, SEm +/- = 2.45

$F_{interaction}$ → 1.40 NS, SEm +/- = 0.394

* - significant at 5 %, ** - significant at 1 %, NS – non-significant

Values with the similar alphabets do not differ significantly.

Control – Full-sunlight

Table 13 (b): **Two-way tables showing combined effects of shade and light quality on rate of photosynthesis (μ mol m^{-2} s^{-1}) in sandal seedlings**

Month 4

Light quality	Shade level			Mean
	25	50	75	
Blue	25.297[ab]	17.367[c]	8.800[d]	17.154[y]
Green	21.923[ab]	26.297[a]	23.983[ab]	24.068[x]
Red	23.263[ab]	21.557[b]	24.287[ab]	23.036[x]
Mean	23.494[l]	21.740[l]	19.023[m]	5.457 (control)

$F_{control} \rightarrow$ 94.24**, SEm +/- = 6.864
$F_{shade} \rightarrow$ 6.26*, SEm +/- = 1.44
$F_{filter} \rightarrow$ 17.15**, SEm +/- = 2.39
$F_{interaction} \rightarrow$ 12.23**, SEm +/- = 1.17

Month 5

Light quality	Shade level			Mean
	25	50	75	
Blue	27.873[a]	18.347[c]	4.880[d]	17.033[y]
Green	20.590[c]	25.730[ab]	25.437[ab]	23.919[x]
Red	25.630[ab]	27.660[a]	22.237[bc]	25.176[x]
Mean	24.698[l]	23.912[l]	17.518[m]	4.673 (control)

$F_{control} \rightarrow$ 139.96**, SEm +/- = 8.37
$F_{shade} \rightarrow$ 23.98**, SEm +/- = 2.83
$F_{filter} \rightarrow$ 29.71**, SEm +/- = 3.15
$F_{interaction} \rightarrow$ 26.49**, SEm +/- = 1.72

* - significant at 5 %, ** - significant at 1 %, NS – non-significant
Values with the similar alphabets do not differ significantly.
Control – Full-sunlight

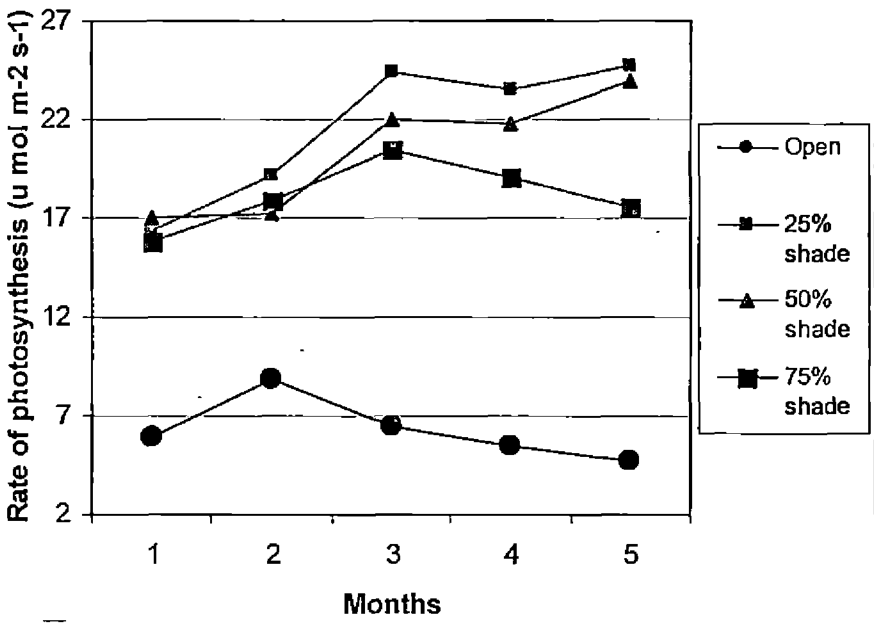

Fig. 10 (a): Effect of shade levels on the rate of photosynthesis in sandal seedlings

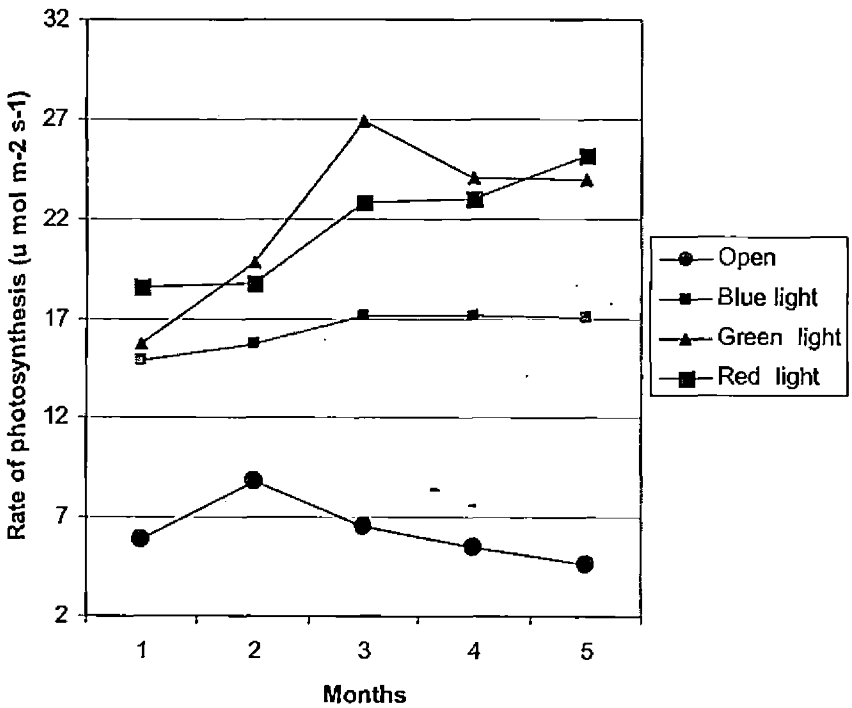

Fig. 10 (b): Effect of light quality on the rate of photosynthesis in sandal seedlings varying light qualities started to give significant effects on the sandal seedlings in the third month whereas different levels of shades still did not show any significant difference in the same month. Both the factors (*i.e.* light quality and light quantity) affected the rate of photosynthesis in the fourth and fifth months of the growth period. At five month stage the maximum photosynthesis was seen in seedlings under 25 and 50 per cent shade levels with mean values of 24.698 (μ mol m^{-2} s^{-1}) and 23.912 (μ mol m^{-2} s^{-1}) respectively without any significant difference as far as different levels of shades were concerned. On the other hand, seedlings under green and red light qualities gave the maximum values for the rate of photosynthesis in the last month of the study period with mean values of 23.919 and 25.176 respectively, and they were found to be at par with each other when comparison was done for the mean values. However, control produced significantly different values for the complete study period. Interactions between factors had significant impacts on the rate of photosynthesis from the first month up to the fifth month. In the last month, the maximum rate of photosynthesis due to interaction effect was observed in seedlings under the combination of 25 per cent shade and blue light quality (27.873 μ mol m^{-2} s^{-1}) and 50 per cent shade and red light quality (27.660 μ mol m^{-2} s^{-1}), and they were at par with each other. For the same month, the minimum rate of photosynthesis due to interaction effect was observed in seedlings under the combination of 75 per cent shade and blue light quality (4.880 μ mol m^{-2} s^{-1}).

Different light qualities provided statistically significant values in the third month (Table 13a) and among the light qualities the best performance was shown by seedlings under green light quality with a mean value of 26.914 (μ mol m^{-2} s^{-1}). But the seedlings under blue and red light qualities provided significantly different values of 17.156 (μ mol m^{-2} s^{-1}) and 22.836 (μ mol m^{-2} s^{-1}) respectively. Levels of shades did not play any significant role in the same month except the control which showed significant impact on rate of photosynthesis with the lowest mean value of 6.500 μ mol m^{-2} s^{-1} among various levels of shades and light qualities.

In the fourth month (Table 13b), the varying levels of shades as well as light qualities provided significant impacts on the rate of photosynthesis. The highest rate of photosynthesis was observed in seedlings under 25 and 50 per cent shade levels with mean values of 23.494 (μ mol m^{-2} s^{-1}) and 21.740 (μ mol m^{-2} s^{-1}) respectively without any significant difference. This was followed by seedlings under 75 per cent shade level (19.023 μ mol m^{-2} s^{-1}). When different types of light qualities were taken into consideration for the same month, the best performance was given by seedlings under green and red light qualities with recorded mean values of 24.068 (μ mol m^{-2} s^{-1}) and 23.036 (μ mol m^{-2} s^{-1}), and they were not statistically significant from each other. The minimum rate of photosynthesis (5.457 (μ mol m^{-2} s^{-1}) was recorded in seedlings under control which had a significant impact on rate of photosynthesis.

At the fifth month stage, 25 and 50 per cent shade levels performed the best when rate of photosynthesis of the sandal seedlings was measured with mean values being 24.698 (μ mol m^{-2} s^{-1}) and 23.912 (μ mol m^{-2} s^{-1}) respectively. The lowest rate of photosynthesis was observed in seedlings under 75 per cent shade level (17.518 μ mol m^{-2} s^{-1}). Green and red light qualities performed at par with each other in the same month with the mean values of 23.919 (μ mol m^{-2} s^{-1}) and 25.176 (μ mol m^{-2} s^{-1}), and they performed better than the seedlings under blue light quality with a mean value of 17.033 (μ mol m^{-2} s^{-1}). The lowest rate of photosynthesis was observed in seedlings under control with a mean value of 4.673 μ mol m^{-2} s^{-1}.

Hence, in most of the cases seedlings under 25 and 50 per cent shade levels had higher rate of photosynthesis without any significant differences when different levels of shades were taken into consideration. However, green and red light qualities were the best for the photosynthetic activities with regard to the use of different types of light qualities during the course of study period. Seedlings under control had the lowest rate of photosynthesis throughout the study period.

4.6 Relative growth rate

The effects of different treatments on the relative growth rates of dry weight of shoot and dry weight of root are given under this section.

4.6.1 Relative growth rate of dry weight of shoot

The effects of different light qualities and light quantities can be seen in Table 14 (a, b). It can be concluded from the table that different light qualities did not give any influential effect on the RGR of dry weight of shoot throughout the study period while different levels of shades started to give significant effects from the sixth month till the end of the experiment. Control had a significant effect on the RGR of shoot length in the sixth and seventh months. Interactions between the factors had significant effect on the RGR of dry weight of shoot only in the seventh month. The maximum RGR of dry weight of shoot due to interaction effect was observed in seedlings under the combination of 50 per cent shade and green light quality (0.383 mg/month) in the seventh month. The minimum value of RGR of dry weight of shoot due to interaction was however observed in seedlings under the combination of 25 per cent shade and green (0.213 mg/month) and 25 per cent shade and red (0.170 mg/month) in the seventh month, and they were at par with each other.

In the sixth month, varying light quality gave a significant effect on the RGR of dry weight of shoot. Among the different levels of shades, the maximum RGR of dry weight of shoot was observed in seedlings under 25 per cent shade level (0.248 mg/month). This was followed by seedlings under 50 and 75 per cent shade levels with respective mean values of 0.212 mg/month and 0.179 mg/month, and they performed at par with each other. When the performances of the seedlings under different types of light qualities were considered, seedlings under blue light quality had the maximum mean value (0.229 mg/month) although it was not significantly different from the rest.

Table 14 (a): Two-way tables showing combined effects of shade and light quality on relative growth rate of dry weight of shoot (mg/month) in sandal seedlings

Month 2

Light quality	Shade level 25	50	75	Mean
Blue	1.667	1.600	1.300	1.522
Green	1.600	1.200	1.567	1.456
Red	1.400	1.393	1.300	1.364
Mean	1.556	1.398	1.389	1.223 (control)

$F_{control}$ → 0.99 NS, SEm +/- = 0.259
F_{shade} → 0.58 NS, SEm +/- = 0.162
F_{filter} → 0.42 NS, SEm +/- = 0.137
$F_{interaction}$ → 0.71 NS, SEm +/- = 0.103

Month 3

Light quality	Shade level 25	50	75	Mean
Blue	2.460	0.210	0.523	1.064
Green	0.627	0.650	0.583	0.620
Red	0.667	0.463	0.593	0.574
Mean	1.251	0.441	0.567	0.390 (control)

$F_{control}$ → 0.25 NS, SEm +/- = 0.424
F_{shade} → 1.18 NS, SEm +/- = 0.755
F_{filter} → 0.46 NS, SEm +/- = 0.469
$F_{interaction}$ → 0.96 NS, SEm +/- = 0.393

Month 4

Light quality	Shade level 25	50	75	Mean
Blue	0.463	0.503	0.330	0.432
Green	0.387	0.267	0.290	0.314
Red	0.290	0.377	0.297	0.321
Mean	0.380	0.382	0.306	0.457 (control)

$F_{control}$ → 0.86 NS, SEm +/- = 0.110
F_{shade} → 0.61 NS, SEm +/- = 0.075
F_{filter} → 1.43 NS , SEm +/- = 0.115
$F_{interaction}$ → 0.47 NS, SEm +/- = 0.038

* - significant at 5 %, ** - significant at 1 %, NS – non-significant
Values with the similar alphabets do not differ significantly.
Control – Full-sunlight

Table 14 (b): Two-way tables showing combined effects of shade and light quality on relative growth rate of dry weight of shoot (mg/month) in sandal seedlings

Month 5

Light quality	Shade level			Mean
	25	50	75	
Blue	0.447	0.313	0.257	0.339
Green	0.300	0.217	0.293	0.270
Red	0.267	0.323	0.387	0.326
Mean	0.338	0.284	0.312	0.417 (control)

$F_{control}$ → 1.11 NS, SEm +/- = 0.130

F_{shade} → 0.21 NS, SEm +/- = 0.047

F_{filter} → 0.39 NS, SEm +/- = 0.063

$F_{interaction}$ → 0.65 NS, SEm +/- = 0.047

Month 6

Light quality	Shade level			Mean
	25	50	75	
Blue	0.277	0.223	0.187	0.229
Green	0.203	0.227	0.140	0.190
Red	0.263	0.187	0.210	0.220
Mean	0.248^{l}	0.212^{m}	0.179^{m}	0.297 (control)

$F_{control}$ → 9.52**, SEm +/- = 0.10

F_{shade} → 5.24*, SEm +/- = 0.061

F_{filter} → 1.90 NS, SEm +/- = 0.037

$F_{interaction}$ → 1.43 NS, SEm +/- = 0.018

Month 7

Light quality	Shade level			Mean
	25	50	75	
Blue	0.270^{d}	0.293^{cd}	0.337^{ab}	0.300
Green	0.213^{e}	0.383^{a}	0.340^{ab}	0.312
Red	0.170^{e}	0.343^{ab}	0.327^{bc}	0.280
Mean	0.218^{m}	0.340^{l}	0.334^{l}	0.197 (control)

$F_{control}$ → 18.18**, SEm +/- = 0.114

F_{shade} → 30.10**, SEm +/- = 0.120

F_{filter} → 1.75 NS, SEm +/- = 0.029

$F_{interaction}$ → 4.02*, SEm +/- = 0.025

* - significant at 5 %, ** - significant at 1 %, NS – non-significant
Values with the similar alphabets do not differ significantly.
Control – Full-sunlight

The maximum value of RGR of dry weight of shoot in the seventh month was observed in seedlings under 50 and 75 per cent shade levels (respective mean values being 0.340 mg/month and 0.334 mg/month) and they were at par with each other. This was followed by seedlings under 25 per cent shade level with a mean RGR value of 0.218 mg/month and it was significantly different from the rest. On the other hand, different light qualities had no significant effect on the RGR of dry weight of shoot. However, seedlings under green light quality had the maximum RGR of dry weight of shoot (0.312 mg/month). Control had a significant impact on the RGR of dry weight of shoot in the seventh month with a mean value of 0.197 mg/month.

The maximum RGR of dry weight of shoot under different shade levels was observed in seedlings under 25 per cent shade level (1.556 mg/month) in the second month (Table 14a). When different types of light qualities were taken into consideration, the maximum RGR of dry weight of shoot was given by seedlings under blue light quality (1.522 mg/month) in the second month. The lowest RGR of dry weight of shoot from the different levels of shades was seen in the seedlings under 50 per cent shade (0.212 mg/month) in the sixth month whereas the least value from among the different types of light qualities was shown by seedlings under green light quality (0.190 mg/month) in the sixth month.

4.6.2 Relative growth rate of dry weight of root

The influence of different treatments on the relative growth rate of dry weight of root in sandal seedlings is furnished in Table 15 (a, b). The effect of different types of light qualities was seen in sandal seedlings only in the sixth month while the influence of varying quantity of light was seen throughout the study period except in the second month. Interactions between factors had significant impacts on the RGR of dry weight of root in the third, fifth, sixth and seventh months. Seedlings under the combination of 75 per cent shade and blue light quality (0.433 mg/month), 75 per cent shade and green light quality (0.457 mg/month), 50 per cent shade and green light quality (0.467 mg/month) and 50

Table 15 (a): Two-way tables showing combined effects of shade and light quality on relative growth rate of dry weight of root (mg/month) in sandal seedlings

Month 2

Light quality	Shade level			Mean
	25	50	75	
Blue	1.123	1.333	1.133	1.197
Green	0.933	1.633	1.567	1.378
Red	0.833	1.233	1.187	1.084
Mean	0.963	1.400	1.296	0.527 (control)
$F_{control}$ → 9.35**, SEm +/- = 0.806				
F_{shade} → 3.37 NS, SEm +/- = 0.395				
F_{filter} → 1.42 NS, SEm +/- = 0.256				
$F_{interaction}$ → 0.60 NS, SEm +/- = 0.096				

Month 3

Light quality	Shade level			Mean
	25	50	75	
Blue	0.563^{b}	0.343^{c}	0.460^{b}	0.456
Green	0.703^{a}	0.613^{b}	0.243^{c}	0.520
Red	0.573^{b}	0.353^{c}	0.383^{c}	0.437
Mean	0.613^{l}	0.437^{m}	0.362^{m}	0.593 (control)
$F_{control}$ → 3.23 NS, SEm +/- = 0.145				
F_{shade} → 11.5**, SEm +/- = 0.223				
F_{filter} → 1.31 NS, SEm +/- = 0.075				
$F_{interaction}$ → 4.15*, SEm +/- = 0.077				

Month 4

Light quality	Shade level			Mean
	25	50	75	
Blue	0.483	0.423	0.297	0.401
Green	0.663	0.463	0.273	0.467
Red	0.463	0.613	0.420	0.499
Mean	0.537^{l}	0.500^{l}	0.330^{m}	0.433 (control)
$F_{control}$ → 0.21 NS, SEm +/- = 0.039				
F_{shade} → 7.86**, SEm +/- = 0.191				
F_{filter} → 1.64 NS, SEm +/- = 0.088				
$F_{interaction}$ → 2.29 NS, SEm +/- = 0.060				

* - significant at 5 %, ** - significant at 1 %, NS – non-significant
Values with the similar alphabets do not differ significantly.
Control – Full-sunlight

Table 15 (b): Two-way tables showing combined effects of shade and light quality on relative growth rate of dry weight of shoot (mg/month) in sandal seedlings

Month 5

Light quality	Shade level 25	Shade level 50	Shade level 75	Mean
Blue	0.177^{c}	0.337^{ab}	0.290^{bc}	0.268
Green	0.447^{a}	0.253^{bc}	0.480^{a}	0.393
Red	0.370^{ab}	0.163^{c}	0.450^{a}	0.328
Mean	0.331^{m}	0.251^{n}	0.407^{l}	0.300 (control)

$F_{control}$ → 0.70 NS, SEm +/- = 0.059
F_{shade} → 5.50*, SEm +/- = 0.135
F_{filter} → 3.55 NS, SEm +/- = 0.109
$F_{interaction}$ → 3.83*, SEm +/- = 0.065

Month 6

Light quality	Shade level 25	Shade level 50	Shade level 75	Mean
Blue	0.160^{cd}	0.377^{b}	0.380^{b}	0.306^{y}
Green	0.127^{d}	0.440^{ab}	0.260^{c}	0.276^{y}
Red	0.257^{c}	0.477^{ab}	0.537^{a}	0.423^{x}
Mean	0.181^{m}	0.431^{l}	0.392^{l}	0.333 (control)

$F_{control}$ → 0.56 NS, SEm +/- = 0.032
F_{shade} → 45.66**, SEm +/- = 0.233
F_{filter} → 15.41**, SEm +/- = 0.135
$F_{interaction}$ → 3.36*, SEm +/- = 0.037

Month 7

Light quality	Shade level 25	Shade level 50	Shade level 75	Mean
Blue	0.350^{ab}	0.223^{bc}	0.433^{a}	0.336
Green	0.187^{c}	0.467^{a}	0.457^{a}	0.370
Red	0.193^{c}	0.450^{a}	0.233^{b}	0.292
Mean	0.243^{m}	0.380^{l}	0.374^{l}	0.300 (control)

$F_{control}$ → 0.47 NS, SEm +/- = 0.039
F_{shade} → 8.44**, SEm +/- = 0.134
F_{filter} → 2.11 NS, SEm +/- = 0.067
$F_{interaction}$ → 8.79**, SEm +/- = 0.079

* - significant at 5 %, ** - significant at 1 %, NS – non-significant
Values with the similar alphabets do not differ significantly.
Control – Full-sunlight

per cent shade and red light quality (0.450 mg/month) recorded the maximum RGR of dry weight of root due to interaction effects in the seventh month. They were also found to be at par with each other with respect to RGR of dry weight of root. The minimum RGR of dry weight of root due to interaction was observed in seedlings under the combination of 25 per cent shade and green light quality (0.187 mg/month) and 25 per cent and red light quality (0.193 mg/month), and they were at par with each other. Control had significant impact on the RGR of dry weight of root only in the second month with a mean value of 0.527 mg/month.

In the third month, the different levels of shades had a significant impact on the RGR of dry weight of root in sandal seedlings (Table 15a). The maximum RGR of dry weight of shoot was observed in seedlings under 25 per cent shade (0.613 mg/month). This was followed by seedlings under 50 and 75 per cent shade (with respective mean RGR values of 0.437 mg/month and 0.362 mg/month) and they were at par with each other in their performances. Different types of light qualities did not show any significant effect on the RGR of dry weight of root in the same month. The maximum RGR of dry weight of root was however observed in seedlings under green light quality (0.520 mg/month). Control had no significant effect on the RGR of dry weight of root with a mean value of 0.593 mg/month.

The different types of shades had a significant effect in the fourth month (Table 15a). The maximum RGR of dry weight of root was shown by seedlings under 25 and 50 per cent shade levels with mean values of 0.537 mg/month and 0.500 mg/month respectively, and they were at par with each other. The lowest mean RGR value was 0.330 mg/month under 75 per cent shade level and it was significantly different from the rest. At the same stage of growth, light qualities did not have any significant impact on the RGR of dry weight of root. However, the maximum RGR of dry. weight of root was observed in seedlings under red light quality (0.499 mg/month). Control had no significant effect on the RGR of dry weight of root with a mean value of 0.433 mg/month.

In the fifth month, the maximum RGR of dry weight of root (0.407 mg/month) was observed in seedlings under 75 per cent shade level (Table 15b) and it was significantly different from the rest. This was followed by seedlings under 25 and 50 per cent shade levels with mean RGR values of 0.331 mg/month and 0.251 mg/month respectively, and they were also found to be significantly different from each other. However the different light qualities did not show any significant impact on the RGR of dry weight of root in the same month. The maximum RGR value (0.393 mg/month) was however observed in seedlings under green light quality at the same stage of growth. Control had no significant effect on the RGR of dry weight of root with a mean value of 0.300 mg/month.

Different types of light qualities and shades showed significant impacts on the RGR of dry weight of root in the sixth month (Table 15b). The maximum RGR of dry weight of root was shown by seedlings under 50 and 75 per cent shade levels with mean RGR values of 0.431 mg/month and 0.392 mg/month respectively, and they were at par with each other. The least RGR value was observed in the seedlings under 25 per cent shade level (0.181 mg/month) and it was significantly different from the rest. When different types of light qualities were taken into consideration, the maximum RGR of dry weight of root was obtained from seedlings under red light quality (0.423 mg/ month). This was followed by seedlings under blue and green light qualities with respective mean RGR values of 0.306 mg/month and 0.276 mg/month, and they were at par with each other. Control had no significant effect on the RGR of dry weight of root with a mean value of 0.333 mg/month.

Different types of shades provided a significant impact on the RGR of dry weight of root in the seventh month (Table 15b). The maximum RGR of dry weight of root was observed in seedlings under 50 and 75 per cent shade levels (with respective mean values of 0.380 mg/month and 0.374 mg/month respectively), and they were at par with each other. The lowest mean RGR value was observed in seedlings under 25 per cent shade level (0.243 mg/month) and it was significantly different from the rest. Different types of light qualities did not show any significant impact on the RGR of dry weight of root in the same month. However the maximum RGR value was observed in seedlings under green light quality (0.370 mg/month). Control had no significant effect on the RGR of dry weight of root with a mean value of 0.300 mg/month.

4.7 Incremental Growth

4.7.1 Incremental growth of collar diameter

The tabulated data for the influence on the incremental growth of collar diameter in sandal seedlings are shown in Table 16 (a to c). It is clear from the table that there was no significant effect of different levels of shades and light qualities on the incremental growth of collar diameter in sandal seedlings during the study period except in the sixth month when the different levels of shades showed the significant effect. When the absolute growth rate was taken into consideration there was no such significance in the same month. But it provided significant influence on the absolute growth rate in the fifth month due to the application of different types of light qualities and in the seventh month due to use of different levels of shades and light qualities as seen in Table 2 (b, c). Interactions between factors had no significant effect on the IG of collar diameter throughout the study period. Control had no significant impact on the IG of collar diameter of sandal seedlings throughout the study period.

In the sixth month, the maximum IG of collar diameter was observed in seedlings under 25 and 50 per cent shade levels with respective mean values of 0.348 mm/month and 0.364 mm/month, and their performances were at par with each other. This was followed by seedlings under 75 per cent shade level (0.263 mm/month) and its performance was significantly different from the seedlings under 25 and 50 per cent shade level. However, different light qualities did not affect the IG collar diameter significantly for the same month.

Table 16 (a): Two-way tables showing combined effects of shade and light quality on incremental growth of collar diameter (mm/month) in sandal seedlings

Month 2

Light quality	Shade level 25	50	75	Mean
Blue	0.713	0.850	0.740	0.768
Green	0.650	0.723	0.697	0.690
Red	0.757	0.780	0.763	0.767
Mean	0.707	0.784	0.733	0.647 (control)

$F_{control}$ → 2.91 NS, SEm +/- = 0.107
F_{shade} → 1.77 NS, SEm +/- = 0.068
F_{filter} → 2.28 NS, SEm +/- = 0.077
$F_{interaction}$ → 0.41 NS, SEm +/- = 0.019

Month 3

Light quality	Shade level 25	50	75	Mean
Blue	0.480	0.463	0.550	0.498
Green	0.633	0.483	0.603	0.573
Red	0.470	0.467	0.617	0.518
Mean	0.528	0.471	0.590	0.440 (control)

$F_{control}$ → 1.13 NS, SEm +/- = 0.092
F_{shade} → 2.13 NS, SEm +/- = 0.103
F_{filter} → 0.93 NS, SEm +/- = 0.068
$F_{interaction}$ → 0.52 NS, SEm +/- = 0.029

Month 4

Light quality	Shade level 25	50	75	Mean
Blue	0.497	0.357	0.373	0.409
Green	0.457	0.507	0.440	0.468
Red	0.343	0.353	0.427	0.374
Mean	0.432	0.406	0.413	0.343 (control)

$F_{control}$ → 2.03 NS, SEm +/- = 0.089
F_{shade} → 0.32 NS, SEm +/- = 0.029
F_{filter} → 2.53 NS, SEm +/- = 0.082
$F_{interaction}$ → 1.65 NS, SEm +/- = 0.038

* - significant at 5 %, ** - significant at 1 %, NS – non-significant
Values with the similar alphabets do not differ significantly.
Control – Full-sunlight

Table 16 (b): Two-way tables showing combined effects of shade and light quality on incremental growth of collar diameter (mm/month) in sandal seedlings

Month 5

Light quality	Shade level			Mean
	25	50	75	
Blue	0.310	0.343	0.417	0.357
Green	0.393	0.417	0.497	0.436
Red	0.370	0.413	0.287	0.357
Mean	0.358	0.391	0.400	0.367 (control)
$F_{control}$ → 0.25 NS, SEm +/- = 0.039				
F_{shade} → 0.37 NS, SEm +/- = 0.039				
F_{filter} → 1.53 NS, SEm +/- = 0.079				
$F_{interaction}$ → 1.05 NS, SEm +/- = 0.038				

Month 6

Light quality	Shade level			Mean
	25	50	75	
Blue	0.377	0.333	0.250	0.320
Green	0.307	0.410	0.240	0.319
Red	0.360	0.350	0.300	0.337
Mean	0.348^{l}	0.364^{l}	0.263^{m}	0.347 (control)
$F_{control}$ → 1.03 NS, SEm +/- = 0.039				
F_{shade} → 9.14**, SEm +/- = 0.094				
F_{filter} → 0.34 NS, SEm +/- = 0.018				
$F_{interaction}$ → 1.90 NS, SEm +/- = 0.025				

Month 7

Light quality	Shade level			Mean
	25	50	75	
Blue	0.403	0.407	0.317	0.376
Green	0.440	0.427	0.397	0.421
Red	0.337	0.427	0.383	0.382
Mean	0.393	0.420	0.366	0.360 (control)
$F_{control}$ → 1.25 NS, SEm +/- = 0.045				
F_{shade} → 2.19 NS, SEm +/- = 0.048				
F_{filter} → 1.88 NS, SEm +/- = 0.045				
$F_{interaction}$ → 1.33, SEm +/- = 0.022				

* - significant at 5 %, ** - significant at 1 %, NS – non-significant
Values with the similar alphabets do not differ significantly.
Control – Full-sunlight

It can also be seen from Table 16 (a) that the maximum IG of collar diameter of sandal seedlings was observed in the second month of the study period. On the other hand, the lowest incremental growth was observed in the sixth month.

4.7.2 Incremental growth of shoot length

The influence of incremental growth (IG) of shoot length in sandal seedlings is furnished in Table 17 (a, b) and Fig. 11 (a, b). It is clear from the table that different levels of shades had a significant effect on the IG of shoot length in sandal seedlings from the second month till the end of the study period. On the other hand, the different types of light qualities affected the IG of shoot length significantly from the second month up to the fourth month. In the seventh month, the maximum IG of shoot length was observed in seedlings under 25 per cent shade level (0.331 cm/month) and red light quality (0.303 cm/month) when varying light qualities and light quantities were considered individually. Interactions between the factors had significant impact on the IG of shoot length in the second, third, fourth and seventh months. At the end of the study period, the maximum IG of shoot length due to interaction effect was observed in seedlings under the combination of 25 per cent shade and red light quality (0.423 cm/month). However, the minimum IG of shoot length (0.208 cm/month) due to interaction effect was observed in seedlings under the combination of 75 per cent shade and green light quality for the same month. Control had significant impacts on the IG of shoot length in sandal seedlings during second, fourth, sixth and seventh months with the lowest mean values among the different levels of shades and light qualities.

In the second month, the maximum IG of shoot length was observed in seedlings under 50 and 75 per cent shade levels with mean values of 0.345 cm/month and 0.401 cm/month respectively, and they were at par from each other (Table 17a). The minimum value was observed in seedlings under 25 per cent shade level (0.246 cm/month) and it was significantly different from the rest. The

Table 17 (a): Two-way tables showing combined effects of shade and light quality on incremental growth of shoot length (cm/month) in sandal seedlings

Month 2

Light quality	Shade level 25	50	75	Mean
Blue	0.315[bc]	0.209[d]	0.417[b]	0.314[y]
Green	0.254[cd]	0.609[a]	0.392[b]	0.418[x]
Red	0.170[d]	0.219[cd]	0.395[b]	0.261[y]
Mean	0.246[m]	0.345[l]	0.401[l]	0.188 (control)

$F_{control}$ → 12.79**, SEm +/- = 0.166
F_{shade} → 12.91**, SEm +/- = 0.136
F_{filter} → 19**, SEm +/- = 0.138
$F_{interaction}$ → 13.37**, SEm +/- = 0.08

Month 3

Light quality	Shade level 25	50	75	Mean
Blue	0.229[bc]	0.197[c]	0.290[bc]	0.239[y]
Green	0.257[bc]	0.463[a]	0.446[a]	0.388[x]
Red	0.228[bc]	0.226[bc]	0.316[b]	0.257[y]
Mean	0.238[m]	0.295[l]	0.351[l]	0.324 (control)

$F_{control}$ → 0.40 NS, SEm +/- = 0.032
F_{shade} → 5.70*, SEm +/- = 0.097
F_{filter} → 12**, SEm +/- = 0.141
$F_{interaction}$ →2.55 NS, SEm +/- = 0.038

Month 4

Light quality	Shade level 25	50	75	Mean
Blue	0.234[cd]	0.245[bcd]	0.288[bc]	0.256[y]
Green	0.238[cd]	0.451[a]	0.476[a]	0.388[x]
Red	0.172[d]	0.274[bc]	0.340[b]	0.262[y]
Mean	0.214[n]	0.323[m]	0.368[l]	0.182 (control)

$F_{control}$ → 10.64**, SEm +/- = 0.138
F_{shade} → 15.69**, SEm +/- = 0.137
F_{filter} → 14.29** , SEm +/- = 0.130
$F_{interaction}$ →2.73 NS, SEm +/- = 0.033

* - significant at 5 %, ** - significant at 1 %, NS – non-significant
Values with the similar alphabets do not differ significantly.
Control – Full-sunlight

Table 17 (b): Two-way tables showing combined effects of shade and light quality on incremental growth of shoot length (cm/month) in sandal seedlings

Month 5

Light quality	Shade level			Mean
	25	50	75	
Blue	0.253	0.265	0.314	0.278^{y}
Green	0.258	0.438	0.372	0.356^{x}
Red	0.163	0.255	0.324	0.247^{y}
Mean	0.225^{m}	0.319^{l}	0.337^{l}	0.245 (control)
$F_{control}$ → 2.52 NS, SEm +/- = 0.032				
F_{shade} → 9.10**, SEm +/- = 0.104				
F_{filter} → 7.98**, SEm +/- = 0.097				
$F_{interaction}$ → 2.03 NS, SEm +/- = 0.028				

Month 6

Light quality	Shade level			Mean
	25	50	75	
Blue	0.202	0.279	0.317	0.266
Green	0.190	0.327	0.295	0.271
Red	0.211	0.218	0.238	0.222
Mean	0.201^{m}	0.275^{l}	0.284^{l}	0.143 (control)
$F_{control}$ → 16.19**, SEm +/- = 0.130				
F_{shade} → 8.81**, SEm +/- = 0.079				
F_{filter} → 3.10 NS, SEm +/- = 0.047				
$F_{interaction}$ → 1.90 NS, SEm +/- = 0.021				

Month 7

Light quality	Shade level			Mean
	25	50	75	
Blue	0.237^{cd}	0.319^{b}	0.276^{bc}	0.277
Green	0.334^{b}	0.320^{b}	0.208^{d}	0.287
Red	0.423^{a}	0.237^{cd}	0.249^{cd}	0.303
Mean	0.331^{l}	0.292^{m}	0.245^{n}	0.187 (control)
$F_{control}$ → 23.08**, SEm +/- = 0.128				
F_{shade} → 11.89**, SEm +/- = 0.075				
F_{filter} → 1.05 NS, SEm +/- = 0.022				
$F_{interaction}$ → 12.24**, SEm +/- = 0.044				

* - significant at 5 %, ** - significant at 1 %, NS – non-significant
Values with the similar alphabets do not differ significantly.
Control – Full-sunlight

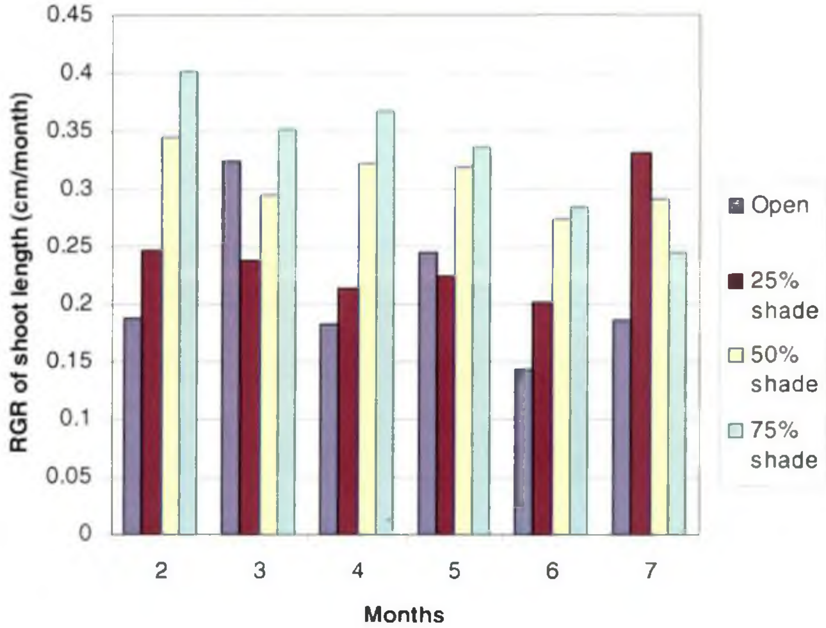

Fig. 11 (a): Effect of shade levels on incremental growth of shoot length in sandal seedlings

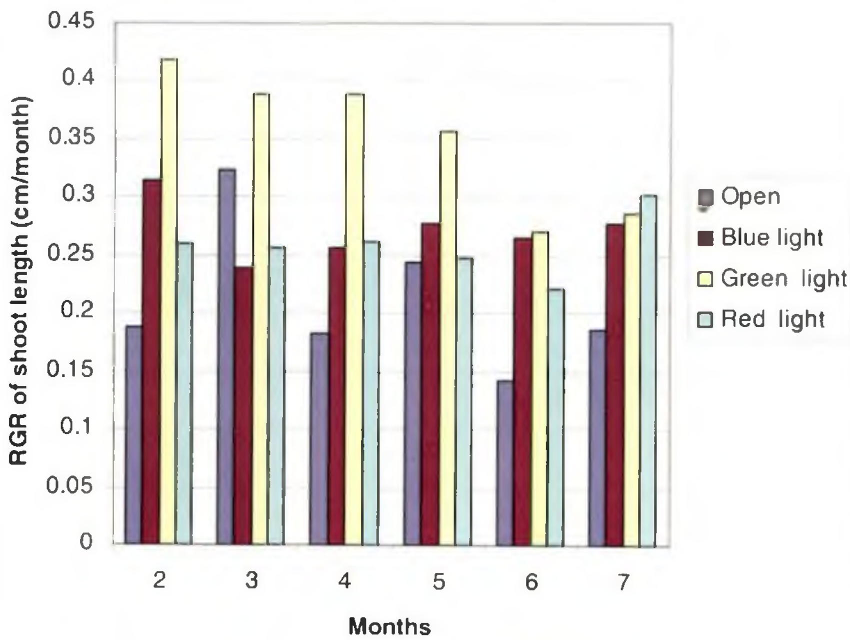

Fig. 11 (b): Effect of light quality on incremental growth of shoot length in sandal seedlings

seedlings under green light quality had the maximum IG of shoot length with a mean value of 0.418 cm/month from among the different types of light qualities. However the seedlings under blue and red light qualities produced mean values of 0.314 cm/month and 0.261 cm/month of IG of shoot length respectively and they were at par with each other. Control had the lowest mean value of 0.188 cm/month among the different levels of shades and light qualities.

Seedlings under 50 and 75 per cent shade level performed at par with each other with mean values of 0.295 cm/month and 0.351 cm/month of IG of shoot length respectively in the third month (Table 17a). The least IG of shoot length was seen in the seedlings under 25 per cent shade level (0.238 cm/month). With regard to the use of different types of light qualities the maximum IG of shoot length was shown by seedlings under green light quality (0.388 cm/month). This was followed by seedlings under blue and red light qualities with mean values of 0.239 cm/month and 0.257 cm/month respectively and they were at par with each other. Control had no significant impact on the IG of shoot length in this month.

In the fourth month, the seedlings under 75 per cent shade level had the maximum IG of shoot length (Table 17a). This was followed by seedlings under 50 and 25 per cent shade levels with recorded mean values of 0.323 cm/month and 0.214 cm/month of IG of shoot length respectively. They were also significantly different from each other. Among the different types of light qualities the seedlings under green light quality had the maximum IG of shoot length (0.388 cm/month) followed by seedlings under blue (0.256 cm/month) and red light qualities (0.262 cm/month). However the mean IG values of shoot length under blue and red light qualities were at par with each other. Control had the lowest mean value of 0.182 cm/month among the different levels of shades and light qualities.

Seedlings under 50 and 75 per cent shade levels were at par with each other with respect to IG of shoot length in the fifth month mean values of 0.319 cm/month and 0.337 cm/month respectively (Table 17b). The lowest mean value was observed in seedlings under 25 per cent shade level (0.225 cm/month). When different types of light qualities were considered for the same month, the maximum IG of shoot length was observed in seedlings under green light quality (0.356 cm/month). However the seedlings under blue and red light qualities had respective mean values of IG of shoot length as 0.278 cm/month and 0.247 cm/month, and these values were at par from each other. Control had no significant impact on the IG of shoot length in this month.

Different levels of shades showed significant influence on IG of shoot length in the sixth month with seedlings under 50 and 75 per cent shade levels having the maximum IG values (0.275 cm/month and 0.284 cm/month respectively) and they were at par with each other (Table 17b). The least IG mean value was seen in seedlings under 25 per cent shade level (0.201 cm/month) and it was significantly different from the rest. The light qualities did not show any significant effect on the IG of shoot length in the same month. However, the maximum IG of shoot length was recorded in seedlings under green light quality (0.271 cm/month). Control had a significant impact on the IG of shoot length with a mean value of 0.143 cm/month among different levels of shades and light qualities.

In the seventh month, light qualities did not show any influence on the IG of shoot length in sandal seedlings. Different levels of shades had significant effect on the IG of shoot length in the same month and seedlings under 25 per cent shade had the maximum IG of shoot length (0.331 cm/month). However seedlings under 50 and 75 per cent shade levels recorded mean IG values of 0.292 cm/month and 0.245 cm/month respectively, and they were significantly different from each other. Control had a significant impact on the IG of shoot length with a mean value of 0.187 cm/month among different levels of shades and light qualities.

When the incremental growth of shoot length during the study period was considered altogether, the maximum IG of shoot length was observed in seedlings under 75 per cent shade level in the second month with a mean value of 0.401 cm/month with respect to seedlings under different shade levels. On the other hand, the highest IG mean value for the seedlings under different light qualities was observed in seedlings under green light quality in the second month with a mean value of 0.418 cm/month. The minimum value of IG of shoot length was observed in seedlings under control most of the time during the study period.

4.7.3 Incremental growth of root length

The influence of different levels of shades and light qualities on the IG of root length is furnished in Table 18 (a, b). The effects of different treatments were insignificant during the study period. Although the maximum value of IG of root length in sandal seedlings was found to be under 50 per cent shade level (0.384 cm/month) with respect to different shade levels in the seventh month. Seedlings under green light quality had the maximum value (0.373 cm/month) with regard to different light qualities. The maximum IG of root length from the during the study period was observed in sandal seedlings under 50 per cent shade (0.844 cm/month) and red light quality (0.830 cm/month) in the second month when varying light quality and light quantity were taken into consideration separately. On the other hand, the minimum values were observed in seedlings under 25 per cent shade level (0.338 cm/month) and red light quality (0.352 cm/month) in the seventh month when the different levels of shades and light qualities were taken individually. Interaction between different factors had no significant impact on the IG of root length throughout the study period. Control also did not have any significant effect on the IG of root length in sandal seedlings throughout the study period.

EXPERIMENT NO. II

4.8 Anatomical studies of haustoria

Table 18 (a): Two-way tables showing combined effects of shade and light quality on incremental growth of root length (cm/month) in sandal seedlings

Month 2

Light quality	Shade level			Mean
	25	50	75	
Blue	0.860	0.730	0.760	0.783
Green	0.570	0.940	0.813	0.774
Red	0.783	0.863	0.843	0.830
Mean	0.738	0.844	0.806	0.680 (control)
$F_{control}$ → 1.83 NS, SEm +/- = 0.130				
F_{shade} → 1.40 NS, SEm +/- = 0.093				
F_{filter} → 0.43 NS, SEm +/- = 0.052				
$F_{interaction}$ → 2.66 NS, SEm +/- = 0.074				

Month 3

Light quality	Shade level			Mean
	25	50	75	
Blue	0.620	0.633	0.677	0.643
Green	0.587	0.660	0.653	0.633
Red	0.550	0.693	0.670	0.638
Mean	0.586	0.662	0.667	0.563 (control)
$F_{control}$ → 1.17 NS, SEm +/- = 0.10				
F_{shade} → 1.08 NS, SEm +/- = 0.079				
F_{filter} → 0.01 NS, SEm +/- = 0.007				
$F_{interaction}$ →0.19 NS, SEm +/- = 0.019				

Month 4

Light quality	Shade level			Mean
	25	50	75	
Blue	0.673	0.583	0.567	0.608
Green	0.570	0.580	0.497	0.549
Red	0.490	0.593	0.580	0.554
Mean	0.578	0.586	0.548	0.537 (control)
$F_{control}$ → 0.13 NS, SEm +/- = 0.032				
F_{shade} → 0.22 NS, SEm +/- = 0.034				
F_{filter} → 0.61 NS , SEm +/- = 0.056				
$F_{interaction}$ →0.70 NS, SEm +/- = 0.035				

* - significant at 5 %, ** - significant at 1 %, NS – non-significant

Values with the similar alphabets do not differ significantly.

Control – Full-sunlight

Table 18 (b): Two-way tables showing combined effects of shade and light quality on incremental growth of root length (cm/month) in sandal seedlings

Month 5

Light quality	Shade level			Mean
	25	50	75	
Blue	0.437	0.453	0.463	0.451
Green	0.513	0.510	0.500	0.508
Red	0.433	0.490	0.493	0.472
Mean	0.461	0.484	0.486	0.370 (control)
$F_{control}$ → 3.78 NS, SEm +/- = 0.116				
F_{shade} → 0.21 NS, SEm +/- = 0.022				
F_{filter} → 1.05 NS, SEm +/- = 0.05				
$F_{interaction}$ → 0.175 NS, SEm +/- = 0.012				

Month 6

Light quality	Shade level			Mean
	25	50	75	
Blue	0.330	0.383	0.363	0.359
Green	0.377	0.497	0.430	0.434
Red	0.337	0.590	0.450	0.459
Mean	0.348	0.490	0.414	0.350 (control)
$F_{control}$ → 0.45 NS, SEm +/- = 0.063				
F_{shade} → 2.54 NS, SEm +/- = 0.123				
F_{filter} → 1.37 NS, SEm +/- = 0.09				
$F_{interaction}$ → 0.45 NS, SEm +/- = 0.03				

Month 7

Light quality	Shade level			Mean
	25	50	75	
Blue	0.317	0.373	0.333	0.341
Green	0.350	0.420	0.350	0.373
Red	0.347	0.360	0.350	0.352
Mean	0.338	0.384	0.344	0.257 (control)
$F_{control}$ → 3.23 NS, SEm +/- = 0.122				
F_{shade} → 0.59 NS, SEm +/- = 0.043				
F_{filter} → 0.27 NS, SEm +/- = 0.029				
$F_{interaction}$ → 0.11 NS, SEm +/- = 0.011				

* - significant at 5 %, ** - significant at 1 %, NS – non-significant
Values with the similar alphabets do not differ significantly.
Control – Full-sunlight

Microphotographs of sandal haustorium, the haustorium on cocoa root, the haustorium on teak root and haustorium in association with casuarina root are given in Plates 3, 4, 5 and 6 respectively. The different sections were observed carefully for understanding the formation of haustoria.

From the morphology of the haustorium, it can be observed that they appear as a small hemispherical outgrowth. It then gradually flattens after coming into contact with the host root. The young haustorium consists of a narrow neck which is known as penetration peg, a clasping fold known as ellipsoidal disc and a massive parenchymatous body. Close haustorial connections were shown by all the sandal-host associations (*viz.* sandal-casuarina, sandal-teak and sandal-cocoa). The formations of clasping folds were seen to be incomplete in all the sandal-host associations as the sections were taken during the seedling stages and hence it may be assumed to form complete clasping folds at the later stages.

In the sandal haustorium, the vascular cylinder appeared as an inverted flask with both xylem and phloem elements in it. It was observed that sandal haustoria established intimate vascular connections between host roots and the sandal roots with xylem as well as phloem connections. Through these vascular connections, translocation of water through xylem and other substances through phloem between sandal and hosts may be facilitated through gradients of water potential or some other transfer mechanism. It can also be observed from the plates that formation of clasping fold was quicker in sandal-casuarina association as compared to other two associations *i.e.* sandal-cocoa and sandal-teak even though the sandal seedlings were of the same age and they were planted together with the host plants at the same time.

Initially the haustorium comes in contact with the host roots and the apex portion becomes radially elongated. The outermost part of the body of haustorium starts to develop rapidly which tries to penetrate the host root and finally forms a connection successfully with the host's root. The other portions, which do not take part in the penetration process, form the clasping fold which is also known as

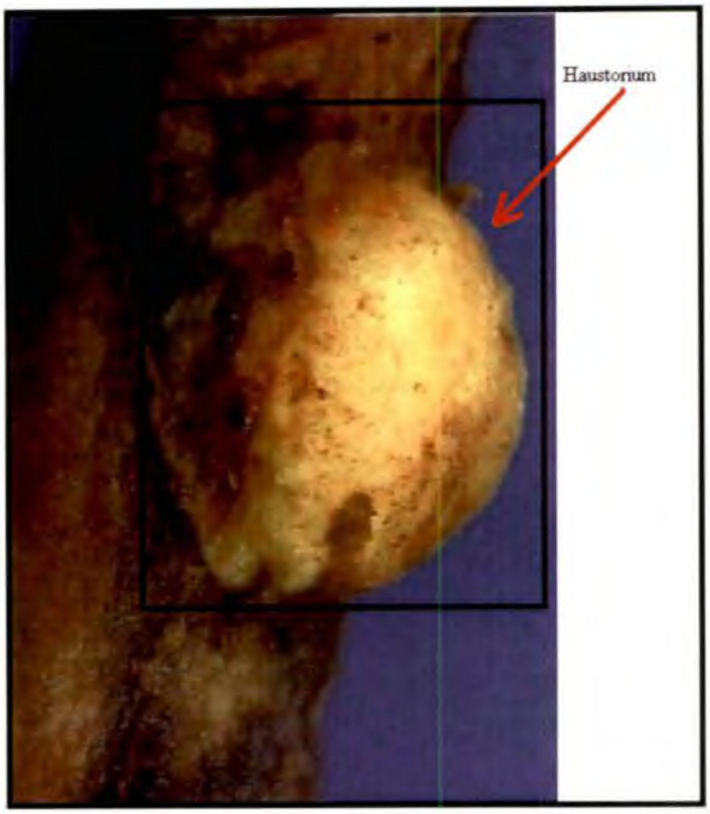

Plate 3: Hemispherical shape haustorium of sandal on teak root (stereoscopic image)

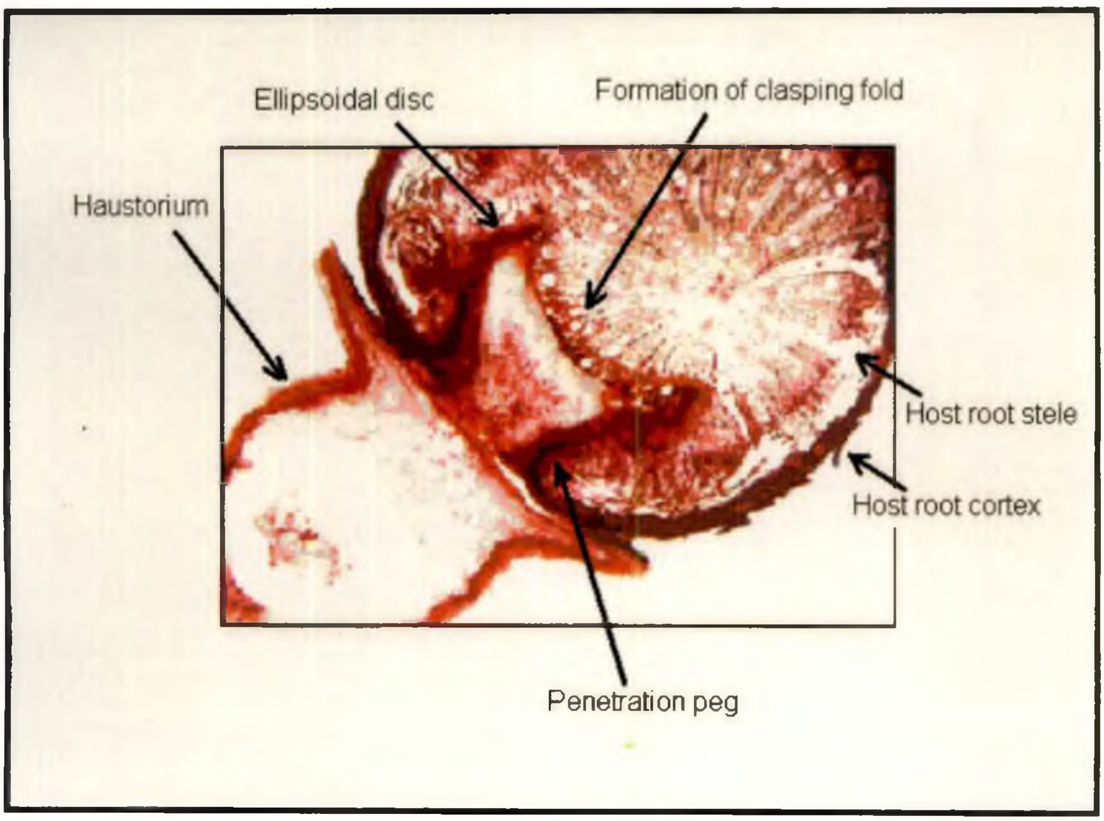

Plate 4: L.S. of young haustorium of sandal when associated with *Theobroma cacao* (4X)

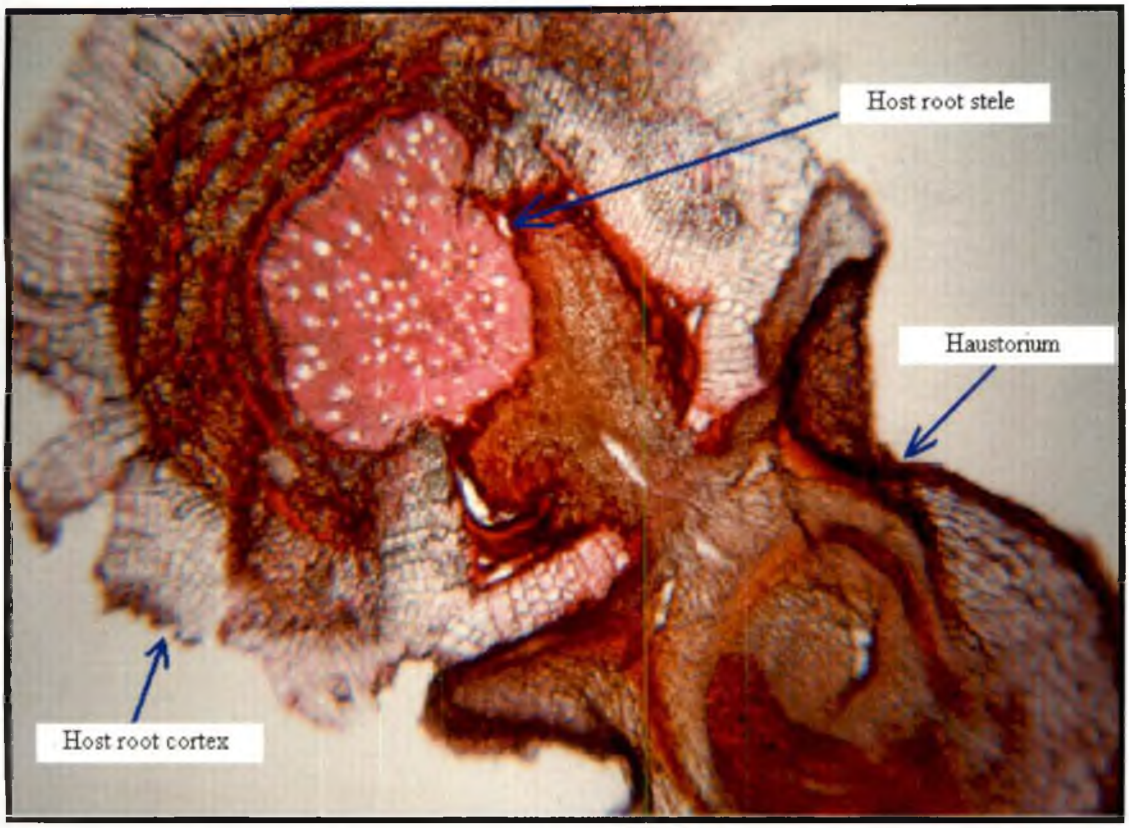

Plate 5: L.S. of young haustorium of sandal when associated with *Tectona grandis* (4X)

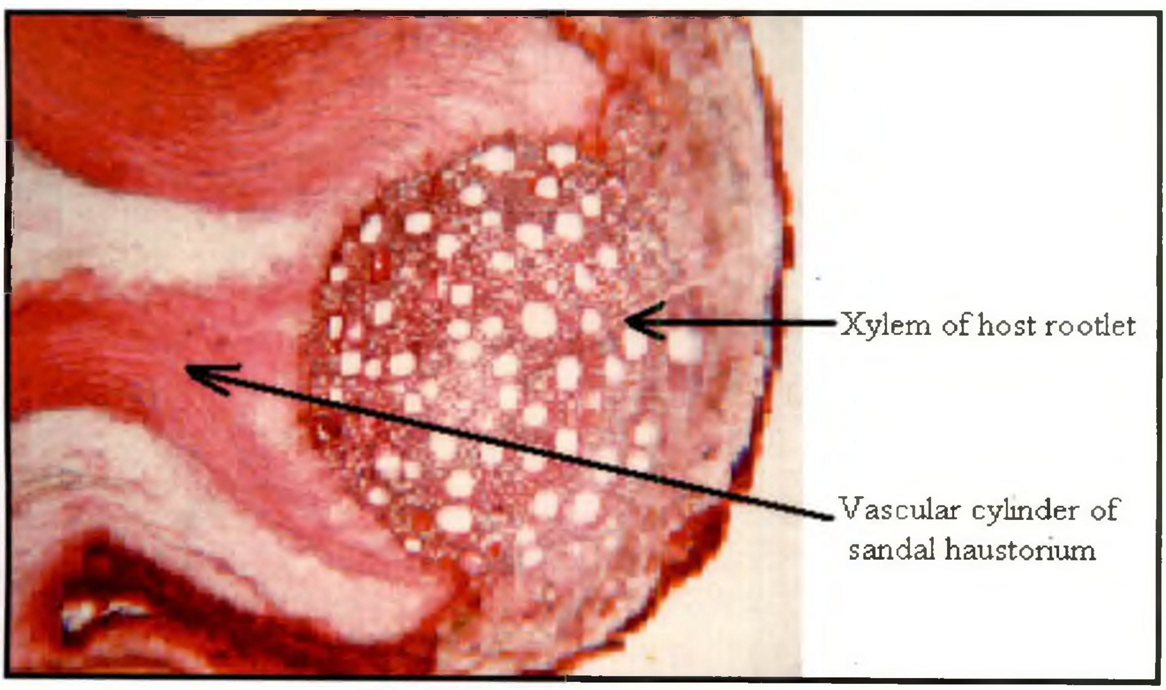

Plate 6: L.S. of young haustorium of sandal showing the established connections with *Casuarina equisetifolia* (4X)

ellipsoidal disc. The roots of *Santalum album* and the hosts showed direct vascular connection with the haustorium. It can be seen from the different plates that there is a constriction in the midway of the haustorium which penetrates the root of the host thereby forming a flask shaped structure.

4.9 Transfer of photosynthates

In order to understand the effectiveness of transfer of photosynthates from host plants to sandal seedlings, radioactive ^{14}C labeled host plants were used and labeling of ^{14}C was done in a closed chamber as shown in plate 2. As a part of normal photosynthesis the radioactive ^{14}C was taken up by the host plants. Later sandal seedlings were found to take up photosynthates from the host plants through haustorial formation. The amount of ^{14}C count using Liquid Scintillation Counter in both ^{14}C labeled host species and sandal seedlings grown along with these host species is furnished in Table 19 and Fig. 12. Without taking into consideration about the litter fall and amount of ^{14}C transferred to the soil from the host plants, the maximum ^{14}C uptake was found in *Casuarina equisetifolia* (86.76 per cent) followed by *Pongamia pinnata* (79.42 per cent), *Terminalia bellerica* (74.99 per cent), *Pterocarpus marsupium* (32.63 per cent) and *Dalbergia latifolia* (16.74 per cent). The experiment showed that *Casuarina equisetifolia* was the best species among the other species when the transfer of photosynthates from host plants to sandal seedlings was taken into consideration with a percentage uptake of 86.76. The least transfer was seen in sandal seedlings grown along with *Dalbergia latifolia* with a percentage uptake of 16.74 per cent only. The experiment also illustrated that *Pongamia pinnata* and *Terminalia bellerica* transferred about 79.42 per cent and 74.99 per cent of ^{14}C to sandal seedlings respectively.

Table 19: Percentage transfer of ^{14}C from host species to sandal seedlings

Host	$Sandal_1$ (S_1) (^{14}C cpm g^{-1} dry weight)	$Sandal_2$ (S_2) (^{14}C cpm g^{-1} dry weight)	$Total_1$ w.r.t. S_1 and host (^{14}C cpm g^{-1} dry weight)	$Total_2$ w.r.t. S_2 and host (^{14}C cpm g^{-1} dry weight)	Percentage transfer of ^{14}C from host to sandal		Average percentage transfer of ^{14}C (P_1+P_2/2)
					P_1	P_2	
Casuarina equisetifolia	2977.78	842.697	3167.495	1059.986	94.01	79.5	86.76
Pongamia pinnata	1055.227	2819.149	1323.427	3564.135	79.73	79.1	79.42
Dalbergia latifolia	435.518		2601.051		16.74		16.74
Pterocarpus marsupium	527.273	1279.412	5950.35	2269.016	8.86	56.39	32.63
Terminalia bellerica	1047.904	426.426	1513.878	528.016	69.22	80.76	74.99

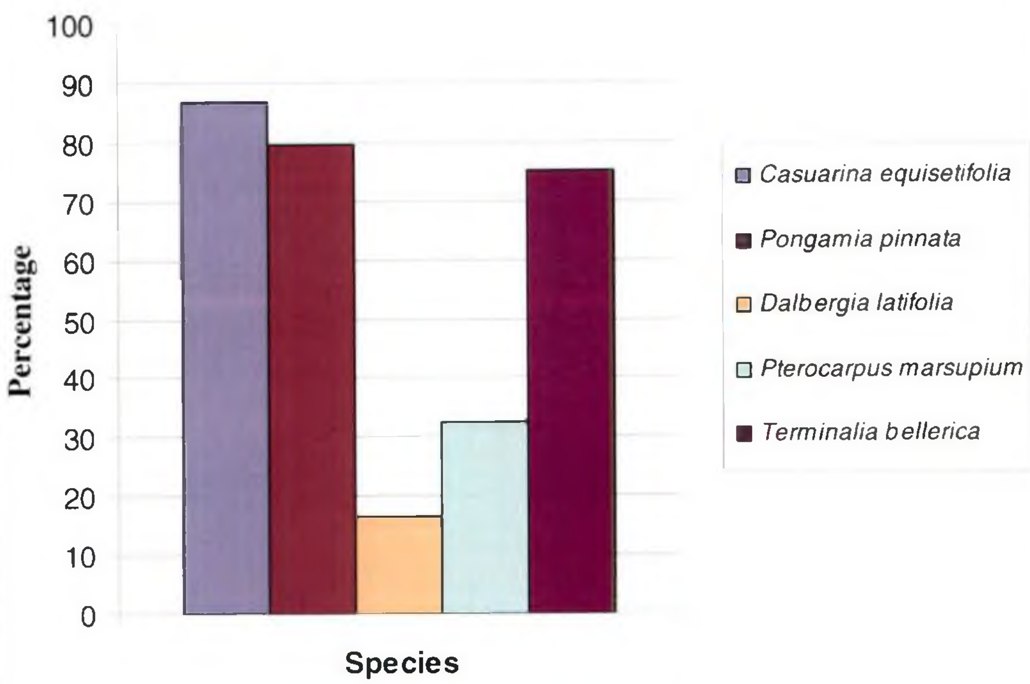

Fig. 12 : Average transfer of photosynthates from different host species to sandal seedlings

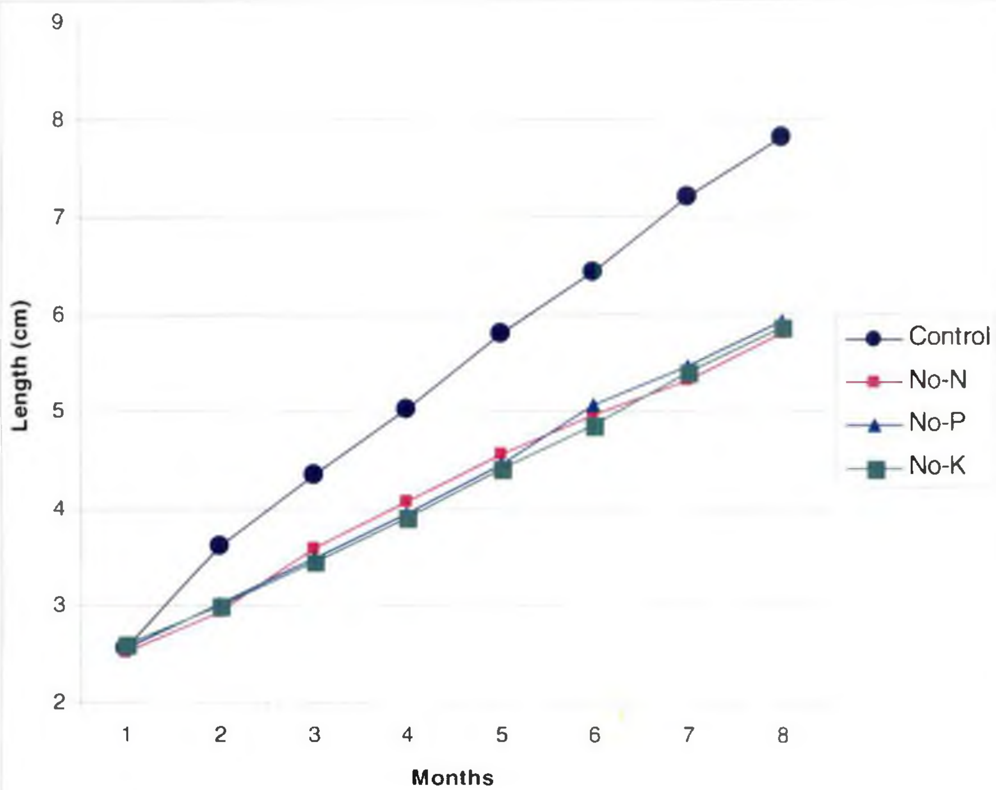

Fig. 13 : Effect of nutrient deficiency treatments on shoot length of sandal seedlings

EXPERIMENT NO. III

Sandal seedlings were grown in sand culture for understanding the effects of nutrient deficiency on the growth behaviours, chlorophyll content and foliar N, P and K contents in sandal seedlings as shown in plate 10.

4.10 Visual deficiency symptoms

The growth of seedlings that received complete Hoagland nutrient solution and the visual deficiency symptoms of other seedlings as influenced by various treatments are summarized below:

4.10.1 Complete nutrients

The seedlings that received all nutrients through complete Hoagland nutrient solution were found to be very vigorous in growth and produced dark green foliage throughout the period of study. The seedlings did not show any visual symptoms of deficiency or toxicity. They had healthy, dark green and normal shaped foliage at the end of the study period.

4.10.2 Nitrogen

Symptoms of N deficiency appeared by the end of the sixth month after the initiation of experiment. In the beginning, small patches of yellow colour at the tip of the leaves began to appear in the oldest leaves which spread to the lower portion of the leaves very slowly reaching only up to one fifth of the leafy portion till the eight month (Plate 7). Stunting of seedlings could also be noticed at this stage.

4.10.3 Phosphorus

Symptoms of phosphorus deficiency first appeared on the fifth month after the treatments were initiated. Symptoms appeared at the oldest leaves initially. Small patches of brown colouration were observed on the upper portion of the

Plate 7: Sandal seedling showing chlorotic leaf tip due to nitrogen deficiency

Plate 8: Leaf curling in sandal seedling due to potassium deficiency in acute stage

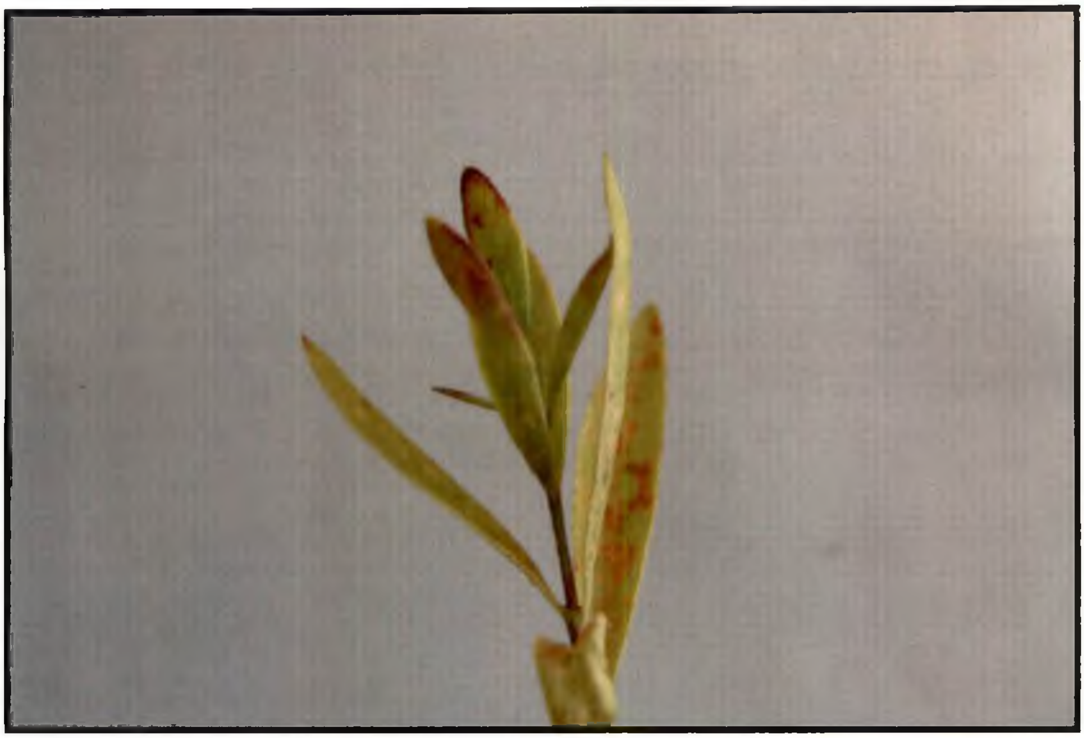

Plate 9: Change in leaf colouration and formation of brown spots in sandal seedling due to phosphorus deficiency

Plate 10: Sandal seedlings arranged for sand culture studies in nursery

older leaves (Plate 9). At the sixth month, it spread gradually to the younger leaves. The new leaves were of pale yellow colouration. Stunted shoot growth was also observed.

4.10.4 Potassium

Potassium deficiency symptoms started appearing by the seventh month after initiation of the treatments. The curling of lower leaves was seen first. It then spread to the older leaves. This was followed by the gradual death of such seedlings (Plate 8).

4.11 Shoot growth parameters

The influence of various treatments on height, collar diameter and number of leaves of sandal seedlings recorded at monthly intervals is presented in Tables 20, 21 and 22 respectively.

4.11.1 Height

The observations on the effect of various treatments on the height of the seedlings are presented in Table 20 and illustrated in Fig. 13. There were no significant differences between various treatments with regard to height of seedlings in the first month. Thereafter, the seedlings showed significant differences due to nutrient deficiency. At the end of the study period, seedlings grown with complete nutrient solution had the maximum height growth of 7.80 cm, while N deficient seedlings recorded the lowest height growth of 5.80 cm. The seedlings grown in various nutrient deficient solutions however did not differ statistically between them.

Among the various nutrient deficient seedlings, P generally had the maximum height growth (5.93 cm) during the last month which was 23.94 per cent lower than the control, which was followed by K deficient seedlings (5.87 cm). But all the nutrient deficient seedlings were on par with each other in terms

Table 20: Effect of nutrient deficiencies on shoot length in sandal seedlings

Nutrient element deleted from complete solution	Shoot length (cm)							
	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Month 7	Month 8
Nitrogen	2.53	2.93[b]	3.60[b]	4.10[b]	4.57[b]	4.97[b]	5.33[b]	5.80[b]
Phosphorus	2.57	3.03[b]	3.50[b]	3.97[b]	4.47[b]	5.07[b]	5.47[b]	5.93[b]
Potassium	2.60	3.00[b]	3.47[b]	3.93[b]	4.43[b]	4.87[b]	5.40[b]	5.87[b]
Control	2.57	3.63[a]	4.37[a]	5.03[a]	5.80[a]	6.43[a]	7.20[a]	7.80[a]
F – value	0.127 NS	7.037*	13.067**	14.198**	25.978**	40.000**	66.515**	82.309**
SEm +/-	0.075	0.122	0.118	0.138	0.129	0.117	0.111	0.106

* - significant at 5 %, ** - significant at 1 %, NS – non-significant
Values with the similar alphabets do not differ significantly.
Comparison is done within a column.

height starting from the second month of the treatments onwards. At the end of the study, the height was found to be relatively lower in all the treatments compared to control. Seedlings receiving complete nutrient solution started to produce significantly different height from the second month till the end of the study period. Control recorded an increase of 204.69 % in shoot length from initial to final stage. However seedlings deficient in N, P and K recorded increase of 129.25%, 130.74% and 125.77% respectively in shoot length from initial to the final stage.

4.11.2 Collar diameter

Observations on collar diameter of seedlings as influenced by various nutrient deficiencies are furnished in Table 21 and Fig. 14. In the present study, it was found that there was no significant difference between the various treatments in terms of collar diameter till the fourth month of the treatments. From the fifth month onwards, control had the best growth in collar diameter till the end of the study at eight month (2.01 mm). The lowest growth in collar diameter was recorded in P and K deficient seedlings with the recorded values of 1.58 mm and 1.60 mm respectively at the end of eight month and there was no significant difference between them. Better performance was shown by N deficient seedlings with the recorded value of 1.75 mm among the nutrient deficiency seedlings under various treatments.

In the fifth month, all other nutrient deficient seedlings under various treatments were on par with each other with regard to collar diameter growth. In the sixth month, N deficient seedlings (1.52 mm) performed better than P (1.41 mm) and K (1.43 mm) deficient seedlings. But in the seventh month, the performances of all nutrient deficient seedlings under various treatments were on par with each other. However, at the end of the study (*i.e.* in the eight month) the best performance was given by control followed by N deficient seedlings and which was again followed by both P and K deficient seedlings. An increase of 124.72% in collar diameter from the first month till the end of the study was

Table 21: Effect of nutrient deficiencies on the collar diameter (cm) in sandal seedlings

Nutrient element deleted from complete solution	Collar diameter (mm)							
	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Month 7	Month 8
Nitrogen	0.90	1.07	1.19	1.29	1.42[b]	1.52[ab]	1.62[b]	1.75[b]
Phosphorus	0.91	1.05	1.13	1.23	1.31[b]	1.41[b]	1.49[b]	1.58[c]
Potassium	0.92	1.06	1.18	1.26	1.33[b]	1.43[b]	1.51[b]	1.60[c]
Control	0.89	1.11	1.27	1.41	1.58[a]	1.76[a]	1.87[a]	2.01[a]
F - value	0.289 NS	0.545 NS	2.401 NS	3.113 NS	8.307**	15.974**	13.924**	21.802**
SEm +/-	0.019	0.038	0.038	0.044	0.044	0.04	0.047	0.042

* - significant at 5 %, ** - significant at 1 %, NS – non-significant
Values with the similar alphabets do not differ significantly.
Comparison is done within a column.

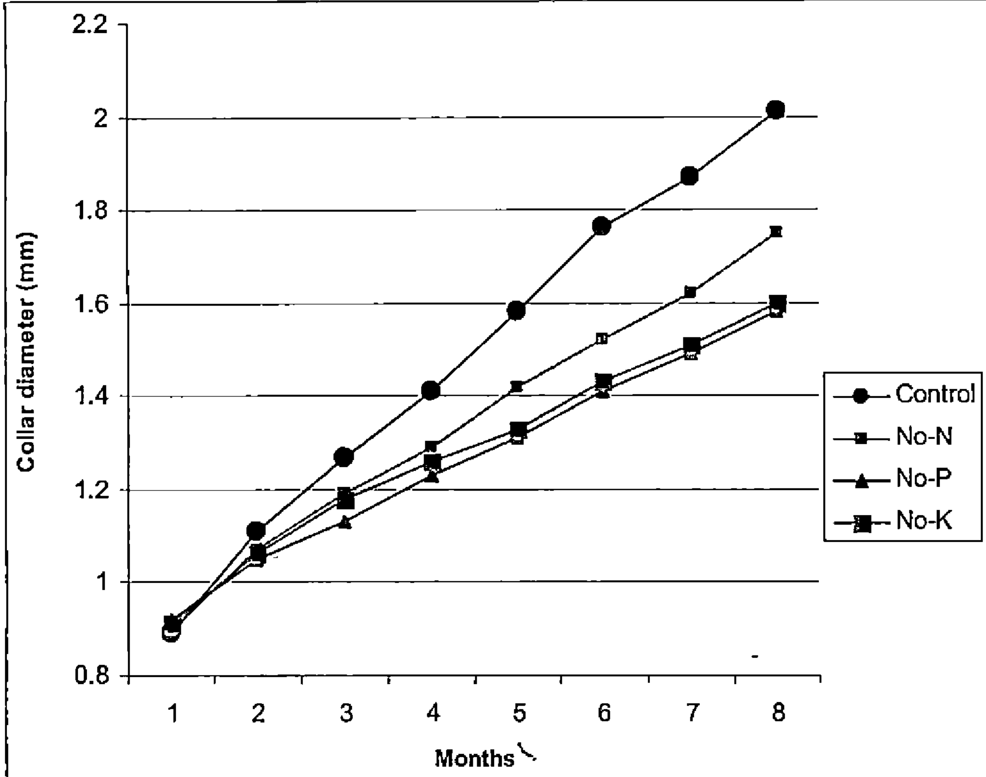

Fig. 14 : Effect of nutrient dificiency treatments on collar diameter of sandal seedlings

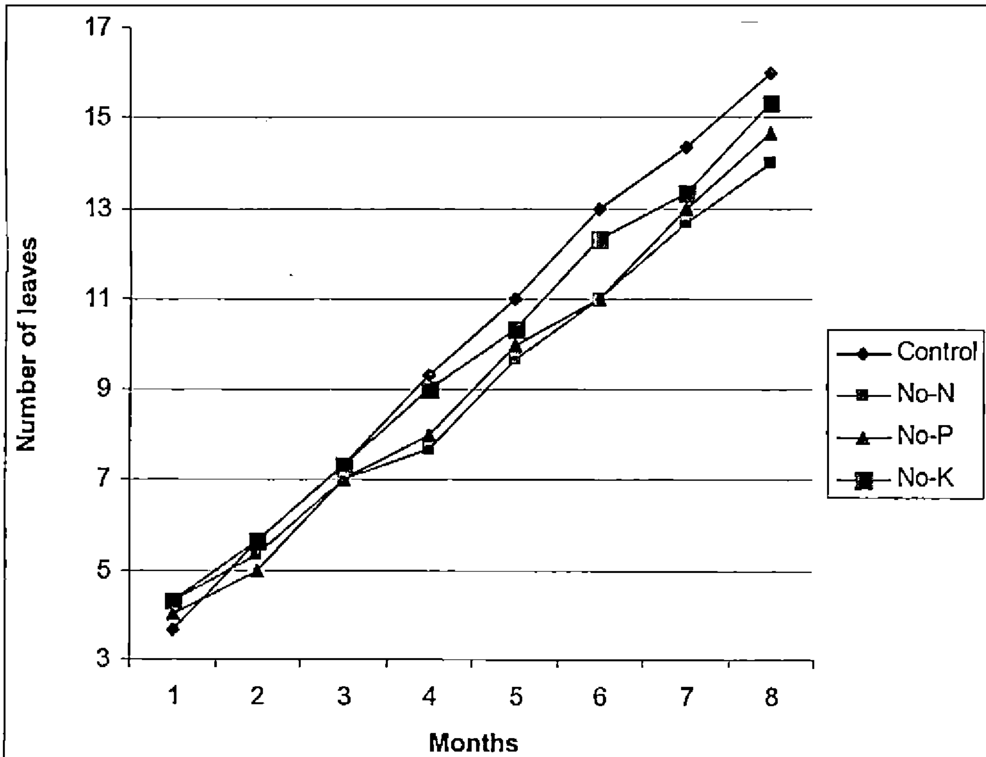

Fig. 15 : Effect of nutrient deficiency treatments on leaf number of sandal seedlings

observed in seedlings under control. However, seedlings lacking N, P and K recorded increase of 94.44%, 73.62% and 73.91% respectively in collar diameter from initial to the final stage.

4.11.3 Number of leaves

The result on number of leaves is furnished in Table 22 and Fig. 15. The result indicates the effect of deficiency of various nutrients on the number of leaves produced by seedlings. Treatment differences were found to be insignificant with regard to this parameter throughout the study period. All the treatments were on par with each other regarding the number of leaves produced during the growth period. However, control produced the highest number of leaves from the fourth month up to the eighth month (9.33, 11, 13 and 16 respectively).

Nitrogen deficient seedlings tended to produce the lowest number of leaves from the seventh month onwards till the end of the study period (12.67 and 14 respectively). The best performance under nutrient deficient conditions was given by K deficient seedlings with a value of 15.33. This was closely followed by P deficient seedlings (14.67). An increase of 335.97% in number of leaves was recorded in seedlings under control from initial stage to final stage. However, seedlings lacking N, P and K produced only 224.88%, 266.75% and 254.04% increase in number of leaves from initial stage to the final stage.

4.12 Root growth parameters

The various root growth parameters like length of the main root and the number of secondary roots as affected by different treatments are presented here. The root growth parameters were found to be statistically influenced by deficiency of the elements in the nutrient solution.

Table 22: Effect of nutrient deficiencies on number of leaves in sandal seedlings

Nutrient element deleted from complete solution	Number of leaves							
	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Month 7	Month 8
Nitrogen	4.33	5.33	7.00	7.67	9.67	11.00	12.67	14.00
Phosphorus	4.00	5.00	7.00	8.00	10.00	11.00	13.00	14.67
Potassium	4.33	5.67	7.33	9.00	10.33	12.33	13.33	15.33
Control	3.67	5.67	7.33	9.33	11.00	13.00	14.33	16.00
F – value	0.306 NS	0.306 NS	0.078 NS	0.872 NS	0.449 NS	1.161 NS	1.037 NS	1.333 NS
SEm +/-	0.577	0.577	0.687	0.850	0.850	0.928	0.707	0.745

* - significant at 5 %, ** - significant at 1 %, NS – non-significant
Values with the similar alphabets do not differ significantly.
Comparison is done within a column.

4.12.1 Length of the main root

Length of the main root showed significant differences due to treatment from the second month of the study period. This is clearly evident from the data furnished in Table 23 and Fig. 16. Control showed superiority over other nutrient deficiency treatments right from the second month, with a value of 7.20 cm at the end of the study period. On the other hand, all the seedlings under various nutrient deficiency treatments performed at par with each other from the second month onwards till the end of the study period.

However, phosphorus deficient seedlings seemed to record the lowest root length starting from the seventh month onwards till the end of the study (5.80 cm). Among all the nutrient deficient treatments, K deficient seedlings performed the best (5.93 cm) which is 17.60 per cent lower than the control. This was followed by N and P deficient seedlings with values of 5.83 cm and 5.80 cm respectively. An increase of 173.76% in the main root length was observed in seedlings under control from the initial to the final stage. However, nitrogen, phosphorus and potassium deficient seedlings recorded increase of 139.92%, 138.68% and 144.03% in the main root length respectively from the initial stage to final stage.

4.12.2 Number of secondary roots

The effect of treatments on the number of secondary roots produced by the plant is depicted in Table 24 and Fig. 17. The treatments started to bring significant differences only from the fourth month after the application of the treatments. From the fourth month onwards till the end of the study period, control gave the best performance (18) followed by N (15.00), K (13.33) and P (12.67) deficient seedlings respectively.

From the fourth to the seven month of the application of treatments, the nutrient deficient seedlings performed at par with each other with regard to the production of number of secondary roots. In the fifth month, the seedlings

Table 23: Effect of nutrient deficiencies on root length in sandal seedlings

Nutrient element deleted from complete solution	Root length (cm)							
	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Month 7	Month 8
Nitrogen	2.43	2.87[b]	3.50[b]	3.97[b]	4.50[b]	5.00[b]	5.47[b]	5.83[b]
Phosphorus	2.43	2.73[b]	3.37[b]	3.90[b]	4.43[b]	4.93[b]	5.37[b]	5.80[b]
Potassium	2.43	2.80[b]	3.40[b]	3.80[b]	4.37[b]	4.90[b]	5.40[b]	5.93[b]
Control	2.63	3.50[a]	4.13[a]	4.77[a]	5.37[a]	5.97[a]	6.53[a]	7.20[a]
F – value	1.161	22.583**	16.092**	10.005**	6.622*	7.955**	13.567**	19.739**
SEm +/-	0.093	0.075	0.089	0.140	0.183	0.182	0.153	0.152

* - significant at 5 %, ** - significant at 1 %, NS – non-significant
Values with the similar alphabets do not differ significantly.
Comparison is done within a column.

Table 24: **Effect of nutrient deficiencies on number of secondary roots in sandal seedlings**

Nutrient element deleted from complete solution	Number of roots							
	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Month 7	Month 8
Nitrogen	4.00	5.33	6.67	8.33[b]	10.00[ab]	11. 33[b]	13.33[b]	15.00[b]
Phosphorus	3.67	4.67	6.33	7.00[b]	8.67[b]	10.33[b]	11.67[b]	12.67[c]
Potassium	4.00	5.33	6.33	7.33[b]	8.67[b]	10.33[b]	11.67[b]	13.33[bc]
Control	4.33	6.00	8.00	10.67[a]	12.67[a]	15.00[a]	17.00[a]	18.00[a]
F – value	0.333 NS	0.711 NS	1.889 NS	5.481**	4.267**	11.800*	18.972*	14.548*
SEm +/-	0.472	0.645	0.577	0.707	0.913	0.645	0.577	0.624

* - significant at 5 %, ** - significant at 1 %, NS – non-significant
Values with the similar alphabets do not differ significantly.
Comparison is done within a column.

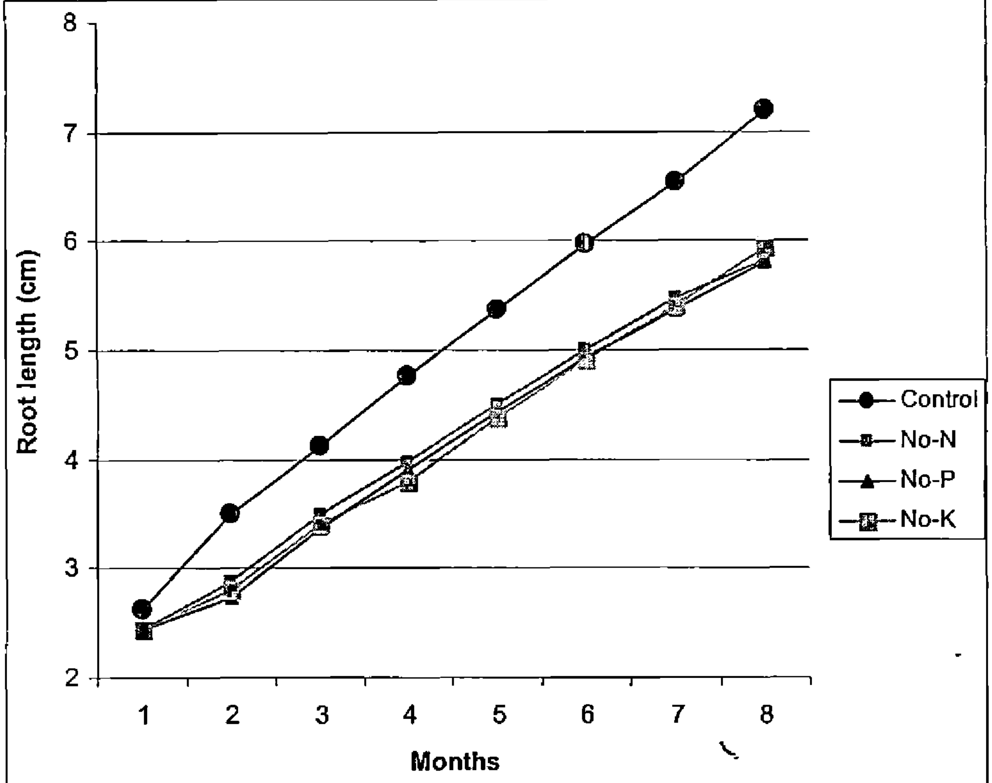

Fig. 16 : Effect of nutrient deficiency treatments on root length of sandal seedlings

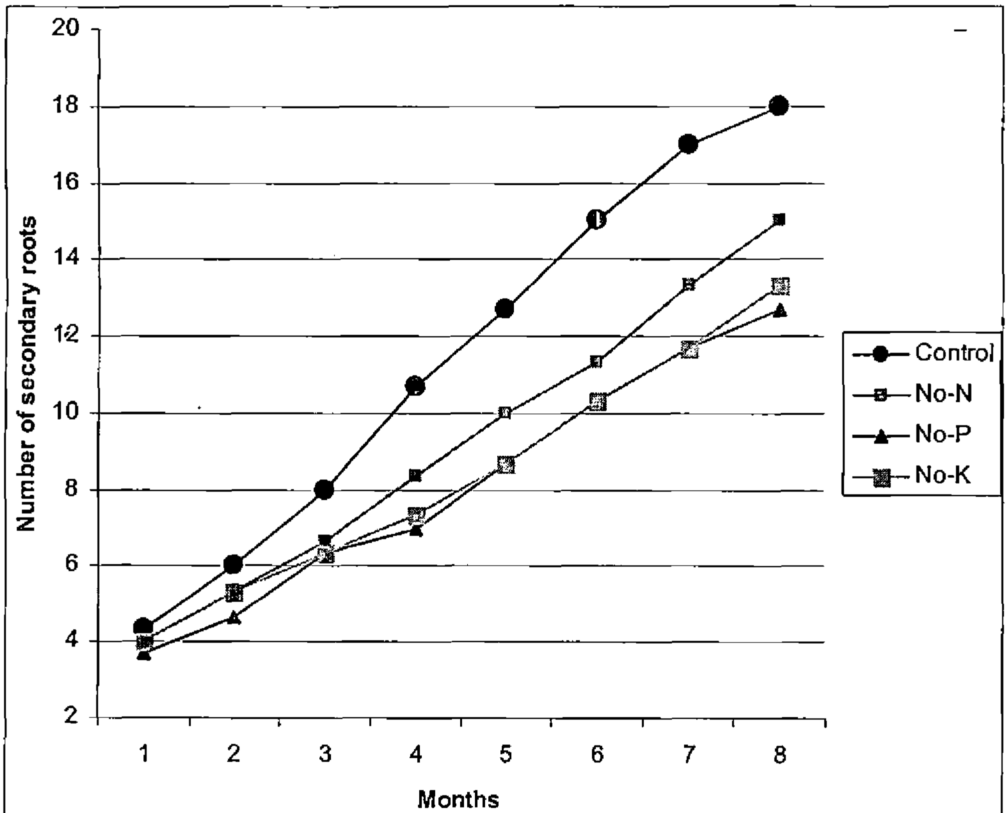

Fig. 17 : Effect of nutrient deficiency treatments on secondary root numbers in sandal seedlings

deficient in N (10) showed better performance in term of secondary root number as compared to seedlings deficient in P (8.67) and K (8.67). Significant differences between treatments were observed at the end of the study period and N deficient seedlings performed better than P and K deficient seedlings. In the eight month, potassium deficient seedlings (13.33) performed better than the P deficient seedlings (12.67). An increase of 315.70% in the number of secondary roots was detected in seedlings under control from the initial to the final stage. However, seedlings deficient in N, P and K recorded increase of only 275%, 245.23% and 233.25% respectively in the number of secondary roots from the initial to the final stage.

4.13 Dry matter of seedlings

The effects of nutrient stress on the fresh and dry weights of the shoot and root portions of the seedlings are clearly evident from the data tabulated in Tables 25, 26, 27 and 28. The various nutrient treatments significantly influenced dry as well as fresh weights of shoot and root portions.

4.13.1 Fresh weight of shoot

The influence of various treatments on fresh weight of shoot is given in Table 25 and Fig. 18. At the start of the application of the treatment (*i.e.* in the first month) and in the fifth month, the different treatments did not give any significant difference. Statistically significant values were found from the second month to the fourth month and from the sixth month to the end of the study period.

Seedlings that received complete nutrient solution recorded the highest shoot fresh weight from the second month to fourth month and from sixth month to the end of the study period. Among the nutrient deficient treatments, the best performance was given by N deficient seedlings from the seventh month to the end of the experiment (0.589 g). This was followed by P and K deficient seedlings

Table 25: Effect of nutrient deficiencies on fresh weight of shoot in sandal seedlings

Nutrient element deleted from complete solution	Fresh weight of shoot (gm)							
	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Month 7	Month 8
Nitrogen	0.262	0.307[ab]	0.353[b]	0.403[b]	0.449	0.499[b]	0.542[b]	0.589[b]
Phosphorus	0.242	0.287[b]	0.333[b]	0.379[b]	0.554	0.457[b]	0.504[bc]	0.548[bc]
Potassium	0.257	0.286[b]	0.325[b]	0.354[b]	0.391	0.428[b]	0.449[c]	0.485[c]
Control	0.263	0.334[a]	0.424[a]	0.505[a]	0.584	0.670[a]	0.735[a]	0.822[a]
F – value	0.828 NS	5.200*	9.365**	13.009**	1.582 NS	20.758**	27.105**	31.673**
SEm +/-	0.01	0.009	0.014	0.018	0.072	0.024	0.024	0.026

* - significant at 5 %, ** - significant at 1 %, NS – non-significant
Values with the similar alphabets do not differ significantly.
Comparison is done within a column.

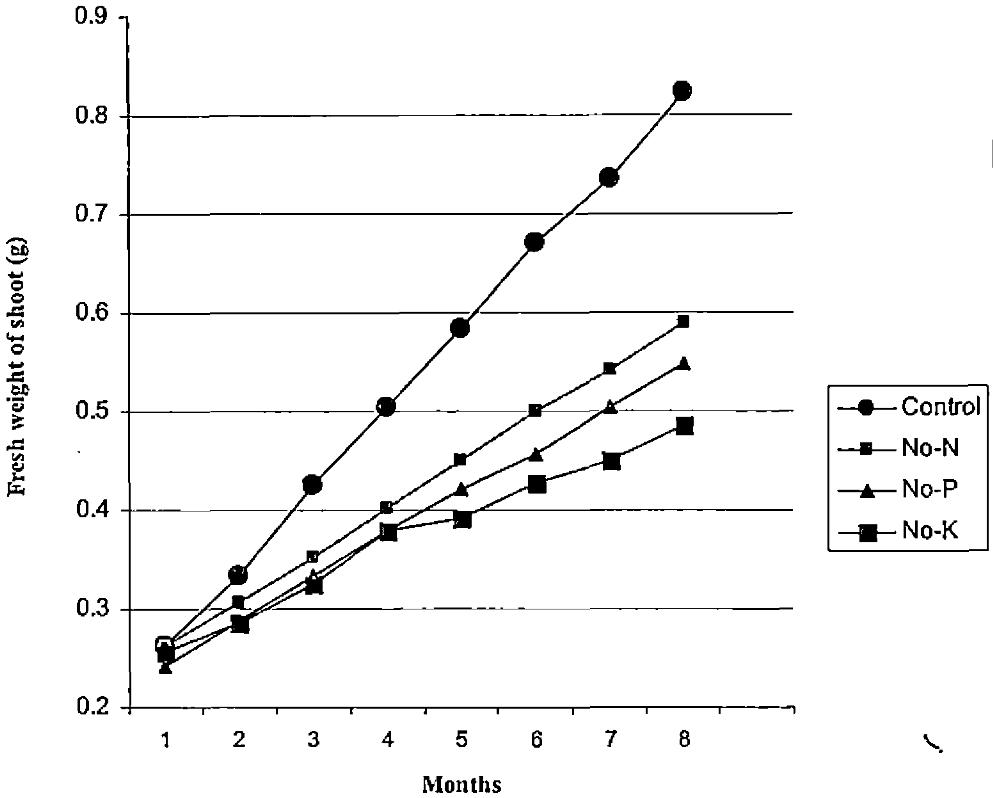

Fig. 18 : Effect of nutrient deficiency treatments on fresh weight of shoot in sandal seedlings

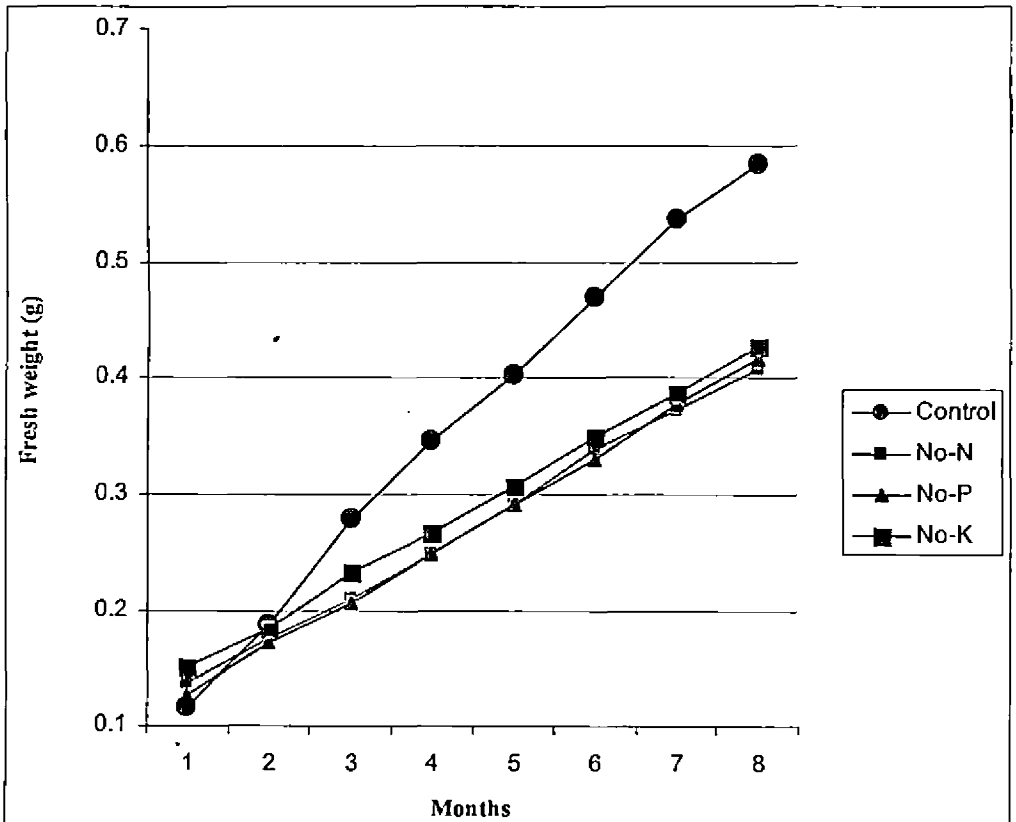

Fig. 19 : Effect of nutrient deficiency treatments on fresh weight of root in sandal seedlings

with recorded values of 0.548 g and 0.485g. Starting from the second to fourth month and in the sixth month of the application of treatments, the performances of the nutrient deficient seedlings under various treatments were at par with each other with regard to fresh weight of shoot. But at the seventh and eighth month, N deficient seedlings performed better than the seedlings deficient in P and K. The lowest performance was given by K deficient seedlings at the end of the study period (0.485 g). Nitrogen deficient seedlings performed better than P deficient seedlings at the end of the experiment. An increase of 212.55% in fresh weight of shoot was observed in seedlings receiving all nutrients from initial stage to the final stage. However, seedlings deficient in N, P and K recorded increase of 124.81%, 126.45% and 88.72% in fresh weight of shoot respectively from initial to the final stage.

4.13.2 Fresh weight of root

The effect of different treatments on fresh weight of root is furnished in Table 26 and Fig. 19. The different treatments gave significantly different values right from the fourth month of the application of treatments. The best performance was given by control from the fourth till the end of the study period (0.583 g). However, the seedlings under different nutrient deficient regimes did not show any significant difference from the first month till the end as their performances were at par with each other. In the eighth month, the lowest value was observed in N deficient seedlings with a recorded value of 0.408 g. The highest value in nutrient deficient seedlings was observed in K deficient seedlings which recorded a fresh weight of root as 0.428 g, closely followed by seedlings deficient in P. The differences were however insignificant. An increase of 406.96% in fresh weight of root was observed in seedlings under control from initial to the final stage. Seedlings deficient in N, P and K recorded respective increase of 197.81%, 227.56% and 183.44% in fresh weight of root from the initial to the final stage.

Table 26: Effect of nutrient deficiencies on fresh weight of root in sandal seedlings

Nutrient element deleted from complete solution	Fresh weight of root (gm)							
	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Month 7	Month 8
Nitrogen	0.137	0.176	0.211	0.249[b]	0.292[b]	0.339[b]	0.372[b]	0.408[b]
Phosphorus	0.127	0.172	0.207	0.249[b]	0.291[b]	0.331[b]	0.378[b]	0.416[b]
Potassium	0.151	0.185	0.233	0.268[b]	0.307[b]	0.350[b]	0.387[b]	0.428[b]
Control	0.115	0.188	0.279	0.346[a]	0.403[a]	0.470[a]	0.536[a]	0.583[a]
F – value	3.250 NS	0.261 NS	2.520 NS	5.198*	8.007**	10.147**	13.187**	20.120**
SEm +/-	0.009	0.014	0.021	0.02	0.019	0.02	0.021	0.018

* - significant at 5 %, ** - significant at 1 %, NS – non-significant
Values with the similar alphabets do not differ significantly.
Comparison is done within a column.

4.13.3 Dry weight of shoot

The impact of various treatments on dry weight of shoot is given in Table 27 and Fig. 20. This table shows the influence of various treatments on the dry weight of shoot of sandal seedlings right from the second month till the end of the study period. In the first month there was no significant difference in the dry weight of shoot between treatments. At the end of study period, the maximum value of dry weight of shoot (0.089 g) was observed in control while the minimum (0.074 g) was found in P deficient seedlings. The performances of N and K deficient seedlings were at par with each other at the end of the study period. Control dominated all the other treatments from the second month onwards till the end with regard to dry weight of shoot.

However, in the second and eight month the performance of K deficient seedlings was better than the N and P deficient seedlings; and the readings were also close to control in these two months. From the third to the seventh month of the application of treatments, the seedlings under different nutrient deficiency regimes did not differ significantly. However, in the seventh month, N deficient seedlings (0.075 g) performed better than the seedlings lacking P (0.072 g) and K (0.074 g). In the eight month, N (0.076 g) and K deficient seedlings (0.076 g) were at par from each other. An increase of 34.85% in dry weight of shoot was observed in seedlings under control from initial stage to the final stage. However, seedlings lacking N, P and K recorded respective increase of 18.75%, 17.46% and 15.15% in dry weight of shoot from initial to the final stage.

4.13.4 Dry weight of root

The dry weight of root was found to be significantly influenced by the deficiency of various nutrient elements, especially from the third month of the application of treatments. This can be seen from the data given in Table 28 and Fig. 21.

Table 27: Effect of nutrient deficiencies on dry weight of shoot in sandal seedlings

Nutrient element deleted from complete solution	Dry weight of shoot (gm)							
	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Month 7	Month 8
Nitrogen	0.064	0.066[b]	0.067[b]	0.070[b]	0.072[b]	0.074[b]	0.075[ab]	0.076[ab]
Phosphorus	0.063	0.064[b]	0.066[b]	0.067[b]	0.069[b]	0.071[b]	0.072[b]	0.074[b]
Potassium	0.066	0.067[ab]	0.068[b]	0.070[b]	0.071[b]	0.073[b]	0.074[b]	0.076[ab]
Control	0.066	0.070[a]	0.074[a]	0.077[a]	0.079[a]	0.082[a]	0.086[a]	0.089[a]
F – value	3.773 NS	6.300*	13.074**	12.965**	14.531**	13.657**	28.806**	33.478**
SEm +/-	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004

* - significant at 5 %, ** - significant at 1 %, NS – non-significant
Values with the similar alphabets do not differ significantly.
Comparison is done within a column.

Table 28: Effect of nutrient deficiencies on dry weight of root in sandal seedlings

Nutrient element deleted from complete solution	Dry weight of root (gm)							
	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Month 7	Month 8
Nitrogen	0.027	0.032	0.037^{b}	0.040^{b}	0.045^{b}	0.048^{b}	0.053^{b}	0.057^{b}
Phosphorus	0.026	0.030	0.034^{bc}	0.036^{c}	0.039^{c}	0.043^{c}	0.047^{c}	0.050^{c}
Potassium	0.025	0.029	0.032^{c}	0.035^{c}	0.037^{c}	0.040^{c}	0.042^{d}	0.045^{d}
Control	0.027	0.035	0.044^{a}	0.051^{a}	0.062^{a}	0.067^{a}	0.076^{a}	0.083^{a}
F – value	0.446 NS	1.613 NS	4.438*	12.276**	15.911**	9.897**	24.360**	25.313**
SEm +/-	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004

* - significant at 5 %, ** - significant at 1 %, NS – non-significant
Values with the similar alphabets do not differ significantly.
Comparison is done within a column.

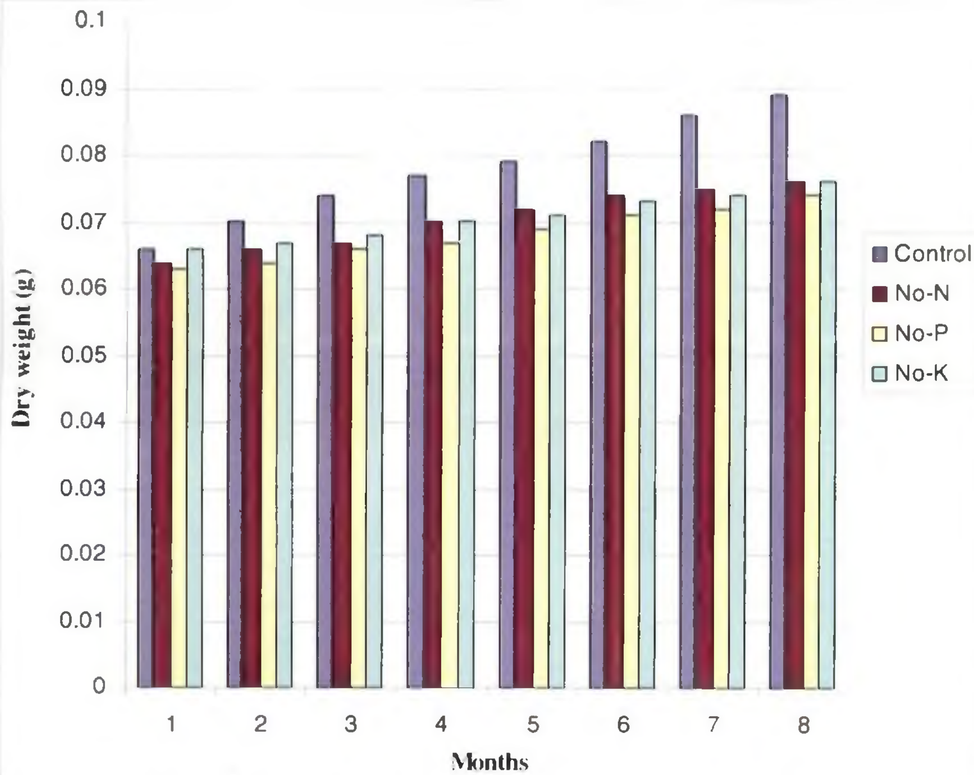

Fig. 20 : Effect of nutrient deficiency treatments on dry weight of shoot in sandal seedlings

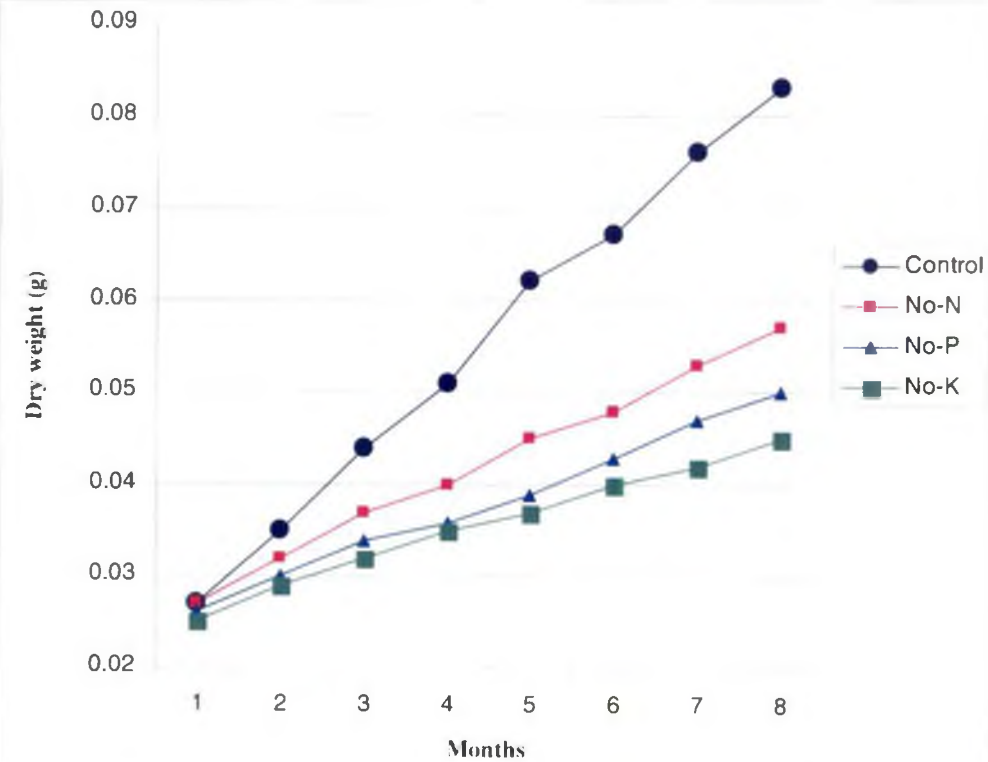

Fig. 21 : Effect of nutrient deficiency treatments on dry weight of root in sandal seedlings

In the first two months, the different treatments did not give any significantly different values. But at the end of the study period, the highest value was observed in control (0.083 g). This was followed respectively by N deficient seedlings (0.057 g), P deficient seedlings (0.050 g) and K deficient seedlings (0.045 g). Right from the third month till the end, control gave the best performance.

Observations at the end of third month revealed that among nutrient deficient seedlings, the best performance was shown by N deficient seedlings (0.037 g) followed by P (0.034 g) and K (0.032 g) respectively. However, seedlings deficient in P and K also showed significant difference in the third month where seedlings lacking P performed better than the K deficient seedlings. From fourth to sixth month, N deficient seedlings gave the best performance followed by P and K deficient seedlings which were at par with each other till that period. However, from the seventh month till the end of the study period, the best performance was still shown by N deficient seedlings among nutrient deficient seedlings followed by P and K deficient seedlings respectively. In the seventh month, seedlings lacking N reported dry weight of root as 0.053 g. However, seedlings deficient in P and K recorded dry weight of root as 0.047 g and 0.042 g respectively in the same month and they were also found to be significantly different. In the eight month, N deficient seedlings (0.057 g) produced significantly better value of dry weight of root as compared to seedlings lacking P (0.050 g) and K (0.045 g). In the same month, P and K deficient seedlings did not show any significant difference. An increase of 207.41% in dry weight of root was observed from initial to the final stage. However, seedlings lacking N, P and K recorded respective increase of 111.11%, 92.31% and 80% in dry weight of root from initial to the final stage. Hence, it can be seen that K deficient seedlings was highly affected by nutrient deficiency treatments at the end of the study period. Seedlings lacking N and P were also severely affected by the nutrient deficiency treatments during the study period.

4.14 Chlorophyll content

The chlorophyll content of leaves was found to be significantly influenced by the deficiency of various nutrient elements. The data related to chlorophyll content are tabulated in Tables 29, 30 and 31.

4.14.1 Chlorophyll-a

The amount of chlorophyll-a in the leaves had a significant effect due to the application of various treatments as shown in Table 29. In the first month, the values did not differ significantly. From the second month to the end of study period, control gave the best performance with regard to chlorophyll-a content. At the end (*i.e.* in eighth month) the chlorophyll-a content was the highest in control (0.417 mg/g). On the other hand, potassium deficient seedlings (0.329 mg/g) performed better than N (0.214 mg/g) and P (0.213 mg/g) deficient seedlings.

In nutrient depleted treatments, potassium deficient seedlings performed better than seedlings lacking N and P, starting from the second month till the end of study period. While starting from the second month to the end, N and P deficient seedlings performed at par with each other. In the second month, seedlings deficient in K recorded chlorophyll-a content of 0.335 mg/g and it was significantly higher than the chlorophyll-a content in N (0.326 mg/g) and P deficient seedlings (0.323 mg/g). On the other hand, seedlings lacking N and P were at par with each other in the same month. However, in the third month, potassium deficient seedlings had chlorophyll-a content of 0.346 mg/g and it was significantly better than seedlings under N (0.292 mg/g) and P deficient seedlings (0.296 mg/g). In the same month, however, N and P deficient seedlings were at par with each other as far as chlorophyll-a content was considered. The same trend continued till the fifth month. In the sixth month, potassium deficient seedlings (0.335 mg/g) performed significantly better than N (0.232 mg/g) and P deficient seedlings (0.222 mg/g) in term of chlorophyll-a content. In the same month, N deficient seedlings showed significantly better performance than P

Table 29: Effect of nutrient deficiencies on chlorophyll-a content (mg/g) in sandal seedlings

Nutrient element deleted from complete solution	Chlorophyll-a (mg/g)							
	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Month 7	Month 8
Nitrogen	0.345	0.326[b]	0.292[c]	0.269[c]	0.248[c]	0.232[c]	0.216[c]	0.214[c]
Phosphorus	0.352	0.323[b]	0.296[c]	0.277[c]	0.257[c]	0.222[d]	0.218[c]	0.213[c]
Potassium	0.342	0.335[ab]	0.346[b]	0.348[b]	0.346[b]	0.335[b]	0.329[b]	0.329[b]
Control	0.365	0.359[a]	0.379[a]	0.377[a]	0.392[a]	0.424[a]	0.408[a]	0.417[a]
F – value	1.883 NS	8.704**	108.096**	120.529**	202.360**	465.751**	394.116**	490.906**
SEm +/-	0.006	0.006	0.004	0.006	0.006	0.004	0.009	0.009

* - significant at 5 %, ** - significant at 1 %, NS – non-significant
Values with the similar alphabets do not differ significantly.
Comparison is done within a column.

deficient seedlings. In the seventh month, potassium deficient seedlings (0.329 mg/g) once again showed its better performance in term of chlorophyll-a content than N (0.216 mg/g) and P deficient seedlings (0.218 mg/g). However, nitrogen and phosphorus deficient seedlings were at par with each other in the same month as far as chlorophyll-a content was taken into consideration. The case was the same in the eight month with K deficient seedlings (0.329 mg/g) performing better than N (0.214 mg/g) and P deficient seedlings (0.213 mg/g).

4.14.2 Chlorophyll -b

The effect of chlorophyll-b content due to various treatments is given in Table 30. From the data, it can be concluded that chlorophyll-a content varied significantly from the first month till the end of study period. Control had the highest chlorophyll-b content beginning from the first month till the end with a value of 0.811 mg/g. At the final period of study, the lowest value of chlorophyll-b was observed in N deficient seedlings with a recorded value of 0.496 mg/g. Among the nutrient deficient seedlings the best performance was given by K deficient seedlings (0.628 mg/g) followed by P (0.575 mg/g) and N deficient seedlings (0.496 mg/g) respectively. These values differed significantly from each other.

Among the nutrient deficient seedlings, chlorophyll-b content in the first month varied statistically significantly. It was the highest in P deficient seedlings (0.709 mg/g) followed by N (0.675 mg/g) and K deficient seedlings (0.649). On the other hand, in the second month, P deficient seedlings performed significantly better than N and K seedlings and their recorded values being 0.681 mg/g, 0.639 mg/g and 0.623 mg/g respectively. In this month, the chlorophyll-b content in N and K seedlings were at par with each other. In the third month, the chlorophyll-b content differed significantly from each other with P deficient seedlings performing better than N and K deficient seedlings. Chlorophyll-b content in K deficient seedlings (0.642 mg/g) was higher than the chlorophyll-b content in N deficient seedlings (0.618 mg/g). In the fourth month, P (0.643 mg/g) and K

Table 30: **Effect of nutrient deficiencies on chlorophyll-b content (mg/g) in sandal seedlings**

Nutrient element deleted from complete solution	Chlorophyll-b (mg/g)							
	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Month 7	Month 8
Nitrogen	0.675[c]	0.639[c]	0.618[d]	0.592[c]	0.552[d]	0.516[d]	0.588[c]	0.496[d]
Phosphorus	0.709[b]	0.681[b]	0.658[b]	0.643[b]	0.623[c]	0.598[c]	0.628[b]	0.575[c]
Potassium	0.649[d]	0.623[c]	0.642[c]	0.647[b]	0.637[b]	0.632[b]	0.504[d]	0.628[b]
Control	0.742[a]	0.739[a]	0.770[a]	0.759[a]	0.788[a]	0.816[a]	0.800[a]	0.811[a]
F – value	17.334**	44.889**	278.890**	71.212**	721.976**	521.120**	506.822**	461.669**
SEm +/-	0.009	0.006	0.003	0.009	0.004	0.006	0.006	0.006

* - significant at 5 %, ** - significant at 1 %, NS – non-significant
Values with the similar alphabets do not differ significantly.
Comparison is done within a column.

(0.647 mg/g) deficient seedlings performed at par with each other followed by N deficient seedlings (0.592 mg/g). Potassium deficient seedlings performed better than N and P deficient seedlings in the fifth month and sixth months with recorded values of 0.637 mg/g and 0.632 mg/g respectively, followed by P (0.623 mg/g, 0.598 mg/g) and N deficient seedlings (0.552 mg/g, 0.516 mg/g) in descending order for the concerned two months. Whereas in the seventh month the chlorophyll-b content was maximum in P deficient seedlings (0.628 mg/g) which was followed by N (0.588 mg/g) and K deficient seedlings (0.504 mg/g); and the chlorophyll-b content also differed significantly in all the three nutrient deficient treatments in this month. In the final month the chlorophyll-b content varied significantly between nutrient deficient treatments. It was the highest in K deficient seedlings with a recorded value of 0.628 mg/g followed by P (0.575 mg/g) and N deficient seedlings (0.496 mg/g) respectively.

4.14.3 Total chlorophyll

The treatments showed considerable differences on the total chlorophyll content of the sandal seedlings and the data is presented in Table 31 and Fig. 22. The influence of different treatments could be seen from the first month itself till the end of the study period. At the final stage, the highest total chlorophyll was observed in control (1.232 mg/g) which was followed by K (0.960 mg/g), P (0.801 mg/g) and N deficient seedlings (0.712 mg/g) in the descending order. In the first and from the third to the eighth month, total chlorophyll content was found to be highest in control.

In the first month, control recorded the highest total chlorophyll content (1.112 mg/g). This was followed by P deficient seedlings (1.065 mg/g). The next highest chlorophyll content was found in seedlings deficient in N (1.029 mg/g) and it was followed by K deficient seedlings with recorded value of 0.995 mg/g. The performance of P deficient seedlings was found to be as good as that of control. Nitrogen deficient seedlings also gave a better value of total chlorophyll content which can be comparable with that of P deficient seedlings.

Table 31: Effect of nutrient deficiencies on total chlorophyll content (mg/g) in sandal seedlings

Nutrient element deleted from complete solution	Total chlorophyll (mg/g)							
	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Month 7	Month 8
Nitrogen	1.029[bc]	0.970[bc]	0.957[c]	0.867[d]	0.807[d]	0.751[d]	0.727[d]	0.712[d]
Phosphorus	1.065[ab]	0.961[c]	0.997[b]	0.998[b]	0.885[c]	0.825[c]	0.808[c]	0.801[c]
Potassium	0.995[c]	1.107[a]	0.918[d]	0.926[c]	0.988[b]	0.974[b]	0.963[b]	0.960[b]
Control	1.112[a]	1.009[b]	1.152[a]	1.142[a]	1.187[a]	1.244[a]	1.210[a]	1.232[a]
F – value	9.438**	23.782**	188.050**	112.504**	397.936* *	503.723**	569.516**	356.176**
SEm +/-	0.018	0.018	0.006	0.011	0.009	0.009	0.009	0.013

* - significant at 5 %, ** - significant at 1 %, NS – non-significant
Values with the similar alphabets do not differ significantly.
Comparison is done within a column.

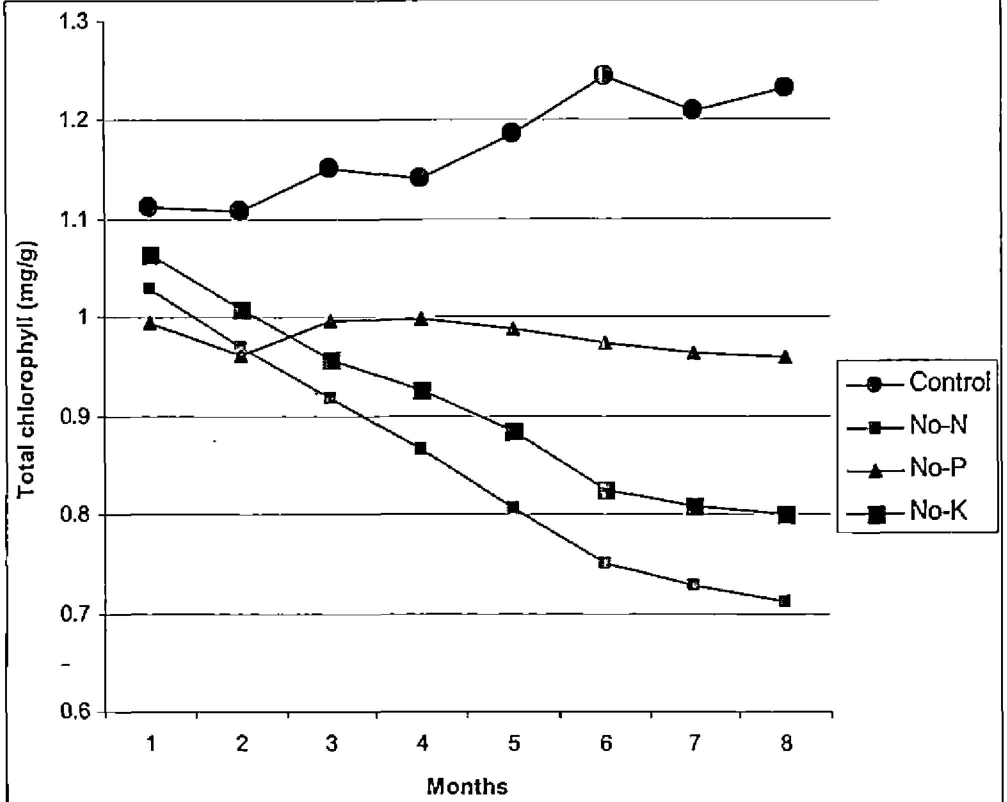

Fig. 22 : Effect of nutrient deficiency treatments on total chlorophyll content in sandal seedlings

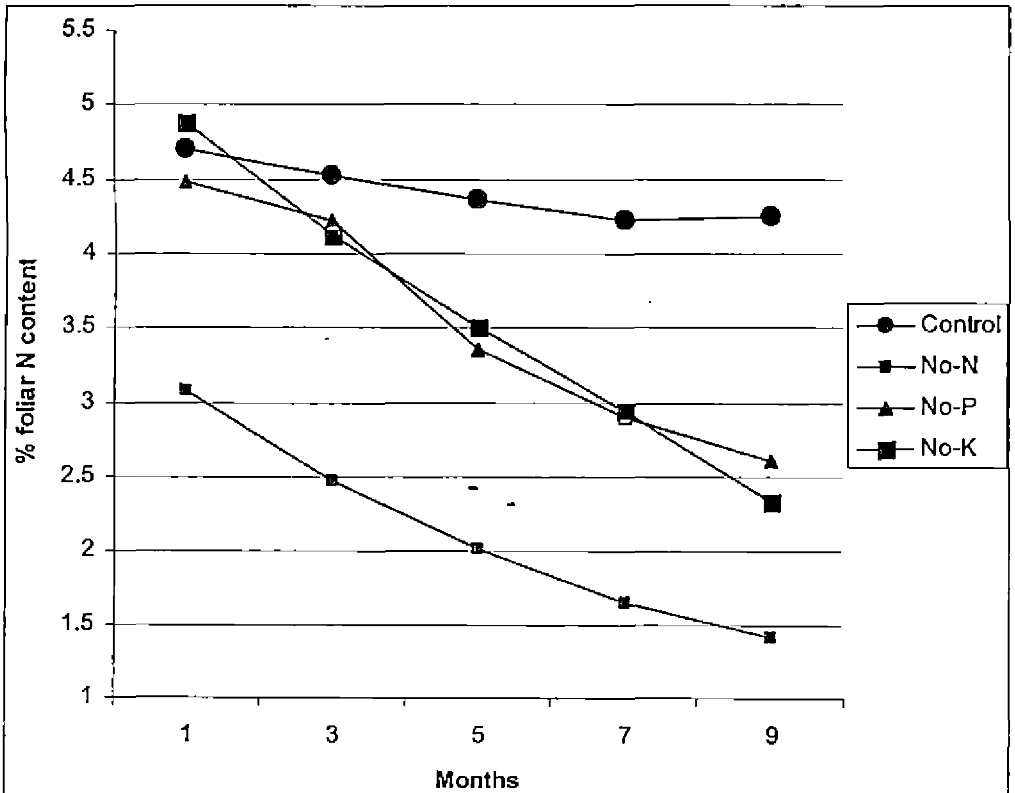

Fig. 23 : Effect of nutrient deficiency treatments on foliar nitrogen content in sandal seedlings

In the second month, the best performance was seen in seedlings deficient in K with a value of 1.107 mg/g which was even higher than the value of total chlorophyll content in seedlings under control condition (1.009 mg/g). This was followed by N (0.970 mg/g) and P deficient seedlings (0.961 mg/g).

From the third month till the end of study period, total chlorophyll content was found to be highest in control. Among the nutrient deficient seedlings, the best performance in the third month was produced by P deficient seedlings (0.997 mg/g) followed by N (0.957 mg/g) and P deficient seedlings (0.918 mg/g) in descending order. In the fourth month also the seedlings without P performed the best with a value of 0.998 mg/g and this was followed by seedlings deficient in K (0.926 mg/g) and N (0.867 mg/g). Whereas from the fifth month to the end of the study period, K deficient seedlings was the best in performance with regard to total chlorophyll content followed by P and N deficient seedlings.

4.15 Foliar tissue nutrient concentration

The effects of various treatments on foliar nutrient concentrations like N, P and K grown in sand culture and recorded at bimonthly intervals are presented in this section.

4.15.1 Nitrogen

The nitrogen content of leaves was found to decrease in sandal seedlings from the first month till the end of the study period supplied with various nutrient solutions including the control as shown in Table 32 and Fig. 23. In the nitrogen deficient seedlings, the N content gradually decreased from 3.08 to 1.417 per cent by the end of ninth month when the study was completed. Likewise the P deficient seedlings also recorded a gradual decrease in N content from 4.48 to 2.613 per cent in the end of study period. In the same manner the seedlings lacking K also had a decline in N content from 4.883 to-2.333 per cent at the end

Table 32: **Effect of nutrient deficiencies on foliar nitrogen content (per cent) in sandal seedlings**

Nutrient element deleted from complete solution	Nitrogen (per cent)				
	Month 1	Month 3	Month 5	Month 7	Month 9
Nitrogen	3.080[c]	2.473[c]	2.023[c]	1.650[c]	1.417[d]
Phosphorus	4.480[b]	4.217[ab]	3.360[b]	2.893[b]	2.613[b]
Potassium	4.883[a]	4.123[b]	3.500[b]	2.940[b]	2.333[c]
Control	4.697[ab]	4.527[a]	4.357[a]	4.217[a]	4.247[a]
F – value	124.795**	83.613**	107.431**	159.063**	816.713**
SEm +/-	0.073	0.101	0.093	0.083	0.041

* - significant at 5 %, ** - significant at.1 %, NS – non-significant
Values with the similar alphabets do not differ significantly.
Comparison is done within a column.

of study period. Control also showed a decrease in foliar N content from 4.697 to 4.247 per cent.

Nitrogen content also differed significantly due to the treatments for each month. In the first month K deficient seedlings had the highest per cent of N in their leaves with a recorded value of 4.883 per cent. The seedlings under control had a value of N content as 4.697 per cent which was lower than the N content in the K deficient seedlings by 3.81 per cent; and this was comparable with the N content of seedlings under K deficient treatment. This was followed by P and N deficient seedlings with values of N content as 4.48 per cent and 3.08 per cent in the descending order.

From the second month till the end of study period, the highest N per cent was found in seedlings under control. Among the nutrient deficient seedlings under various treatments lacking nutrients, the highest N content was found in seedlings lacking P (4.217 per cent) during the third month and this value was as good as that of the value of N content in seedlings deficient in K; and the lowest value was recorded in N deficient seedlings (2.473 per cent). In the fifth and seven months, the N contents in seedlings deficient in K (3.50 and 2.94 per cent) did not differ significantly with the N content of the seedlings lacking P (3.36 and 2.893 per cent); and the minimum value was observed in seedlings deficient in N (2.023 and 1.65 per cent) which were significantly different from the N contents of P and K. In the ninth month, the N content varied significantly from each other due to various nutrient deleted treatments. The highest value was observed in seedlings deficient in P (2.613 per cent) and it was followed in descending order by seedlings deficient in K (2.333 per cent) and N (1.417 per cent).

It can also be concluded that the change in N content was more abrupt in seedlings deficient in N which changed from the initial N content of 3.08 per cent to 1.417 percent, a decrease by 54 per cent from the initial value.

Table 33: **Effect of nutrient deficiencies on foliar phosphorus (per cent) content in sandal seedlings**

Nutrient element deleted from complete solution	Phosphorus (per cent)				
	Month 1	Month 3	Month 5	Month 7	Month 9
Nitrogen	0.237	0.357	0.353	0.330[a]	0.430[a]
Phosphorus	0.303	0.257	0.190	0.143[b]	0.093[b]
Potassium	0.240	0.330	0.390	0.410[a]	0.457[a]
Control	0.260	0.397	0.373	0.423[a]	0.520[a]
F – value	0.721 NS	2.764 NS	2.599 NS	14.193**	45.540**
SEm +/-	0.037	0.037	0.058	0.037	0.026

* - significant at 5 %, ** - significant at 1 %, NS – non-significant
Values with the similar alphabets do not differ significantly.
Comparison is done within a column.

Table 34: **Effect of nutrient deficiencies on foliar potassium (per cent) content in sandal seedlings**

Nutrient element deleted from complete solution	Potassium (per cent)				
	Month 1	Month 3	Month 5	Month 7	Month 9
Nitrogen	1.457	2.157[a]	2.280[a]	2.450[c]	3.097[b]
Phosphorus	1.553	2.523[a]	3.010[a]	2.870[b]	3.057[b]
Potassium	1.523	1.130[b]	0.733[b]	0.560[d]	0.343[c]
Control	1.387	2.623[a]	2.967[a]	3.497[a]	4.107[a]
F – value	0.695 NS	10.896**	8.618**	106.334**	104.158**
SEm +/-	0.089	0.207	0.362	0.122	0.158

* - significant at 5 %, ** - significant at 1 %, NS – non-significant
Values with the similar alphabets do not differ significantly.
Comparison is done within a column.

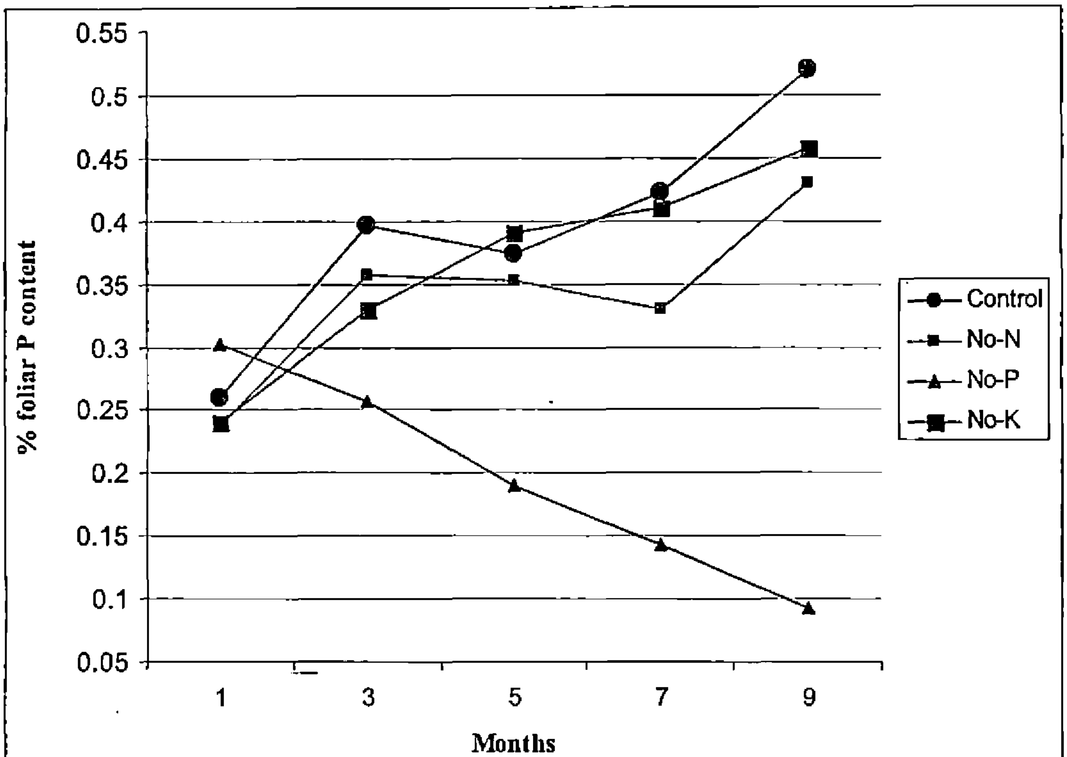

Fig. 24 : Effect of nutrient deficiency treatments on foliar phosphorus content in sandal seedlings

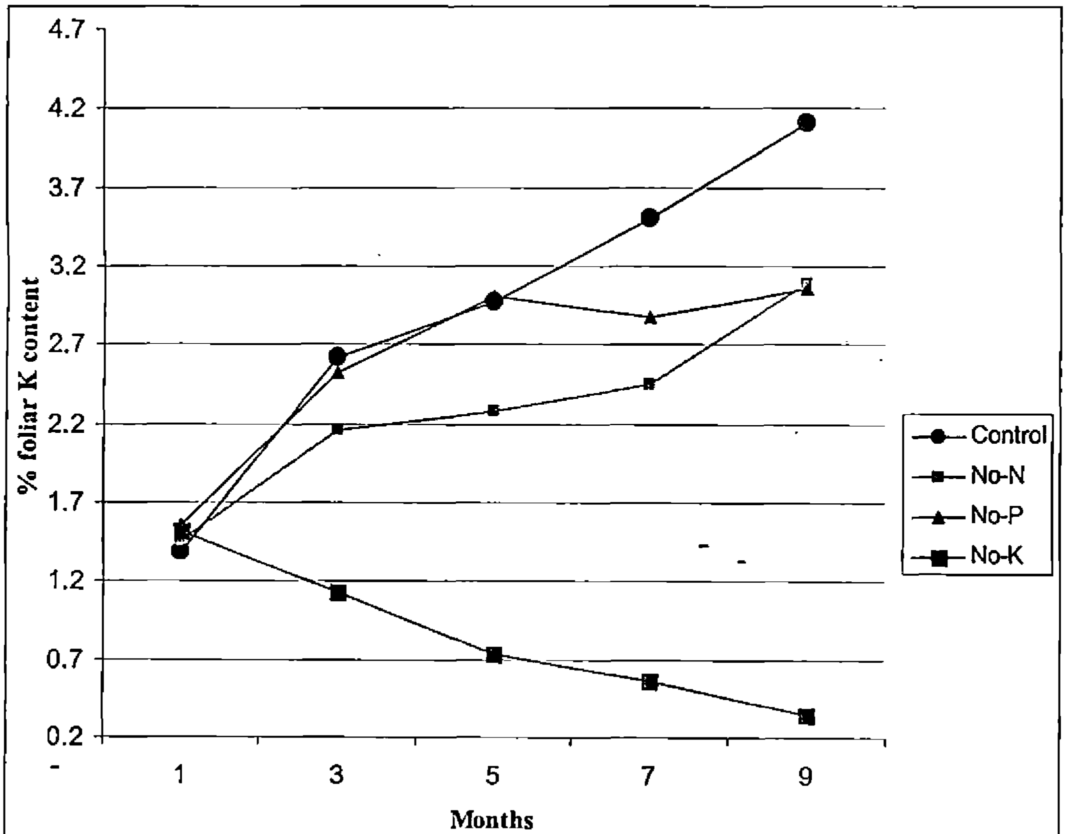

Fig. 25 : Effect of nutrient deficiency treatments on foliar potassium content in sandal seedlings

4.15.2 Phosphorus

The effect of various treatments on the P content of seedlings is given in Table 33 and Fig. 24. The phosphorus content under various treatments started to differ significantly from the seventh month till the ninth month. However, seedlings did not show any significant difference in foliar P content from the first month till the fifth month. In the seventh and the ninth months, the foliar P content in seedlings under control (0.423 and 0.520 per cent respectively) did not vary significantly when compared with seedlings grown under N deficient (0.330 and 0.430 per cent respectively) and K deficient conditions (0.410 and 0.457 per cent respectively). The lowest value was recorded in seedlings deficient in P in the seventh and ninth months (0.143 and 0.093 per cent respectively). The phosphorus content of leaves was found to decrease in seedlings supplied with nutrient solution lacking P. In these seedlings, the phosphorus content gradually decreased from 0.303 to 0.093 per cent by the end of the ninth month when the study was completed. An increase of 0.26%, 0.217% and 0.193 % in foliar P content was observed in seedlings under control, deficient in K and N respectively from the initial to the final stage. However, seedlings lacking P showed a decreasing trend from the first month till the ninth month with a value of 0.210%.

4.15.3 Potassium

The potassium concentration of seedlings as affected by the various treatments is furnished in Table 34 and Fig. 25. In the first month, the difference in the K content due to the treatments was not significant. Whereas in the third month, the K contents in the seedlings deficient in N (2.157 per cent) and P (2.523 per cent), and control (2.623 per cent) were at par with each other. In the same month, potassium deficient seedlings had the lowest K per cent in the leaves. In the fifth month also, the situation was the same. But a slight increase in K content was seen in seedlings under control (2.967 per cent), N (2.280 per cent) and P deficient seedlings (3.01 per cent). In the seventh month, all the seedlings under various treatments differed significantly from each other. The maximum value was put forth by seedlings grown under control (3.497 per cent) followed by P (2.87 per cent), N (2.45 per cent) and K deficient seedlings (0.56 per cent). In the ninth month, the seedlings under control condition gave the maximum value of K content (4.107 per cent). It was then trailed by seedlings deficient in N (3.097 per cent) and P (3.057 per cent), and they were at par with each other with regard to K content. The minimum value was recorded in K deficient seedlings (0.343 per cent) for the same month. A gradual decrease of K content in the seedlings deficient in K was observed and the change of K content from the initial to final stage was found to be 77.48 per cent. On the contrary, a gradual increase in K content was observed in seedlings grown under control condition.

4.16 Relative growth rate

The influence of different treatments on the relative growth rates of dry weight of shoot and dry weight of root are studied under this section.

4.16.1 Relative growth rate of dry weight of shoot

Table 35 gives the data on the RGR of dry weight of shoot as observed during the study. It can be concluded from the table that the values were significantly different only in the second and seventh months where control gave the best performance in both the months. All the nutrient deficient seedlings had the values of RGRs in both these months which were not significantly different. In the last stage, the maximum value was seen in seedlings grown under control condition (0.114 g/month) and the minimum value was recorded in the seedlings deficient in P (0.061 g/month). The RGR values of dry weight of shoot showed very less variation in most of the periods. Hence, it can be concluded that absolute growth rate of dry weight of shoot is a better sign of deficiency symptom as compared with the RGR of dry weight of shoot.

Table 35: **Effect of nutrient deficiencies on relative growth rate of dry weight of shoot in sandal seedlings**

Nutrient element deleted from complete solution	Relative Growth Rate of Dry Weight of Shoot (gm/month)						
	Month 2	Month 3	Month 4	Month 5	Month 6	Month 7	Month 8
Nitrogen	0.085[b]	0.067	0.114	0.110	0.076	0.045[b]	0.102
Phosphorus	0.071[b]	0.085	0.067	0.082	0.095	0.078[b]	0.061
Potassium	0.067[b]	0.065	0.080	0.047	0.077	0.076[b]	0.074
Control	0.195[a]	0.170	0.118	0.100	0.138	0.146[a]	0.114
F – value	6.255*	3.787 NS	2.591 NS	1.363 NS	2.497 NS	5.467*	0.994 NS
SEm +/-	0.026	0.026	0.018	0.026	0.018	0.018	0.026

* - significant at 5 %, ** - significant at 1 %, NS – non-significant
Values with the similar alphabets do not differ significantly.
Comparison is done within a column.

4.16.2 Relative growth rate of dry weight of root

The relative growth rate of dry weight of shoot seemed to be only significant in the third, fourth and fifth months where control gave the best results as depicted in Table 36. The maximum value recorded at the end of the study period was 0.003 g/month in seedlings grown under control condition.

In the third month, the RGR of nutrient deficient seedlings performed at par with each other. In the fourth month, among nutrient deficient treatments, the RGR of N (0.003 g/month) and K deficient seedlings (0.004 g/month) did not differ significantly and they were even comparable with the seedlings under control condition (0.006 g/month). In the same month, minimum value was recorded in P deficient seedlings (0.002 g/month). Among the nutrient deficient seedlings, the best RGR was found in N deficient seedlings (0.004 g/month) in the fifth month followed by P (0.0023 g/month) and K deficient seedlings (0.002 g/month).

4.17 Incremental Growth

The Incremental Growth (IG) of shoot length, root length and collar diameter are studied under this section.

4.17.1 Incremental growth of collar diameter

The effect of various treatments on the incremental growth of collar diameter in sandal seedlings is shown in Table 37. Except in the fifth month, the incremental growth of collar diameter due to different treatments did not vary significantly. The maximum incremental growth of collar diameter at the end of the study period was seen in N deficient seedlings (0.0026 mm/month). In the fifth month, the incremental growth of collar diameter was found to be significantly different and the highest value was observed in seedlings under control (0.004 mm/month) and the seedlings deficient in N (0.032 mm/month) performed at par with the seedlings under the control treatment. P and K deficient

Table 36: Effect of nutrient deficiencies on relative growth rate of dry weight of root in sandal seedlings

Nutrient element deleted from complete solution	Relative Growth Rate of Dry Weight of Root (gm/month)						
	Month 2	Month 3	Month 4	Month 5	Month 6	Month 7	Month 8
Nitrogen	0.007	0.004[b]	0.003[ab]	0.004[b]	0.002	0.003	0.002
Phosphorus	0.008	0.004[b]	0.002[b]	0.0023[bc]	0.003	0.003	0.002
Potassium	0.005	0.004[b]	0.004[ab]	0.002[c]	0.003	0.002	0.002
Control	0.008	0.008[a]	0.006[a]	0.006[a]	0.002	0.0047	0.003
F – value	1.647 NS	4.312*	4.204*	12.688**	0.606 NS	2.048 NS	0.825 NS
SEm +/-	0.002	0.001	0.0007	0.0005	0.0005	0.0005	0.0005

* - significant at 5 %, ** - significant at 1 %, NS – non-significant
Values with the similar alphabets do not differ significantly.
Comparison is done within a column.

Table 37: Effect of nutrient deficiencies on incremental growth of collar diameter in sandal seedlings

Nutrient element deleted from complete solution	Incremental Growth of Collar Diameter (mm/month)						
	Month 2	Month 3	Month 4	Month 5	Month 6	Month 7	Month 8
Nitrogen	0.006	0.003	0.003	0.0032[a]	0.0024	0.002	0.0026
Phosphorus	0.005	0.0023	0.003	0.002[b]	0.0026	0.0017	0.002
Potassium	0.005	0.0036	0.0022	0.002[b]	0.0026	0.002	0.002
Control	0.007	0.004	0.0034	0.004[a]	0.0035	0.0021	0.0023
F – value	2.472 NS	1.902 NS	1.632 NS	12.591**	2.471 NS	0.509 NS	0.893 NS
SEm +/-	0.0001	0.0001	0.0001	0.0002	0.0003	0.0002	0.0003

* - significant at 5 %, ** - significant at 1 %, NS – non-significant
Values with the similar alphabets do not differ significantly.
Comparison is done within a column.

seedlings did not differ significantly from each other during this month, but the performances of the seedlings under these nutrient deficient conditions were lower than the seedlings under control and N deficient treatments.

4.17.2 Incremental growth of shoot length

The incremental growth of shoot length in sandal seedlings as affected by various treatments is depicted in Table 38. During most of the time, the differences in the incremental growth of shoot length as influenced by treatments were not found to be statistically significant except in the second month. The control gave the best performance in the second month with regard to incremental growth of shoot with a recorded value of (1.154 cm/month). On the other hand, all the seedlings deficient in N, P and K did not differ significantly from each other for the same month. At the end of study period, the maximum value for incremental growth of shoot length was observed in N deficient seedlings (0.279 cm/month).

4.17.3 Incremental growth of root length

The incremental growth of root length due to the effect of nutrient stress is summarized in Table 39. The data revealed that the treatments were not having significant effect on the incremental growth of root length in the sandal seedlings throughout the period of study except in second month. At the end of study period (eighth month), the maximum value for relative growth of root length was observed in seedlings under control (0.324 cm/month). When the second month was taken into consideration, control performed the best with an incremental growth of root length as 0.958 cm/month, and the seedlings deficient in N, P and K were equally effective. The variation was found to be very less in IG of root length as compared to absolute growth rate of root length in sandal seedlings. Hence, better indication of deficiency symptoms can be provided by absolute growth rate of root length in sandal seedlings as compared to IG of root length.

Table 38: Effect of nutrient deficiencies on incremental growth of shoot length in sandal seedlings

Nutrient element deleted from complete solution	Incremental Growth of Shoot Length (cm/month)						
	Month 2	Month 3	Month 4	Month 5	Month 6	Month 7	Month 8
Nitrogen	0.490[b]	0.685	0.432	0.360	0.282	0.237	0.279
Phosphorus	0.556[b]	0.477	0.417	0.396	0.422	0.253	0.274
Potassium	0.474[b]	0.481	0.424	0.401	0.312	0.347	0.276
Control	1.154[a]	0.617	0.473	0.474	0.345	0.377	0.267
F – value	35.498**	3.161 NS	0.208 NS	1.573 NS	1.752 NS	3.397 NS	0.030 NS
SEm +/-	0.055	0.058	0.055	0.037	0.045	0.037	0.032

* - significant at 5 %, ** - significant at 1 %, NS – non-significant
Values with the similar alphabets do not differ significantly.
Comparison is done within a column.

Table 39: **Effect of nutrient deficiencies on incremental growth of root length in sandal seedlings**

Nutrient element deleted from complete solution	Incremental Growth of Root Length (cm/month)						
	Month 2	Month 3	Month 4	Month 5	Month 6	Month 7	Month 8
Nitrogen	0.546[b]	0.665	0.418	0.420	0.352	0.299	0.217
Phosphorus	0.388[b]	0.696	0.481	0.424	0.360	0.284	0.259
Potassium	0.467[b]	0.648	0.371	0.463	0.384	0.324	0.314
Control	0.958[a]	0.554	0.476	0.394	0.353	0.304	0.324
F – value	8.465**	1.345 NS	0.541NS	0.327 NS	0.157 NS	0.201 NS	2.807 NS
SEm +/-	0.088	0.052	0.071	0.052	0.037	0.037	0.032

* - significant at 5 %, ** - significant at 1 %, NS – non-significant
Values with the similar alphabets do not differ significantly.
Comparison is done within a column.

Discussion

DISCUSSION

The effects of light quality, quantity and nutritional deficiency on the seedlings of *Santalum album* L. were taken up in the present investigation. Studies on the transfer of photosynthates and anatomical studies of haustoria were also done. The salient findings of the studies are discussed hereunder.

EXPERIMENT NO. I

5.1 Growth behaviours

5.1.1 Shoot and root length

Shoot length was significantly affected by different shade levels. The seedlings grown under 75 per cent shade level gave the maximum value of shoot length (8.37 cm) at the end of the experiment when compared to seedlings grown under 25% shade, 50% shade and full sunlight. Incremental growth of shoot length was also significantly affected by different shade levels and higher IG of shoot length was found in seedlings under 50 and 75 per cent shade levels most of the time during the study period. The best combination of factors influencing shoot length in sandal seedlings was found to be 50 per cent shade and green light quality. The best combination of the factors with regard to IG of shoot length was found to be 50 per cent shade and green light quality most of the time during the study period. Bush and Auken (1987) reported that light intensity had substantial relationship with growth of aerial parts of plants in *Prosopis glandulosa*, especially at the seedling stage. The effect of shade levels on height growth varies with the nature of species. *Azadirachta indica* seedlings recorded more height growth when grown under full sunlight, whereas seedlings of *Leucaena leucocephala* performed better under 25 per cent shade (Vimal, 1993). Height growth of seedlings of *Dalbergia sissoo* and *Acacia* *catechu* was found to be the maximum when grown under 50 per cent shade conditions, as against *Casuarina equisetifolia* which performed well under unshaded conditions (Saxena *et al.*, 1995). Similarly Fairbarian and Neustein (1970) reported that seedlings of *Picea sithensis, Pseudotsuga menziesii, Tsuga heterophylla, Abies grandis, Picea abies* and *Abies alba* showed the highest shoot growth under 50 per cent shade. *Tilia tomentosa* was also found to record maximum height growth when grown under 50 per cent shade as reported by Lyapova and Palashev (1982). However, *Tectona grandis* and *Grevellia robusta* seedlings performed well under full sunlight conditions (Saju *et al.*, 2000). Yoo and Kim (1997) also reported that three cultivars of *Hibiscus syriacus* L. in Korea had longer shoot lengths when grown under shaded condition. Studies done by Oscinkoya and Ash (1992) with six species at 37, 10 and 2.5 per cent shades showed the positive effect of 37 per cent shade on shoot growth of all the species. Saju *et al.* (2000) also found that *Ailanthus triphysa* performed well under 75 per cent shade with regard to stem height. The better performance of shoot growth in *Santalum album* under 75 per cent shade in the present study suggests that this species requires shaded conditions for their height growth in the nursery stage. Kamalolbhavan (2002) too reported on the requirement of shade in the seedling stage of *Santalum album*. However, Barrett and Fox (1994) reported that plant height did not change significantly in response to varying shade levels. Thus, the present study proves that growth of shoot length and IG of shoot length in sandal seedlings are better in shaded condition and the best combination of the factors is 50 per cent shade and green light quality for the same growth parameters.

Root length was found to be affected significantly by the use of different levels of shades in the study. The highest value of root length was observed in seedlings under 50 per cent shade (7.16 cm) at the end of the study period which was an increase of 183% from initial to the final stage. This was followed by seedlings under 25 and 75 per cent shade levels which did not vary significantly from each other. Incremental Growth of root length was however unaffected by shading. It can be concluded that sandal seedlings need a moderate shade level for better absolute root growth. The best combination of factors influencing root length in sandal seedlings was found to be 50 per cent shade and green light quality. However, IG of root length was found to be unaffected due to the interaction of the factors. Chathurvedi and Bajpai (1999) also reported that root length was the maximum under semi shady condition in *Bridelia retusa* and *Holarrhaena antidysenterica* when they were grown under three light conditions viz., semi shade, shade and full sunlight. Prasad (2002) however reported that root growth was the best under 75 per cent shade in *Terminalia arjuna* during the seedling stage when grown under different light regimes *viz.* full sunlight, 25, 50 and 75 per cent shade levels. In the present study, main root length was found to be the maximum under medium shade condition *i.e.* 50 per cent shade. This may be due to the nature of the species which prefers moderate shade condition. Similar conclusions were also drawn by Chathurvedi and Bajpai (1999) in the seedlings of *Bridelia retusa* and *Holarrhena antidysentrica*, and by Prasad (2002) in the seedlings of *Terminalia arjuna*. Hence, the present study proves that growth of root length in sandal seedlings is better in moderate shade condition and under the combination of 50 per cent shade and green light quality.

Seedlings grown under green light quality recorded the highest root length (6.83 cm) and shoot length (8.78 cm) compared with seedlings under full sunlight, blue and red light qualities. Increase of 168.9% in root length and 90.04% in shoot length from initial to the final stage were observed in seedlings under green light quality. Incremental Growth of root length was unaffected by the use of different light qualities throughout the study period. However, IG of shoot length was found to be higher in seedlings under green light quality most of the time during the study period. Baiyeri (2006) also reported that plant height was the maximum in *Carica papaya* when grown under green polyethylene shade when it was grown under different light qualities *viz.* blue, green, yellow, red, colourless polyethylene, palm frond (*Elaeis guineensis* Jacq) and non-shaded frame. The better performance of sandal under green light quality in the present study may be due to the reason that rate of photosynthesis was always found to be higher in seedlings under green light quality which in turn might increase more biomass production in terms of shoot and root length. Mortensen and Sandvik (1988) reported that seedling of Norway spruce (*Picea abies* L.) grown under blue light with a high red/far-red ratio decreased shoot length. Seedlings under red light quality showed the minimum value in the present study as far as shoot length is concerned. Tinoco-ojanguren and Pearcy (1995) also found that *Cecropia obtusifolia* and *Heliocarpus appendiculatus* responded badly to R/FR in terms of greater height growth. Mateen and Simon (2005) also reported that antirrhinum plant showed maximum height when grown under blue absorbing light quality as compared to plants under different light qualities *viz.* 'red light', 'blue light', 'blue and red light' and two 'partially blue light' and one clear polythene as a control. The present study also showed that blue light quality performed significantly better than red light quality.

From the present study it can be concluded that growth of shoot and root length of sandal in nursery condition is better under green light quality.

5.1.2 Collar diameter

Collar diameter was also significantly affected by different light qualities and quantities at the end of study period. The seedlings grown under 50 per cent shade had the highest collar diameter (2.21 mm) when compared with the seedlings grown under full sunlight, 25 and 75 per cent shade levels. Incremental Growth of collar diameter was however unaffected by shading except in the sixth month. The combination of 50 per cent shade and green light quality was the best for the growth of collar diameter in sandal seedlings during the end of the study period. However, IG of collar diameter was found to be unaffected due to interaction of the factors. Vimal

(1993) also reported that seedlings of *Leucaena leucocephala* recorded more girth when grown under 25 and 50 per cent shade levels. Rezende *et al.* (1998) also noticed that growth of collar diameter in *Cryptocaria aschersoniana* seedlings grown under various light regimes *viz.* 0, 50, 70 and 90 per cent in the nursery was the best under 90 per cent followed by 50 per cent shade levels. A study by Saxena *et al.* (1995) also revealed that stem diameter per unit of dry weight of stem was higher in *Dalbergia sissoo, Acacia catechu* and *Casuarina equisetifolia,* when grown under high shade conditions. Prasad (2002) also reported that *Terminalia tomentosa* and *Terminalia bellerica* grown under 50 per cent shade recorded the maximum growth in collar diameter when the seedlings were grown under different light regimes *viz.* full sunlight, 25, 50 and 75 per cent shade levels. The present study proves that growth of collar girth is better under moderately shaded condition and under the combination of 50 per cent shade and green light quality.

Use of different types of light qualities also affected the collar diameter growth in sandal seedlings significantly. Seedlings under green light quality showed the best performance (2.20 mm) with regard to collar diameter, when compared to seedlings under full sunlight, blue and red light qualities. An increase of 139.13% in collar diameter was seen in seedlings under green light quality. The result of the present study also agrees with the findings of Baiyeri (2006) in *Carica papaya* where the best stem girth was shown by the plants under green polyethylene shade when it was grown under different light qualities *viz.* blue, green, yellow, red, colourless polyethylene, palm frond (*Elaeis guineensis* Jacq.) and non-shaded frame. This difference in collar diameter growth can be attributed to the fact that rate of photosynthesis was more in seedlings under green light quality (table 14) and hence addition of biomass in term of collar diameter might be more in this case. At the same time, the best level of light quality and temperature for the test crop might have been provided by the green light quality. Incremental Growth of collar diameter was however unaffected by different light qualities significantly *viz.* blue, green and red.

5.1.3 Root and shoot biomass

Root and shoot biomass *viz.* fresh weight of root, fresh weight of shoot, dry weight of shoot and dry weight of root were significantly affected by the different levels of shades and light qualities at the end of the study period. The highest fresh weight of shoot was observed in seedlings grown under 50 per cent shade (0.818 g) and 75 per cent shade level (0.789 g), and they were at par with each other. The least value of fresh weight of shoot was observed in seedlings under 25 per cent shade (0.724 g). The maximum dry weight of shoot at the end of study period was observed in seedlings under 50 per cent shade (0.171 g) followed by seedlings under 75 per cent shade (0.169 g) and 25 per cent shade (0.166 g). Relative Growth Rate of dry weight of shoot was also significantly affected by shading. The maximum RGR of dry weight of shoot was observed in seedlings under 50 (0.340 mg/month) and 75 per cent shade (0.334 mg/month), and they were at par with each other. The least value was observed in seedlings under full sunlight (0.197 mg/month). The best combination of different factors for the production of fresh and dry weight of shoot in sandal seedlings was 50 per cent shade and green light quality. The best combination for the RGR of dry weight of shoot in sandal seedlings was found to be 50 per cent shade and green light quality at the end of the study period. Control had the lowest values of fresh weight of shoot, dry weight of shoot and RGR of dry weight of shoot.

The highest fresh weight of root was recorded in seedlings under 50 per cent shade level (0.695 g) followed by seedlings under 25 per cent shade (0.639 g) and 75 per cent shade (0.615 g) in the seventh month. The dry weight of root was also found to be the maximum in seedlings under 50 per cent shade level (0.074 g) followed by seedlings under 25 per cent shade (0.065 g) and 75 per cent shade (0.071 g) at the end of the study period. At the same time, RGR of dry weight of root was also significantly affected by shading effect at the end of the study period with the maximum values in seedlings under 50 per cent shade (0.380 mg/month) and 75 per cent shade (0.374 mg/month). The minimum value of RGR for dry weight of root was recorded in seedlings under 25 per cent shade (0.243 mg/month). Sandal seedlings grown under full sunlight always showed lower values of fresh weight of root and dry weight of root. The combination of 50 per cent shade and green light quality was the best for the production of fresh weight of root. As far as dry weight of root and RGR of dry weight of root were concerned, the combinations of 50 per cent shade and green light quality, 75 per cent shade and green light quality and 50 per cent shade and red light quality were found to be at par and the best for the better production of dry weight of root.

Role of varying levels of shade in improving biomass has been reported by many workers earlier. Lyapova and Palashev (1982) reported that *Tilia tomentosa* produced greater aerial biomass under 50 per cent shade when it was grown under different shade conditions. Lyapova and Palashev (1988) also observed that seedlings of *Sorbus torminalis* performed the best under 50 per cent shade level with regard to biomass production while *Corylus avelana* performed equally well in both 50 and 25 percent light. Cornelissen (1992) studied the growth of *Gordonia acuminata* grown under four shade levels (55%, 33%, 18% and 0%) and observed the best growth to be at 33 per cent shade. Studies done by Oscinkoya and Ash (1992) with six species at 37, 10 and 2.5 per cent shades showed the positive effect of 37 per cent shade on shoot growth of all the species. In *Cupressus sempervirens* the maximum weight was produced under 75 per cent shade (Cregg and Teskey, 1993). Sharma *et al.* (1994) also found that fresh weight and dry weight of *Enicostemma littorale* were found to be the best under shaded condition as compared to plants grown under full sunlight. Saju *et al.* (2000) also found that seedlings of *Ailanthus triphysa* performed well under 75 per cent shade with regard to shoot dry weight. *Ailanthus triphysa* recorded maximum root dry weight under 25 per cent and minimum under full sunlight (Vimal, 1993). *Ailanthus triphysa* was also recorded to produce more root weight when grown under shade (Saju *et al.*, 2000). Ravindra (2007) also reported that the highest root biomass in *Mucuna pruriens* (L.) DC. was recorded in case of seedlings grown under 75 per cent shade followed by 50 per cent and 25 per cent shade levels. The study proves that shades in nursery have beneficial effect on the biomass production in sandal seedlings.

It can be concluded from the present study that sandal performs better under shaded conditions in nursery stage for the production of fresh weight (50 per cent shade and 75 per cent shade) and dry weight of shoot (50 per cent shade). At the same time, sandal prefers moderately shaded condition for the better production of fresh and dry weight of root during nursery stage.

When different light qualities were taken into consideration, it was seen that varying light qualities significantly affected the production of fresh weight of root, fresh weight of shoot, dry weight of shoot and dry weight of root at the end of the study period. However, RGRs of dry weight of root and shoot were not significantly affected by the use of different light quality. Fresh weight of root was found to be the maximum in seedlings under green light quality (0.684 g) in the seventh month with 521.82% increase from the initial value. Seedlings under blue (0.633 g) and red light qualities (0.631 g) were at par with each other with respect to fresh weight of root at the end of the study period. Seedlings under green light quality had the maximum fresh weight of shoot (0.838 g) at the end of the experiment. Seedlings under blue (0.744 g) and red light qualities (0.749 g) did not produce significant difference on the fresh weight of shoot. The maximum dry weight of shoot was seen in seedlings under green light quality (0.173 g) in the seventh month. Seedlings under blue (0.167 g) and red light qualities (0.166 g) were at par with respect to dry weight of shoot. At the same time, the maximum value of dry weight of root (0.075 g) was observed in seedlings under green light quality in the seventh month. Red and blue light qualities also produced significantly different dry weight of root (0.069 g and 0.067 g). However, control had the minimum values of fresh weight of shoot, fresh weight root, dry weight of shoot and dry weight of root. Hence, green light quality showed a positive effect in every aspect of biomass production. This may be due to higher rate of photosynthesis and more chlorophyll content in leaves in seedlings under green light quality. Similar result was found by Baiyeri (2006) in *Carica papaya* where fresh weight of root, stem and total dry matter yield of the seedlings grown under green polyethylene shade performed the best among various types of light qualities. Anderson and Martin (2005) however reported that fresh weight and dry weight of *Lemna minor* grown under green and blue plastic were lesser than the control (full sunlight) but better performance was given by the plant under red plastic. It was contradictory to the finding of the present study where sandal seedlings under green light quality performed the best under various light regimes *viz.* blue, red, green and open conditions. Alam *et al.* (2007) reported that RGR values in *Allium cape* were not significantly affected by the use of different light qualities *viz.* blue, red and control. This finding is parallel to the result obtained in the present study where RGRs of dry weight of root and dry weight shoot were not significantly affected. Hence, the present study proves that use of green light quality is more effective in the production of biomass as compared to blue light quality, red light quality and full sunlight.

5.1.4 Number of leaves

In the present study, shade had a significant impact on the production of number of leaves and seedlings under control had the minimum leaf number (11.33) at the end of the study period. The maximum number of leaves was observed in seedlings under 50 per cent shade (19.56) followed by 75 per cent (17.78) and 50 per cent shade (17.22), and they were at par with each other. However, the combination of 50 per cent shade and green light quality was found to be the best for the leaf production in sandal seedlings. The result of the present study is similar to the findings of Sharma *et al.* (1994) who reported that number of leaves in *Enicostemma* *littorale* was enhanced when grown under shade compared to full sunlight. However, Barrett and Fox (1994) reported that sandal seedlings grown under different shade conditions *viz.* full sun, 32%, 50%, 70% and 80% shade had no significant effect on the leaf number. Thus, it can be concluded from the present study that sandal seedlings produce less number of leaves under full sunlight.

Light quality provided significant effect on the number of leaves in sandal seedlings at the end of the study period. Seedlings under green light quality had the highest number of leaves (20.22) in the present experiment. Blue and red light qualities did not produce any significant difference in the number of leaves. Seedlings under full sunlight recorded the lowest value (11.33). Similar result was obtained by Baiyeri (2006) in *Carica papaya* where green polyethylene shade gave the highest leaf-count when grown under different light qualities. Zalewska and Wozny (2006) also reported that Chrysanthemums grown while exposed to blue light and short day demonstrated fewer leaves as compared with plants exposed to daylight. The positive effect of green light quality on sandal seedlings with respect to leaf number may be due to the fact that it has the best blend of the light quality and temperature regime needed by the plant. Thus, it can be concluded that the production of leaf in sandal is better under green light quality in nursery stage.

5.1.5 Root number

Production of secondary roots was affected significantly by the use of different types of light qualities in the present study. However, shade had a significant effect on root numbers of the sandal seedlings and the minimum number of secondary roots was observed in seedlings under control (11.00) at the end of the study period. However, seedlings under 25, 50 and 75 per cent shades were at par with each other with respect to secondary root numbers. Green light quality produced the maximum number of secondary roots (17.11) in sandal seedlings as compared to seedlings under full sunlight, blue and red light qualities in the seventh month. The higher number of secondary roots may be attributable to the high rate of photosynthesis under green light quality which in turn produced more biomass. At the same time, the green light quality might be providing the best blend of the light quality and temperature regime needed by the sandal seedlings. However, minimum number of secondary roots was observed in seedlings under control as compared to seedlings under different levels of shades and light qualities. The combination of different factors was found to be non-significant with regard to number of secondary roots in sandal seedlings. No recent research report on the effect of light on root number is available in the literature. Thus, it can be concluded from the present study that sandal seedlings produce minimum number of secondary roots under full sunlight. However, green light quality is the best at inducing the growth of more number of secondary roots.

5.2 Rate of photosynthesis

Rate of photosynthesis was also found to be affected by different shade levels and light qualities in the present study. Sandal seedlings under 25 and 50 per cent shade had the best rates of photosynthesis (24.698 μ mol $m^{-2} s^{-1}$ and 23.912 μ mol $m^{-2} s^{-1}$ respectively) and they did not vary significantly. Seedlings under control had the lowest rate of photosynthesis (4.673 μ mol m^{-2} s^{-1}). Rate of photosynthesis was always found to be lower in full sunlight condition when compared to seedlings under different shade levels. The combinations of 50 per cent shade and red light quality, 25 per cent shade and blue light quality were found to be the best with regard to rate of photosynthesis in sandal seedlings at the end of the study period. The result of the present study was opposite to the finding of Kuapp (1992) where the rate of photosynthesis of *Quercus macrocarpa* was found to be higher in full sunlight compared to the plants under shaded condition. Gross *et al.* (1996) also reported that net photosynthesis was higher in full sunlight when compared with shaded condition.

However, in the present study, it was found that sandal seedlings did not perform well under full sunlight all throughout the study period. This may be attributed to the fact that sandal is a shade loving species at nursery stage which can perform better under shaded condition as already reported by Kamalolbhavan (2002).

Green and red light qualities had significant effects on the rate of photosynthesis of sandal seedlings with recorded mean values of 23.919 μ mol m^{-2} s^{-1} and 25.176 μ mol m^{-2} s^{-1} respectively. The lowest rate of photosynthesis was observed in seedlings under blue light quality. However, rate of photosynthesis was always found to be lower in full sunlight condition when compared to seedlings under different light qualities. Zhang and Xu (2008) also reported that the photosynthetic rate under green film was the highest in the seedlings of ginger when compared to seedlings under white, red and blue film. In the same study, the authors also showed that blue light quality performed better than red light quality in ginger seedlings as far as photosynthesis was concerned. In the present study also, the rate of photosynthesis was also the best under green light quality, but seedlings under red light quality did not show significant variation in the rate of photosynthesis when compared with the seedlings under green light quality. This was contradictory to the findings of Zhang and Xu (2008) who reported that the rate of photosynthesis was the lowest in ginger seedlings under red light quality. However, Saebo *et al.* (1995) also reported that *Betula pendula* recorded the highest photosynthetic capacity when exposed to blue light and lowest when irradiated with light high in red and/or far-red wavelengths. The photosynthetically active region of the spectrum of light is at wavelengths 400-700 nm. In the red and blue regions of the spectrum, plants show high photosynthesis. However, most effective wavelengths differ with different plants. Plants show high photosynthesis in the blue and red light most of the time (Malik, 2002). However, in the present study sandal seedlings under green and red light qualities had the highest rate of photosynthesis. At the same time, seedlings under blue light quality gave the lowest rate of photosynthesis. Sandal seedlings under green light quality were also found to contain more chlorophyll in its leaf portions and hence it may give a positive effect on the rate of photosynthesis. The high rate of photosynthesis under green and red light qualities may be due to the fact that seedlings under these colours got the best blend of the light quality and temperature needed for photosynthesis in sandal.

5.3 Chlorophyll content

In the present study chlorophyll content was significantly affected by different levels of shades and light qualities. When shade was taken into consideration a gradual increase in chlorophyll content was seen in seedlings under 50 per cent shade level from first month to the seventh month. Seedlings under 25 and 50 per cent shade levels had the highest total chlorophyll content (with respective values of 0.789 mg/g and 0.775 mg/g) without any significant differences in the seventh month. Seedlings under 50 per cent shade also had the highest chlorophyll-a content (0.285 mg/g) in the seventh month. An increase of 14.39 per cent in chlorophyll-a content from initial to the final stage was recorded in the seedlings under 50 per cent shade. However, chlorophyll-b content was found to be the highest in seedlings under 25 per cent shade level (0.502 mg/g) and when it was compared with the seedlings under full sunlight it had 39.06% more chlorophyll content in the leaves in the seventh month. Seedlings under control had the lowest chlorophyll contents as compared to seedlings under different shade levels. Chlorophyll-a content in sandal seedlings was found to be the maximum in the combination of 50 per cent shade and green light quality throughout the study period. However, seedlings under the combinations of 50 per cent shade and green light quality and 25 per cent shade and green light quality were found to contain more chlorophyll-b and total chlorophyll in their leaves as compared to other combinations. Gross *et al.* (1996) also reported that the chlorophyll content of oak saplings was found higher under shade compared to saplings grown under open condition. Barrett and Fox (1994) however found that sandal seedlings had more total chlorophyll content which were grown under 80% shade level compared with the seedlings under full sun, 32%, 50% and 70% shade. Nygren and Kellomaki (1983) reported an increase in the chlorophyll content in seedlings of *Betula pendula* and *B. pubscens* with increasing shade. As the quantity of light available under shade is less, more photosynthetic pigments are required to trap the available light. Thus, under shade, plants are adapted to increase the chlorophyll content in order to keep up the carbon assimilation as reported by Niinemets (1997). This view is also supported by the findings of Saju *et al.* (2000). Johnston and Onwueme (1998) reported that tropical root crops compensate shade by production of more chlorophyll in leaves, when grown under shaded conditions. Shaded plants normally compensate the reduction in light by an increase in radiation use efficiency *i.e.* by increasing chlorophyll content in leaves. Increases in chlorophyll content (mass basis) are also an adaptive and common response to shade, since they can provide a higher light harvesting capacity in low-light environments (Lei *et al.,* 1996; Lei and Lechowicz, 1997). This may be the probable reason for higher chlorophyll content in sandal seedlings under shaded conditions as compared to seedlings under full sunlight in the present study.

Seedlings under green light quality also contained the highest amount of chlorophyll-a (0.293 mg/g), chlorophyll-b (0.514 mg/g) and total chlorophyll (0.810 mg/g) at the end of the study period when compared to seedlings under full sunlight, blue and red light qualities. Seedlings under blue light quality performed better than red light quality when chlorophyll-a and total chlorophyll contents were taken into consideration. However they did not show any significant difference as far as chlorophyll-b was considered. Seedlings under control had the minimum chlorophyll contents as compared to seedlings under different light qualities. Contrasting result was obtained by Alam *et al.* (2007) who reported that the highest total chlorophyll content was obtained under red light quality followed by blue light quality when onion plant was grown under blue light quality and red light quality. However, the author also reported that control treatment produced the lowest total chlorophyll content in the same study, which is similar to the present observations. Similar result was also observed by Islam *et al.* (2000) who studied the effect of different light qualities on *cattleya* orchid. Saebo *et al.* (1995) also reported that the highest chlorophyll content in *Betula pendula* was found in cultures irradiated with blue light. Alam *et al.* (2007) reported that chlorophyll-a content was not affected significantly by three light qualities *viz.* blue light quality, red light quality and control (full sunlight). Islam *et al.* (2000) also reported that chlorophyll-a content in *cattleya* orchid was not significantly affected by different light qualities. However, in the present study, the light qualities provided significantly different values where green light quality was the best in having the maximum chlorophyll-a content, and blue and red light qualities were at par with each other. In the present study, different light qualities significantly affected the chlorophyll-b content in sandal seedlings. Green light quality provided the best effect. It was followed by seedlings under blue and red light qualities and they were also significantly different from each other. This was contradictory to the finding of Alam *et al.* (2007) who found that the highest amount of chlorophyll-b content was obtained under red light quality which was significantly higher over other treatments *i.e.* blue light quality and control (full sunlight). Similar result as found by Alam *et al.* (2007) was also reported by Islam *et al.* (2000) in *cattleya* orchid. The result of the present study was also similar to the findings of Zhang and Xu (2008) who reported that shading with green or blue film induced the greatest chlorophyll content in ginger leaves, followed by shading with white film and red film. Thus, it can be concluded from the present study that seedlings under green light quality have a positive effect on chlorophyll content of the sandal leaves.

EXPERIMENT NO. II

5.4 Anatomical studies

From the anatomical studies of haustoria in connection with different host plants *viz. Tectona grandis, Casuarina equisetifolia* and *Theobroma cacao*, it can be concluded that they formed close connections with the sandal haustoria. But the better formation of clasping fold was observed in sandal-Casuarina association even though the sandal seedlings were of the same age and planted with the host plants at the same time. This may be due to better host-sandal interactions physiologically. The formations of clasping folds were also incomplete in all the sandal-host associations and it may be due to the reason that the sections were taken from the sandal-hosts associations at an earlier stage. Hence, it may also be assumed to form complete clasping folds at the later stages. Barber (1906), Taide (1991) and Varghese (1997) also observed direct vascular connections between host and sandal roots through haustoria. Taide (1991) opined that the vascular connections between the host and sandal become so intimate that the host root and parasitic root become almost a single physiological unit catering to the nutritional requirements of sandal.

Varghese (1997) also found that sandal haustoria established intimate vascular connections with the good host casuarina as well as the bad host erythrina. Taide (1991) observed lack of well developed haustorial connections between sandal and host species like acacia, ailanthus and emblica with poor growth of sandal associated with them. The same author also reported that the success in establishing a contact depends on the disintegration of the thick cortex layer in the root of the host plants. Hence, it can be concluded that sandal forms haustorial connections with most of the host species.

5.5 Translocation of photosynthates

From the radioactivity study, it is clear that the transfer of photosynthates took place from the selected host plants to sandal seedlings and the amount of transfer also varied from one host species to another host species. The maximum amount of ^{14}C transfer was found in sandal seedlings grown along with *Casuarina equisetifolia* with a percentage transfer of 86.76 per cent. Other host species like *Pongamia pinnata* and *Terminalia bellerica* with respective percentage transfer of 79.42 and 74.99 were also found to be good in the transfer of photosynthates. However, species like *Dalbergia latifolia* and *Pterocarpus marsupium* with 16.74 % and 32.63 % transfer of ^{14}C respectively to sandal seedlings were the worst performers in this experiment. Varghese (1997) also found that transfer of carbon compounds from hosts to sandal occurred. Kunda *et al.* (1974 a, b) also indicated transfer of organic substances between sandal and hosts. However, the amount of ^{14}C transfer from *Casuarina equisetifolia* to sandal seedlings was very low (0.05 per cent) in the experiment conducted by Varghese (1997) as compared to the result of the present study. In the same experiment, the author found that erythrina transferred about 5.5 per cent of the ^{14}C fixed by it to sandal seedlings. Hence, a precise method for knowing the amount of ^{14}C transfer from hosts to sandal seedlings need to be developed in order to avoid such difference in the count rates.

EXPERIMENT NO. III

5.6 Deficiency symptoms and uptake pattern of various nutrient elements

5.6.1 Nitrogen

5.6.1.1 Visual deficiency symptoms and growth behaviour

The initial symptom of nitrogen deficiency was the development of yellow chlorotic patches in the older leaves of the seedlings. It was seen developing by the end of the sixth month and it started to become larger by the eighth month. The first chlorotic spot appeared as a very small yellow spot at the tip of the leaves and it gradually became enlarged towards the base of the leaves. The seedlings were also stunted in growth compared to control plants.

Chlorophyll content was also found to decline gradually in these seedlings. Nitrogen deficient plants incidentally recorded the lowest chlorophyll-b (0.496 mg/g) and total chlorophyll content (0.712 mg/g). Similarly the chlorophyll-a content was also found to decline gradually in these seedlings throughout the study period. The reduction in the chlorophyll content of chlorotic leaves due to N deficiency was also reported by Nazeem (1989) in nutmeg, Anoop (1993) in ailanthus and Varghese (1997) in teak. Chlorosis of the older leaves and stunting of the growth are the common visual symptoms of N deficiency observed in tree crops (Jones, 1975). Nitrogen is reported to be mobile inside the plant system and hence, its deficiency leads to the movement of this element from older leaves to younger ones resulting in the development of symptoms first on the older leaves (Gauch, 1972). Chlorosis of older leaves was as a result of inadequate supplies of nitrogen for chloroplast protein synthesis (Greulach, 1973). These types of visual symptoms were observed by Landis *et al.* (1989) in seedlings of paper birch. Maskell *et al.* (1953) reported stunted growth, yellowing of older leaves, dieback and reduced rate of leaf production in young seedlings of cocoa. Similar types of visual symptoms for nitrogen deficiencies were also reported in citrus (Jones and Embleton, 1959), coffee (Muller, 1966), avocado (Jones, 1975), apple (Pant *et al.*, 1976), nutmeg (Philip, 1986), cashew (Gopikumar and Aravindakshan, 1988), ailanthus (Anoop, 1993) and teak (Varghese, 1997). Reduction in the chlorophyll content was also observed in *Santalum album* by Barrett and Fox (1997).

Nitrogen deficiency had pronounced effect on the growth behaviour of seedlings, particularly with regard to shoot growth. Shoot growth parameters like height, collar diameter and number of leaves recorded at monthly intervals were lower in these seedlings than those grown in complete nutrient solution. In fact, at the end of the study period, the height of these seedlings was found to be 26 per cent less compared to control. Incremental Growths of root and shoot length were also found to be lower in nitrogen deficient seedlings as compared to seedlings which received complete nutrients during most of the occasion of the study. Incremental Growth of collar diameter was always lower in nitrogen deficient seedlings when comparison was done with seedlings under control. In cashew seedlings grown in sand culture also, N deficiency resulted in reduced height, girth and leaf production of the seedlings (Gopikumar and Aravindakshan, 1988). Similar observations were also made in ailanthus (Anoop, 1993) and teak (Varghese, 1997). The various growth parameters like shoot and root length, leaf number, fresh mass and dry mass were also found to be reduced in sandal seedlings due to the lack of nitrogen by Barrett and Fox (1997).

In the present study, shoot fresh and dry weights were respectively 28.35 per cent and 14.61 per cent lower in N deficient seedlings compared to control. Lockard and Asomaning (1964) also observed low dry matter content in seedlings of cocoa grown under N stress. The number of secondary roots produced by N deficient seedlings in this study was 16.67 per cent lower compared to control. Similarly, the fresh weight of the root system in this treatment was the lowest in relation to rest of the treatments. However, the dry weight of root showed a decrease of 31.33 per cent from the seedlings under control. Relative Growth Rates of dry weight of root and shoot were always found to be lower than those of the seedlings under control during most of the months.

The reduction in vegetative growth may be due to the fact that nitrogen supply largely controlled the use of carbohydrates and determined whether the plant will make vegetative or reproductive growth (Kraws and Kraybill, 1918 and Jones, 1975). In addition, nitrogen is also reported to be involved in various other processes associated with protoplasm, enzymatic reactions and photosynthesis (Gauch, 1972 and Jones, 1975).

5.6.1.2 Tissue nutrient concentration

Visual deficiency symptoms in seedlings supplied with treatment solution lacking nitrogen concurred with a significant reduction in the foliar concentration of N in these seedlings. By the end of the study the nitrogen concentration fell to 1.417 per cent from the initial content of 3.08 per cent. This coincided with the acute stage of deficiency when the some of the seedlings appeared chlorotic followed by premature drying. The present results are also in agreement with the findings of Lockard and Asomaning (1964), who observed typical symptoms of N deficiency in cocoa seedlings when the tissue content of N was reduced to 0.96 per cent. Similar results were obtained with N deficient ailanthus seedlings (Anoop, 1993) and teak seedlings (Varghese, 1997).

5.6.2 Phosphorus

5.6.2.1 Visual deficiency symptoms and growth behaviour of seedlings

Symptoms of phosphorus deficiency first appeared on the fifth month after the treatments were initiated. Here the oldest leaves were affected first. Initially, small patches of bronze colouration were observed on the upper portion of the older leaves. At the sixth month, it spread gradually to the younger leaves. The new leaves were of pale yellow colouration. Stunted shoot growth was also observed.

The chlorophyll content decreased gradually as the level of deficiency progressed as seen in nitrogen deficient seedlings. In the tree seedlings similar symptoms were also observed by other workers. In apple, P deficiency symptoms are expressed as small dark green leaves with bronze to purple tinge, sparse foliage and restricted branching (Wallace, 1953). The study conducted at the University of Florida by Childers (1966) also revealed the development of bronze foliage in citrus and strawberry. Bingham (1975) explained the manifestation of P deficiency in tree species as slow growth, sparse, dull bronze to purple tinted foliage and early dropping of leaves. Development of bronze green lower leaves with purple and necrotic blotches followed by defoliation have been described as symptoms of P deficiency in nutmeg (Philip, 1986) while reddish pink colouration of older leaves and stunting of growth have been reported in red maple (Landis *et al.*, 1989). According to Driessche (1989) in Douglas fir and white spruce seedlings, P deficiency resulted in dull, greyish coloured or purple foliage. Appearance of purple bronze patches in older leaves which later extend to entire leaflet was the symptoms of P deficiency observed in ailanthus (Anoop, 1993) and teak (Varghese, 1997).

Since P is a mobile element, deletion of this element from the nutrient solution resulted in its translocation from older leaves to younger tissues, manifesting the P deficiency symptoms to appear first in the older leaves. Phosphorus deficiency is reported to result in the formation and accumulation of anthocyanin pigments which results in the development of purple colouration (Muller, 1966; Gauch, 1972 and Resh, 1978). Greulach (1973) based on his studies stated that reduced quantities of ATP, NAD, NADP and various other P containing compounds resulted in the decrease and disruption of metabolic pathways which was manifested as stunted growth of the plant. It is also to be noted that P is an important structural component of the chloroplasts and hence its deficiency have contributed a lower content of chlorophyll in leaf tissues finally resulting in typical discolouration. Swan (1971) is of the opinion that P deficiency symptoms are extremely variable between species and sometimes even within the species and therefore this problem is difficult to diagnose from visual symptoms alone.

In the present study, shoot growth parameters such as height, collar diameter, leaf production, IG of collar diameter, IG of root length, RGR of dry weight of root and dry weight of shoot were significantly affected by P deficiency. Height growth was lower in these seedlings (5.93 cm) compared to control (7.80). Towards the end of the study, P deficient seedlings had the lowest collar diameter with a difference of 27.22 per cent compared to seedlings that received complete nutrient solution. Leaf production was 9.07 per cent less compared to control seedlings. The lower number of leaves in P deficient plants might have resulted from the premature defoliation as has been reported by other workers. Childers (1966) also observed early droppings of leaves in avocado, citrus and strawberry due to P deficiency. The sand culture studies conducted by Gopikumar and Aravindakshan (1988) in cashew, Anoop (1993) in ailanthus and Varghese (1997) in teak also revealed similar outcome for P deficiency.

Like shoot growth parameters, P deficient seedlings recorded lower shoot fresh and dry weights during the study period compared to control. Such reductions in shoot growth parameters have also been observed in cocoa (Lockard and Asomaning, 1964), cashew (Gopikumar and Aravidakshan, 1988), clove (Nazeem, 1989), ailanthus (Anoop, 1993) and teak (Varghese, 1997). The retardation in growth could be explained by the fact that like N, P also plays an important role as a structural component of cell constituents and other metabolically active compounds (Greulach, 1973 and Agarwala and Sharma, 1976). It is also an established fact that P is the major controlling factor for energy in all living cells and as a constituent of nucleoproteins it is also concerned with cell division (Epstein, 1978).

Length of the main root of seedlings was found to be affected due to P deficiency. Compared to seedlings that received all the nutrients, P deficient seedlings had 24.14 per cent lesser root length. The number of roots was the lowest in seedlings deficient in phosphorus (12.67 cm). Fresh and dry weights of roots were also found in seedlings grown in phosphorus deficient solution. These results are in agreement with a study made by Narayanan and Reddy (1982) wherein they observed a decrease in dry weights in 12 tree species out of 14 studied. Restricted root growth on account of P deficiency was also reported by Childers (1966) in avocado, citrus and strawberry. However, an increase in length of primary and secondary roots was also observed by Narayanan and Reddy (1982) in 12 tree species.

5.6.2.2 Tissue nutrient concentration

In P deficient seedlings, the concentration of P in the leaf tissues decreased gradually as visual deficiency symptoms progressed. In the acute stage of deficiency, P concentration reduced to a very low value of 0.093 per cent. In cashew (Gopikumar and Aravindakshan, 1988), nutmeg (Philip, 1986), Douglas fir and white spruce (Driessche, 1989), ailanthus (Anoop, 1993) and teak (Varghese, 1997) also observed a gradual reduction in foliar concentration of P with the advancement of visual deficiency symptoms. Phosphorus deficiency caused an increase in the foliar levels of N and K. Similar results were reported in apple and nutmeg by different authors. In apple, Matsui *et al.* (1977) noted a negative correlation of P level with K content and in nutmeg. Philip (1986) reported an increase in foliar concentration of N when P was deleted from the nutrient solution.

Deletion of phosphorus from the treatment solution increased the nitrogen concentration in the leaves of seedlings and interestingly it was high (0.430 per cent) in those seedlings at the end of the ninth month. Antagonistic effect of nitrogen and phosphorus has been reported in various crops by several workers (Smith, 1966 in citrus; Dewaard, 1969 and Nybe, 1986 in pepper).

5.6.3 Potassium

5.6.3.1 Visual deficiency symptoms and growth behaviour of seedlings

Curling of leaves was seen in sandal seedlings in the seventh month grown in sand culture deficient in potassium. Younger leaves were first affected by the deficiency of potassium. At the extreme stage of deficiency it showed drooping of leaves and the seedlings finally died. This type of symptom was similarly found in apple where yellowish green leaves curled upward along the entire leaf (Anon., 1998). Backward curling of leaf margin was also found in potato, which was deficient in potassium by Wallace (1953).

The amount of chlorophyll content did not vary much in the seedlings growing in sand culture where potassium was deleted at the end of the study period as compared to other treatments. Though K activated the synthesis of chlorophyll, an increased partitioning of K to the chloroplast has been reported as the reason for no substantial reduction in chlorophyll content and photosynthetic rates in K deficient plants (Capron *et al.*, 1982).

In the present study, the reduction in height, collar diameter, number of leaves and secondary roots and the main root length was found when compared to control. At the same time, lesser IGs of collar diameter, dry weight of root, dry weight of shoot and root length were seen in seedlings grown under potassium deficient condition as compared to control. In cashew, absence of K adversely affected all the shoot growth parameters except the girth of seedlings (Gopikumar and Aravindakshan, 1988). Similar trends in relation to height, leaf and dry matter production as a result of K deficiency have been reported in nutmeg (Philip, 1986), ailanthus (Anoop, 1993) and teak (Varghese, 1997).

The property of K to occur primarily in the ionic form or as charged particles on colloidal surfaces has made it most apt to function as a catalyst or as a co-factor of one or more of many enzymatic reactions of living cells (Ulrich and Ohki, 1975). It also activates protein synthesis and N metabolism (Mulder and Bakema, 1956). This is reported to have a direct influence on cell division resulting in a higher cell number as suggested by Boringer and Schacherer (1982).

5.6.3.2 Tissue nutrient concentration

Potassium deficiency was associated with a decrease in the initial foliar content of K from 1.523 to 0.343 per cent at the end of the study. Visual symptoms of potassium were reported to be concurred with reduced levels of K in foliages of cashew (Gopikumar and Aravindakshan, 1988), nutmeg (Philip, 1986), ailanthus (Anoop, 1993) and teak (Varghese, 1997). Decrease in foliar K content was earmarked with increase in foliar N and P content in sandal seedlings in the present study. Antagonistic effect of K and P was also reported by Anoop (1993) in ailanthus and Varghese (1997) in teak grown in sand culture. Anoop (1993) also reported that decrease in foliar K content increased foliar N concentration in ailanthus seedlings. This finding also agrees with the result of the present study.

Summary

SUMMARY

The effects of light quality and quantity, nutritional deficiency symptoms, transfer of photosynthates and anatomical studies of haustoria in the seedlings of *Santalum album* L. were taken up in the present investigation in College of Forestry, Kerala Agricultural University, Vellanikkara, Thrissur during the year 2006-2008. The basic objectives included understanding the effects of various nutrient deficiencies and light quality and quantity on the growth behaviour of sandal seedlings. Radioisotopic study was conducted with a view to understand the transfer of photosynthates from host species to sandal seedlings. Anatomical study was taken up for elucidating the anatomy of sandal haustoria when grown together with different host species.

The salient results of the present investigations on the effect of light quality and quantity on the growth of sandal seedlings are summarised below:

1. Shoot growth parameters *viz.* shoot length, collar diameter and leaf number were significantly affected by the different light qualities and quantities. Growth of shoot length in sandal seedlings was better in shaded condition. Among the light qualities, growth of shoot in sandal in nursery condition was better under green light quality. Growth of collar girth was better under 50 per cent shade whereas sandal seedlings preferred green light quality for better growth of collar diameter in the nursery stage. With regard to leaf number, sandal seedlings preferred shaded condition and green light quality for better leaf production, when different levels of shades and light qualities are taken into consideration individually. The best response with regard to shoot growth parameters was observed in sandal seedlings under the combination of 50 per cent shade and green light quality.

2. Root growth parameters *viz.* main root length and number of secondary roots were significantly affected by the use of different light qualities and shade levels. Growth of root length in sandal seedlings was better in moderately shaded condition and green light quality when different levels of shades and light qualities were considered separately. Sandal seedlings produced minimum number of secondary roots under full sunlight. Green light quality was the best at inducing the growth of more number of secondary roots. The maximum root length in sandal seedlings was found to be under the combination of 50 per cent shade and green light quality. Incremental Growth of root length was unaffected by the different combination of the factors.

3. Sandal performed better under shaded conditions in nursery stage for the production of fresh weight of shoot, fresh weight of root, dry weight of shoot and dry weight of root. Use of green light quality was found to be more effective in the production of biomass. The best combination of different factors for the production of fresh weight of shoot, dry weight of shoot, fresh weight of root and RGR of dry weight of shoot in sandal seedlings was 50 per cent shade and green light quality. The combinations of 50 per cent shade and green light quality, 75 per cent shade and green light quality and 50 per cent shade and red light quality were found to be at par and the best for the better production of dry weight of root and RGR of dry weight of root.

4. Rate of photosynthesis in sandal seedlings was found to be affected significantly by the different levels of shades and light qualities. Sandal seedlings showed better rate of photosynthesis under 25 and 50 per cent shade levels. Seedlings under green and red light qualities had positive influence on rate of photosynthesis. The combinations of 50 per cent shade and red light quality, 25 per cent shade and blue light quality were found to be the best with regard to rate of photosynthesis in sandal seedlings at the end of the study period.

5. Chlorophyll content in sandal seedlings was significantly affected by the different light qualities and light quantities in the nursery stage. Chlorophyll content in the leaves of sandal seedlings was more under shaded condition. Sandal seedlings under 25 and 50 per cent shade levels recorded the highest total chlorophyll content whereas seedlings under 50 per cent shade also had the highest chlorophyll-a content. Chlorophyll-b content was the maximum in sandal seedlings under 25 per cent shade level. Green light quality had a positive impact on the chlorophyll content in sandal leaves as compared to other types of light qualities. Chlorophyll-a content in sandal seedlings was found to be the maximum in the combination of 50 per cent shade and green light quality throughout the study period. Sandal seedlings under the combinations of 50 per cent shade and green light quality and 25 per cent shade and green light quality were found to be at par and the best with regard to chlorophyll-b and total chlorophyll content in their leaves.

The salient results of the present investigations on the effect of nutrient deficiency on sandal seedlings are summarised below:

1. Characteristics visual symptoms were manifested by the seedlings at different levels of deficiencies of nitrogen, phosphorus and potassium.

2. For nitrogen, the initial visual symptom of deficiency was yellowing of older leaf tips which became conspicuous at the sixth month and reached up to one fifth of the whole leaf portion by the end of the study period. Stunting of growth was also observed. Phosphorus deficiency symptoms also appeared first on the older leaves as small patches of brown colouration which spread to the younger leaves at the later stages. Colour of the leaves also became pale yellow. Stunting of growth was also observed in the phosphorus deficient seedlings.

Curling of lower leaves was the initial symptom of potassium deficiency and seedlings started to die in the acute stage.

3. Vegetative growth was also affected by the deficiency of various nutrient elements. Among the shoot growth parameters studied, height and collar diameter produced by the seedlings were found to be significantly influenced by nutrient deficiency. However, nutrient deficiency did not significantly affect the leaf number during the study period. Deficiency of nitrogen, phosphorus and potassium in the sandal seedlings resulted in the reduction of height. Collar diameter was also reduced significantly in nutrient deficient sandal seedlings. The minimum collar diameter growth at the end of the study period was observed in seedlings deficient in phosphorus and potassium. Incremental Growth of shoot length and collar diameter was however unaffected by the various nutrient deficiency treatments.

4. Fresh weight and dry weight of shoot portion were significantly affected by different nutrient deficiencies. Potassium deficient seedlings showed the lowest value of fresh weight of shoot. Nitrogen deficient seedlings performed better than phosphorus deficient seedlings in terms of fresh weight of shoot in the eighth month. The minimum value of dry weight of shoot was observed in seedlings deficient in phosphorus at the end of the study period. However, seedlings lacking nitrogen and potassium were at par with each other with regard to dry weight of shoot at the end of the study period. Relative Growth Rate of dry weight of shoot was not affected by the different nutrient deficiency treatments except in the second and seventh months.

5. Root growth parameters *viz.* root length, number of secondary roots, fresh weight and dry weight of root were significantly affected by the different treatments. Root length of seedlings lacking different

nutrients were at par with each other and significantly differed from control. Nitrogen deficient seedlings performed better than phosphorus and potassium deficient seedlings at the end of the study period. The lowest performance was shown by seedlings deficient in phosphorus. Fresh weight of root under different nutrient deficient treatments was recorded to be at par with each other significantly differed from control. Nitrogen deficient seedlings also recorded higher dry weight of root among other nutrient deficient seedlings at the end of the study period. The lowest value was observed in seedlings under potassium at the end of the study period. Relative Growth Rate of dry weight of root was not significantly affected by the treatments except in the third, fourth and fifth months.

6. The chlorophyll content of the leaves was found to be significantly affected by the deficiency of various nutrient elements. The amount of chlorophyll-a, chlorophyll-b and total chlorophyll decreased gradually during the study period except in the control. The reduction in all fractions of chlorophyll content in the leaves with the advancement of yellowing of leaves in nitrogen deficiency was very pronounced in the present study.

7. Visual deficiency symptoms of seedlings were concurred with marked reduction in foliar levels of the concerned elements. Compared to seedlings that received all the nutrients through the complete solution, the seedlings showing deficiency symptoms had significantly lower levels of the concerned elements.

The salient results of the present investigations on the transfer of photosynthates from host species to sandal seedlings and anatomical studies of haustoria when grown together with different host species are summarised below:

1. From the radioactivity study it can be concluded that transfer of photosynthates takes place from the host plants to sandal seedlings and the amount of transfer varies from one host species to another host species. The maximum amount of transfer was seen in sandal-casuarina association. Sandal-pongamia and sandal-terminalia associations also showed better transfer of photosynthates as compared to sandal-dalbergia and sandal-bijasal associations. The lowest transfer of photosynthates was however observed in sandal-dalbergia combination.

2. From the anatomical studies of sandal haustoria in connection with different host species (*viz. Casuarina equisetifolia, Tectona grandis* and *Theobroma cacao*), it was observed that they formed close connections with the sandal haustoria. The better formation of clasping fold was observed in sandal-casuarina association.

Hence, it can be concluded from the above experiments that 50% shade level is the best for the growth of sandal seedlings in nursery stage with regard to various growth parameters. Green light quality has also positive effects on the various growth parameters of sandal seedlings in nursery stage. The best sandal-host combination which shows better translocation of photosynthates and better haustorial connection is sandal-casuarina combination.

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Appendices

Appendix i: Meteorological data (mean monthly)

Source: Department of Agricultural Meteorology, KAU, Vellanikkara.

Months	Max. Temperature (°C)		Min. Temperature (°C)		RH (%)		Rainfall (mm)		Rainy days		Sunshine (hr.)		Wind speed (km/hr.)	
	2007	2008	2007	2008	2007	2008	2007	2008	2007	2008	2007	2008	2007	2008
January	32.5	32.3	22.0	21.7	54	59	0.0	0	0	0	268.5	292.9	9.2	7
February	34.0	33.6	22.2	22.9	55	61	0.0	29.7	0	3	275.5	236.9	4.9	4.5
March	36.0	33.2	24.4	23.4	63	64	0.0	205.3	0	7	254.4	212.5	4.3	4.8
April	35.1	-	25.0	-	69	-	61.0	-	4	-	230	-	4.3	-
May	32.8	-	24.6	-	76	-	240.5	-	10	-	205.1	-	3.7	-
June	30.1	-	23.5	-	84	-	826.5	-	23	-	105.5	-	3.8	-
July	28.4	-	22.9	-	88	-	1131.9	-	28	-	22.1	-	3.2	-
August	29.0	-	22.8	-	84	-	549.7	-	19	-	100.5	-	2.7	-
September	29.4	-	22.9	-	86	-	765.9	-	23	-	75.1	-	3.0	-
October	30.5	-	22.5	-	79	-	383.8	-	14	-	135.2	-	3.2	-
November	31.7	-	21.6	-	67	-	24.8	-	3	-	239.2	-	4.5	-
December	31.6	-	22.7	-	56	-	8.7	-	1	-	207.1	-	8.6	-

Appendix ii: The composition of Hoagland No. 2 (Hoagland, 1948) nutrient solution

Complete solution (Stock solution)	Quantity pipetted ml/litre (Working solution)
$NH_4H_2PO_4$ (1M)	1
KNO_3\KCl (1M)	6
$Ca(NO_3)_2$\$CaPO_4$ (1M)	4
$MgSO_4 . 7H_2O$ (1M)	2
Boric Acid (2.86 g/l)	1
$MnCl_2 . 4H_2O$ (1.81 g/l)	1
$ZnSO_4 . 7H_2O$ (0.28 g/l)	1
$CuSO_4 . 5H_2O$ (0.08 g/l)	1
Molybdic Acid (0.02 g/l)	1

INFLUENCE OF HOST, LIGHT AND MINERAL NUTRITION ON THE GROWTH OF SANDAL SEEDLINGS
(*Santalum album* L.)

By

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ABSTRACT OF THE THESIS

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ABSTRACT

Studies on the effects of light quality, quantity and nutrient deficiency on the growth of sandal seedlings were conducted in College of Forestry, Kerala Agricultural University, Vellanikkara, Thrissur during the year 2006-2008. Radioisotopic study to understand the transfer of photosynthates from the host plants to sandal seedlings and anatomical studies of sandal haustoria were also taken up during the investigation.

Sandal seedlings had better shoot growth parameters (*viz.* shoot length, collar diameter and leaf number), root growth parameters (*viz.* root length and number of secondary roots), biomass production and chlorophyll content under shaded condition and green light quality when different light qualities and quantities are taken into consideration individually. Sandal seedlings also had better rate of photosynthesis under shaded condition. As far as different light qualities are concerned, rate of photosynthesis was better under red and green light qualities. Generally, the combination of 50 per cent shade and green light quality was found to give the maximum values of different growth parameters and chlorophyll content in leaves of sandal seedlings. The combinations of 50 per cent shade and red light quality and 25 per cent shade and blue light quality were found to be the best with regard to rate of photosynthesis in sandal seedlings at the end of the study period

Characteristic deficiency symptoms produced by seedlings due to deficiency of N, P and K include yellowing of older leaf tips, formation of brown spots in leaves and change in leaf colouration, curling of leaves and stunting of growth. The seedlings that received complete nutrient solution were healthy with dark green foliage. Vegetative growth of the seedlings was also found to be affected due to the nutrient stress. Nitrogen deficient seedlings showed a decline in all the fractions of chlorophyll during the study period. Visual deficiency symptoms of the nutrient

elements also coincided with a corresponding reduction in foliar levels of the concerned element.

Radioisotopic study showed that transfer of photosynthates takes place from the host plants to sandal seedlings and the amount of transfer varies from one host species to another host species. Anatomical studies showed that sandal roots can establish close vascular connections with host roots through haustoria.