INFLUENCE OF HOST PLANTS AND SOIL MOISTURE STRESS ON THE WATER RELATIONS IN SANDAL

By

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THESIS

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DECLARATION

I here by declare that this thesis entitled "**Influence of host plants and soil moisture stress on water relations in sandal**" is a bonafide record of research work done by me during the course of research and that this thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title of any University or Society.

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Dedicated to my Parents and Friends

INTRODUCTION

1. INTRODUCTION

Sandal (*Santalum album* Linn.) a medium sized semi parasitic tree is the source of aromatic East Indian sandalwood and oil. The heartwood of sandal has a characteristic odour as it contains aromatic oils. The oil is widely employed in fragrance industry particularly in high priced perfumes. Both the oil and wood are used in incense and medicine; besides the wood is used in carving (Srinivasan *et al.*, 1992).

Distribution of sandal

The genus *Santalum* consists of 25 species distributed between 30° North and 40° South from India in the West and Juan Fernandez in the East, from Hawaiian archipelago in the North and New Zealand in the South (Srinivasan *et al.*, 1992). *Santalum* species is characterized by two main features viz., obligate semi parasitism and aromatic heartwood. They vary greatly in habitat from small shrubs to large trees (Radomiljac, 1994). The commercially valuable sandalwood *Santalum album* occurs naturally in Southern India and islands of Eastern Indonesia, notably Timor. Both the countries are major producers of East Indian sandalwood oil (Fox *et al.,* 1994).

In India sandal is found mainly in the Deccan plateau and its extension and in small numbers in almost all regions except Himalayas. Large natural stands of sandal occur in Karnataka (5245 km^2) and Tamilnadu (3040 km^2) accounting for nearly about 90 per cent of sandal in India (Venketasan, 1981). Sandal forest in Kerala are chiefly distributed in Anjaanad valley in the Eastern side of western Ghats falling in the Marayoor forest range of Munnar forest division with an extent of 15.42 km^2 in the reserved forest and 47.26 km^2 in the revenue lands (Mathew, 1995). Limited distribution of sandal is also seen in Aryankavu and Kasargod forest ranges

Production of sandalwood in India has declined from 3000 tonnes per annum during 1995 to around thousand tonnes in 1997. Similarly oil production also declined from 140 tonnes in 1985 to 40 tonnes in 1995 (Jain *et a*l., 1999).

The establishment of sandal populations was mostly not successful due to various reasons. Being a semi parasite the silvicultural requirement of sandal are unique and there are no complete understanding of these requirements. The regeneration and establishment of sandal has been problematic due to poor understanding of the host parasitic relationship (Surendran *et al.*, 1998). So the understanding of the complementary and competitive influences of the host on the sandal is necessary for the successful growing of sandal plantations. There are no reports on the growth response of sandal grown with different host under different soil moisture regime. Hence the present study was carried out with following objectives

1. To evaluate complementary and competitive influence of the host on the growth of sandal seedlings
2. To study the influence of water stress on the growth of sandal seedling when grown with different hosts.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

Sandal (*Santalum album* Linn.) is a valuable evergreen forest tree noted for its highly priced scented heartwood. It is a semi-parasite usually reaching a height of 13.5 m to 16.5 m and girth of 1.0 m to 1.5 m. Sandal is distributed mostly in Southern states of India (Karnataka, Tamilnadu and Kerala). In Kerala, it is seen in the dry tracts of Marayoor.

2.1 REGENERATION OF SANDAL

Sandal produces flowers and fruits twice a year (September/October and March/April) and is capable of regenerating profusely in the sandal tracts of open forests. Fresh seeds have a dormancy of about 2 months and retain their viability up to 12 months. The seeds normally take 4-8 weeks to germinate and the dispersal of the seeds is usually by birds (Venketasan, 1995). Sandal is managed in the natural forests under physical rotation, dead and fallen trees are periodically extracted. Occurrence of fire, excessive grazing, hacking and encroachments often hamper the efficiency of the natural regeneration (Venketasan, 1981).

Artificial regeneration of sandal is achieved by dibbling of seeds in pit, sowing in mounts, trenching around the mother trees for wounding the roots for obtaining the root suckers, and planting of nursery raised, vegetatively multiplied and raised seedlings (Rai and Kulkarni, 1986).

Vegetative propagation is achieved through stem cutting, grafting, air layering or through suckers. But rooting is achieved only in 15-20% of the cuttings (Rao and Srimathi, 1976 and Balasundaran, 1998).

As heart wood formation is genetically controlled it is desirable to obtain seeds from genetically superior trees for developing a successful artificial regenerating programme and improving the productivity of the sandal (Srinivasan *et al.*, 1992).

2.2 SANDAL AND HOST

The semi-parasitic nature of sandal was first established by Scot (1871). Later many scientists described the parasitic nature of sandal (Barber, 1902 and 1907; Pilger, 1935 and Rao, 1942). The scientists also found haustorial connections of sandal with roots of other plants growing near by (Barber, 1902; Rao, 1903 and Lushington, 1904).

The sandal haustoria were developed on lateral roots and are exogenous in nature. Haustorium is formed by the epidermal cortex of root (Rao, 1942). Haustoria is derived from roots by the divisions of cells of pericycle, endodermis and cortex (Pilger, 1935)

The young haustorium appears as small hemispherical outgrowth after coming in contact with host root and the free end of the haustorium flattens gradually. Sandal roots reach a distance of 30 m for establishing haustorial connections with the roots of host plant (Rai and Sarma, 1986). Rao (1911) reported that the structure and extent of haustoria is influenced by the type of host plant. The anatomical studies of sandal haustorium showed that sandal roots and host have direct vascular connections, which later undergo secondary growth (Taide, 1991).

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

2.3 HOST SPECIFICITY

The presence of a suitable host is considered to be necessary for the establishment and good growth of the sandal. Several scientists have identified different hosts of sandal and classified them. 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 and also at various stages of plantation growth. Characteristics of suitable pot host include fine root growth and even distribution of roots within the pot. Rao (1948) opinioned that good and bad host of sandal can only be differentiated when grown individually with host differed on the basis of selective tendency of haustorium and based on this experiments he classified the host into three classes.

Host selection and its management require close investigation, as it is the single most important silvicultural parameter deciding the establishment and growth of sandal plantation. Srinivasan *et al.*, (1992) has recommended *Cajanus cajan* as a good primary host for sandal in the seedling stage where as 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 host for the establishment of sandal plantation. The favoured host species reported are *Calotropis procera, Cassia siamea, Calliadra calothyrus* (Shinde *et al.*, 1993), *Cajanus cajan* (Rai, 1990) and *Casuarina equisetifolia* (Taide, 1991 and Varghese, 1996). Radomiljac (1998) reported that considerable variation exists between pot host in increasing the sandal survival and growth.

Barber (1907) gives a list of 122 species and Rao (1918) for 144 species of sandal host. Out of a large number of associates of sandal found in its natural habitat it is difficult to classify the most favorable host species as sandal may show preference for different plants in different situation.

2.4 THE ROLE OF HOST

The role of host plants on the growth of sandal tree has aroused a lot of curiosity among 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 nitrogen and phosphorous, where as it can directly absorb calcium and potassium. Rangaswamy *et al.*, (1986) suggested that sandalwood depend on its host for phosphorous, potassium and magnesium and that in the absence of a host plant, it is incapable of growing normally. Ananthapadmanabha *et 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 and Mg.

Kamalolbhavan (2002) investigated the occurrence of sandal - Arbuscular Mycorrhizal Fungi (AMF) associations in natural sandal growing forests and the response of sandal seedlings to inoculation with commonly available cultures of AMF, shade levels and nature of host in a pot culture experiment.

Self-parasitism, a phenomenon in which a plant establishes haustorial connections with the same species was also observed in sandal (Iyengar, 1965). Comparative analysis of leaves of sandal plants grown independent or with host show appreciable differences in the mineral make up 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 their growth (Rangaswamy *et al.*, 1986).

2.5 INFLUENCE OF WATER STRESS

Water is considered as the most important limiting factor for the establishment and growth of trees in dry areas, which form about 75 per cent of total cultivated area in India. Water deficits can have a major impact on the establishment of seedlings (Stoneman *et al.,* 1994). Water deficits influences all the phases of tree growth and are probably responsible for more growth loss than all other causes combined (Kramer, 1980).

The primary effects of water deficits include a decrease in water content and cell turgor of plant tissue and a decrease in the free energy status or potential of remaining water. Tree growth is reduced both directly and indirectly, through effects on cell turgor and indirectly through the intermediation of seed germination, photosynthesis, respiration, mineral nutrition, enzymatic activity, hormone relation, nitrogen metabolism etc. Though some studies on the response of agricultural and horticultural crops to water stress (Giles *et al.*, 1974; Alberte *et al.,* 1977; Evans, 1983; Kramer, 1983; Turner *et al.,* 1986 and Momen *et al.*, 1992) are available, such studies are limited in forestry species, especially in tropical forestry. The reported findings pertinent to the present investigation are reviewed here.

2.5.1 Growth parameters

Water stress was observed to reduce the collar diameter of sandal seedlings (Hiremath, 2004). Driessche (1991) observed a drastic reduction in height growth and dry weight of *Pseudotusuga menzeisii, Pinus contorta* and *Picea glauca* seedlings in response to water stress. Waring and Schlensinger (1985) suggested that decreasing predawn water potential could be well correlated with a decreased tree height at maturity. Water stress also decrease the seedling growth of pine (Cannel *et al.*, 1978).

After the seedling stage the effect of water deficit on shoot growth become more complex and depend mostly on the growth habitat. A summer drought may or may not influence current year height growth depending on when the water stress occur and on the inherent pattern of shoot elongation of the species affected (Kozlowski, 1982). One of the damaging effects of water stress is the reduction in leaf area, which not only reduces the water loss but also reduces the surface that carries on photosynthesis. Most of the reduction in leaf area because of drought appears to result from slowing cell expansion. Water deficits were found to reduce the leaf area of sandal (Hiremath, 2004).

Restricted water supply caused a five fold reduction in the number of leaves per plant and a reduction of up to 20 per cent in average leaf size in *Eucalyptus maculata* and *E. brockwayi* seedlings (Myers and Landsberg, 1989). Prolonged periodic water shortage reduced the amount of foliage by 90 per cent in *Fagus sylvatica* (Cermak *et al.*, 1993). Rhizopoulou and Davies (1993) observed in *Eucalyptus globulus* that, although leaf area of unwatered seedlings was less, the corresponding leaf dry weight was quite similar to that of well watered seedling.

Drought stimulated the growth of fine roots on the surface and upper soil layers in *Fagus sylvatica* (Cermak *et al.*, 1993). Root growth of unwatered *Eucalyptus globulus* seedlings gradually increased in deeper soil layers where thick root apices and high soil water depletion per unit length was recorded. As a result, the root absorbing surface area was large in unwatered plants as in well watered plants (Rhizopoulou and Davies, 1993).

Water deficits in roots reduce the rate of elongation of roots, root branching and cambial growth. In a study by Pessin (1939) on long leaf and slash pine seedlings, it was evident that root growth is less affected than shoot growth by varying moisture levels. In addition to reduction in root growth, there will be suberisation of roots when water stressed (Kramer, 1969). Even though it is said that water absorption is reduced by suberisation, Chung and Kramer (1975) showed that considerable absorption occurs through suberised roots.

But in the study conducted by Hiremath (2004) an increase in water stress increased the root length of sandal. Ten week old seedlings of *Acacia mangium* also showed an increase in root growth capacity and root/shoot ratio when subjected to restricted water stress (Awang and Dechavez, 1993).

2.5.2 Dry matter production

Water stress lowered the dry matter production in sandal seedlings (Hiremath, 2004). Water deficits generally have a negative effect on the dry matter accumulation in plants as it impairs with many of the physiological processes, which determines growth, like photosynthesis, respiration, enzyme activity etc. Dry matter production was significantly affected in four *Acacia* spp. when controlled watering was employed (Kireger and Blake, 1994). Water stress reduced dry matter accumulation in *Pseudotsuga menzeisi, Pinus contorta and Picea glauca* seedlings grown in containerized nursery (Driessche, 1991). Phillips and Riha (1993) reported that above ground biomass accumulation decreased by 21 per cent in the moderately stressed and by 47 per cent in severely stressed seedlings.

2.5.3 Physiological parameters

Water loss from plant tissues alters a number of physiological processes. It causes loss of turgor inside the cells followed by closure of stomata, alteration of cellular membrane relations, reduction of leaf water potential etc. All these together cause metabolic disruption in plants

2.5.3.1 Stomatal responses

Stomata begin to close when the turgor of the guard cell decreases. Stomata usually close during relatively early stages of leaf water deficit, often long before leaves wilt (Kozlowski, 1976). The critical leaf water potential for stomatal closure reported for different species should not be taken too seriously because the value varies for different clones and cultivars (Palardy and Kozlowski, 1979) and because the response of stomata to leaf water deficits is modified significantly by factors like internal CO_2 concentration, air humidity, wind, age of leaf, osmotic adjustments etc. (Davies *et al.*, 1974; Kozlowski and Palardy, 1979).

Stomatal conductance has been reported to vary with leaf water potential in several experiments. In *Alnus glutinosa* seedlings, water stressed individuals showed a much lower initial leaf conductance after which it was gradually dropped as leaf water potential decreased (Seiler, 1985). Then Vance and Running (1985) observed that in *Larix occedentalis* seedlings also, the minimum stomatal conductance declines with decreasing pre-dawn water status. Ellsworth and Reich (1992) correlated leaf conductance with pre-dawn leaf water potential in *Acer saccharum* seedlings. Stomatal closure during the middle of the day has been reported for many species of forest trees (Kramer and Kozlowski, 1979 and Kozlowski, 1982). Although mid day stomatal closure has been attributed to several causes, an important factor is the lag of absorption behind transpiration, which induces leaf dehydration and reduction in leaf water potential to a critical level associated with stomatal closure. Driessche (1991) observed a reverse trend of increasing stomatal conductance in Lodge pole pine seedlings when severe nursery drought was induced.

2.5.3.2 Transpiration rate

The rate of transpiration is directly dependent to the gradient of water vapour between intercellular spaces of the leaf and ambient air. Although high transpiration rate often causes injury, transpiration is unavoidable because of leaf structure favourable for the entrance of CO_2 and for the loss of water vapour (Kozlowski *et al.*, 1991). Stomatal closure was found to be an adaptation mechanism for reduced transpiration rate at water deficit condition (Turner and Kramer, 1980). Hiremath (2004) found that transpiration rate was significantly reduced in sandal seedlings grown under water stress. Transpiration rates were often reduced significantly in certain *Acacia* spp in drier soils (Lange *et al.*, 1987).

2.5.3.3 Plant water potential

A pressure chamber measurement of plant moisture status provides an estimate of plant water potential. There are many comprehensive studies made on plant water potential and relevance to water stress (Slatyer, 1967; Slavik, 1974 and Turner and Kramer, 1980). In many species stomatal resistance to air humidity can be correlated with leaf water potential. Hiremath (2004) found that plant water potential is greatly reduced in plants grown under water stress. A study conducted by Guehl *et al.*, (1991) on the leaf gas exchange in response to drought found that stomata closed very rapidly in ***Abies bornmulleriana*** when water supply is withheld even prior to being any important decrease in leaf predawn water potential. In *Quercus petreae,* imposed drought caused predawn leaf water potential to reach as low as -2.0 MPa with a progressive decrease in hydraulic conductance (Breda *et al.*, 1993). Batten *et al.*, (1994) observed a predawn leaf water potential of -0.3 MPa in irrigated trees, whereas it progressively declined to -0.9 MPa in unirrigated trees. Rajesh (1996) reported that the growth characteristics and physiological behaviour of five species of tree seedlings namely *Acacia mangium, Ailanthus triphysa, Pterocarpus marsupium, Swietenia macrophylla* and *Tectona grandis* and most of these were adversely affected due to water stress.

It is evident that, water stress is having a detrimental effect on overall plant growth and survival due to the altered morphological, physiological and biochemical process of the plant. As a general rule, leaf area, shoot growth and root growth are reduced by water stress, root/shoot ratio has been found to increase in certain cases. Many plants respond to low water status by cutting off their transpiration by an active stomatal control and there by maintaining the water potential. In sandal, the co-habitation with host makes the water stress response more complex. It is not known whether different host plants are having a complementary or competitive influence on the internal water status of sandal.

MATERIALS AND METHODS

3. MATERIALS AND METHODS

An investigation was carried out at the College of Forestry, Kerala Agricultural University, Vellanikkara, Thrissur to study the effect of host plants and soil moisture stress on the growth and water relationship in sandal. The experiment was conducted during the period of September 2004 to July 2005.

3.1 CLIMATE AND WEATHER

The area is situated 40 m above the mean sea level at 10°31' N latitude and 76°26' E longitude. The area experiences warm and humid climate with distinct summer and rainy seasons.

3.2 METHODOLOGY

Seeds of sandal from the Marayoor area of Idukki district of Kerala were used for the study. The host seedlings were collected locally.

The sandal seeds were soaked in 500 ppm gibberlic acid for 24 hours and after that the seeds were spread in paper and dried for one day. Then the seeds were rubbed with the hands so that the seed coat is removed. These seeds were sown in trays filled with sand and irrigated daily. The germinated seeds were transplanted to polythene bags (20 x 10 cm) filled with soil, sand and neem cake in 1:1:1 proportion and the host seedlings were planted along with it. Readings were 45 days after transplanting of the seedlings

Different hosts selected for the study

1. Divi divi (*Caesalpinia coriaria* Jacq.)
2. Casuarina (*Casuarina equisetifolia* J.R & H.G. Forst)
3. Pongamia (*Pongamia pinnata* (L.) Pierre)
4. Lantana (*Lantana camara* L.)

5. Erythrina (*Erythrina indica* Lamk.)

Different moisture regimes were created in the polythene bag by irrigating with same quantity of water once in three days and once in six days.

The experiment was laid out in completely randomized design (CRD) and replicated three times. There were 12 treatment combinations; factorial combinations of five hosts, two moisture regimes and two controls.

3.3 OBSERVATIONS

The following observations at various stages of growth of sandal were recorded.

3.3.1 Plant Height

Height of sandal seedlings was taken at monthly intervals using a metre scale and expressed in cm.

3.3.2 Collar Diameter

Collar diameter of sandal was measured with the help of Vernier calipers and expressed in mm.

3.3.3 Number of leaves

Number of leaves in each sandal seedling was counted every month and the average was worked out.

3.3.4 Leaf area

Leaf area of individual plants were measured with a leaf area meter (Model LI-300, LI-Cor, Nebraska, U.S.A) and expressed in cm^2.

3.3.5 Root length

Root length was measured from collar to the tip of the longest root and the mean was worked out.

3.3.6 Total dry matter

Total dry matter was calculated by summing the shoot dry weight and root dry weight of each plant. The seedlings were dried in hot air oven for 24hours and the weights of the dried seedlings were taken with an electronic balance.

3.3.7 Haustorial connection

The haustorial connections between the sandal and host were observed during destructive sampling and recorded as number of connection per plant.

3.3.8 Plant water potential

The pre-dawn water potential of sandal seedlings and host were estimated at the time of destructive sampling using Scholanders pressure bomb type plant water status console (Soil Moisture Equipment Corporation, Ohio USA) and expressed in MPa.

3.3.9 Transpiration rate

The transpiration rate of sandal and host seedlings was measured at the end of water stress cycle using a steady state porometer (Model LI-1600, LI-Cor, Nebraska, USA). Physiologically mature leaves were selected usually for taking measurements and measurements were taken on abaxial surface area. Observations were recorded in monthly intervals at 08.00 hours and 14.00 hours IST and were expressed in units of $\mu g\ H_20\ cm^{-2}s^{-1}$.

3.4 STATISTICAL ANALYSIS

Analysis of variance was performed on the data collected; using the statistical package 'MSTAT' (Freed, 1986). The means were compared by using Duncan's Multiple Range Test (DMRT).

RESULTS

4. RESULTS

The influence of host plants and soil moisture stress on the growth and water relations in sandal is presented in this chapter.

4.1 GROWTH PARAMETERS OF SANDAL

4.1.1 Height

The height of sandal seedlings from 30 to 270 days after planting are shown in Tables 1 and 2 and Fig. 1 and 2 (Plate 1). There was no significant difference in height of sandal seedlings with and without host up to 180 days after planting. The height showed significant difference at 210, 240 and 270 days after planting. The Sandal seedlings without host showed similar height growth compared to sandal seedlings with host, except when *Erythrina* was the host. Though sandal recorded the maximum height growth, this was on par with seedlings where *Pongamia pinnata, Caesalpinia coriaria, Casuarina equisetifolia* and *Lantana camara* were hosts. Sandal seedlings with *Erythrina indica* as host recorded the lowest height growth. The influence of water stress was evident from 120 days after planting. Irrigation once in three days resulted in better height growth as compared to irrigation once in six days (Table 2, Fig. 2 and Plate 2).

The interaction effects of different hosts and irrigation levels on the height of sandal seedlings are shown in Table 3. The interaction effects were not significant at any stage.

4.1.2 Collar diameter

The collar diameters of sandal seedlings from 30 to 270 days after planting are shown in Tables 4 and 5 and Fig. 3 and 4. The collar diameter varied significantly with the host from 60 days after planting. Sandal seedlings alone showed more collar diameter than that with the host at 270 days after planting. Among sandal seedlings with the host,

Table 1. Influence of different hosts on height of sandal seedlings.

	Height (cm)								
	Days after planting								
	30	60	90	120	150	180	210	240	270
Sandal alone	13.2	14.5	15.5	17.6	19.7	22.7	24.4^{A}	26.4^{A}	28.2^{A}
Sandal+ Pongamia	12.9	14.3	15.2	17.1	19.1	21.9	23.6^{A}	25.4^{A}	27.1^{A}
Sandal+ Divi divi	12.8	13.9	15.0	16.8	18.8	21.5	23.1^{AB}	24.9^{A}	26.7^{A}
Sandal+ Erythrina	11.9	13.0	14.0	15.9	17.6	19.9	21.2^{B}	22.9^{B}	24.1^{B}
Sandal+ Casuarina	12.8	13.5	14.7	16.5	18.5	21.1	22.8^{AB}	24.6^{AB}	26.4^{A}
Sandal+ Lantana	12.7	14.1	15.2	17.2	18.9	21.7	23.4^{AB}	25.2^{A}	26.7^{A}
P	NS	NS	NS	NS	NS	NS	0.04	0.03	0.01
SEM ±	0.62	0.64	0.65	0.65	0.64	0.64	0.59	0.59	0.59
Figures having the same alphabet do not differ significantly									

Table 2. Influence of soil moisture stress on height of sandal seedlings.

	Height (cm)								
	Days after planting								
	30	60	90	120	150	180	210	240	270
Irrigation once in 3 days	12.7	13.9	15.1	17.1 [A]	19.0 [A]	21.9 [A]	23.8 [A]	25.8 [A]	27.6 [A]
Irrigation once in 6 days	12.8	13.8	14.8	16.6 [B]	18.5 [B]	21.0 [B]	22.4 [B]	24.0 [B]	25.4 [B]
P	NS	NS	NS	0.023	0.007	0.001	0.001	0.000	0.000
SEM ±	0.13	0.11	0.12	0.12	0.12	0.12	0.14	0.14	0.14
Figures having the same alphabet do not differ significantly									

Table 3. Interaction effects of different hosts and irrigation levels on the height of sandal seedlings

	Height (cm)																	
	Days after planting																	
	30		60		90		120		150		180		210		240		270	
Irrigation	Once in 3 days	Once in 6 days	Once in 3 days	Once in 6 days	Once in 3 days	Once in 6 days	Once in 3 days	Once in 6 days	Once in 3 days	Once in 6 days	Once in 3 days	Once in 6 days	Once in 3 days	Once in 6 days	Once in 3 days	Once in 6 days	Once in 3 days	Once in 6 days
Sandal alone	13.1	13.3	14.5	14.5	15.6	15.5	17.7	17.5	19.9	19.5	23.1	22.4	24.9	23.9	27.1	25.7	29.2	27.2
Sandal+ Pongamia	13.0	12.9	14.4	14.1	15.2	15.2	17.2	17.1	19.1	19.0	22.3	21.6	24.3	23.0	26.3	24.6	28.1	26.1
Sandal+ Divi divi	13.1	12.6	14.0	13.7	15.3	14.7	17.1	16.5	19.1	18.5	21.9	21.1	23.7	22.5	25.7	24.2	27.6	25.8
Sandal+ Erythrina	11.9	12.0	12.9	13.0	14.1	13.9	15.9	15.8	17.7	17.4	20.3	19.6	21.8	20.6	25.7	22.0	25.2	22.9
Sandal+ Casuarina	12.5	13.0	13.8	13.2	15.1	14.2	17.0	16.0	19.1	17.8	21.9	20.3	23.8	21.8	25.8	23.4	27.7	25.0
Sandal+ Lantana	12.4	12.9	14.1	14.1	15.3	15.1	17.4	16.9	19.3	18.7	22.2	21.2	24.2	22.6	26.1	24.2	27.9	25.6
P	NS		NS		NS		NS		NS		NS		NS		NS		NS	
SEM ±	0.3209		0.274		0.294		0.298		0.299		0.296		0.341		0.355		0.346	

Table 4. Influence of different hosts on collar diameter of sandal seedlings.

	Collar diameter (mm)								
	Days after planting								
	30	60	90	120	150	180	210	240	270
Sandal alone	1.45	1.67^{A}	1.88^{A}	1.97^{A}	2.06^{A}	2132^{A}	2.22^{A}	2.30^{A}	2.37^{A}
Sandal+ Pongamia	1.43	1.62^{AB}	1.82^{AB}	1.90^{AB}	1.99^{AB}	2.07^{AB}	2.15^{AB}	2.23^{AB}	2.28^{B}
Sandal+ Divi divi	1.39	1.61^{AB}	1.81^{AB}	1.88^{BC}	1.97^{B}	2.06^{AB}	2.13^{AB}	2.21^{B}	2.28^{B}
Sandal+ Erythrina	1.32	1.52^{C}	1.72^{C}	1.80^{C}	1.87^{C}	1.95^{C}	2.02^{C}	2.08^{C}	2.15^{C}
Sandal+ Casuarina	1.39	1.58^{BC}	1.78^{BC}	1.85^{BC}	1.94^{BC}	2.03^{B}	2.10^{BC}	2.18^{B}	2.27^{B}
Sandal+ Lantana	1.39	1.59^{AB}	1.79^{BC}	1.87^{BC}	1.96^{B}	2.04^{B}	2.12^{AB}	2.19^{B}	2.26^{B}
P	NS	0.015	0.019	0.014	0.005	0.005	0.005	0.005	0.004
SEM $\pm$	0.027	0.023	0.026	0.026	0.025	0.024	0.049	0.027	0.027
Figures having the same alphabet do not differ significantly									

Table 5. Influence of soil moisture stress on collar diameter of sandal seedlings.

	Collar diameter (mm)								
	Days after planting								
	30	60	90	120	150	180	210	240	270
Irrigation once in 3 days	1.41 A	1.62 A	1.83 A	1.97 A	2.01 A	2.10 A	2.21 A	2.26 A	2.35 A
Irrigation once in 6 days	1.38 B	1.58 B	1.77 B	1.84 B	1.92 B	1.99 B	2.06 B	2.13 B	2.19 B
P	0.0149	0.022	0.002	0.001	0.000	0.000	0.003	0.000	0.000
SEM ±	0.007	0.011	0.009	0.009	0.010	0.011	0.028	0.013	0.015

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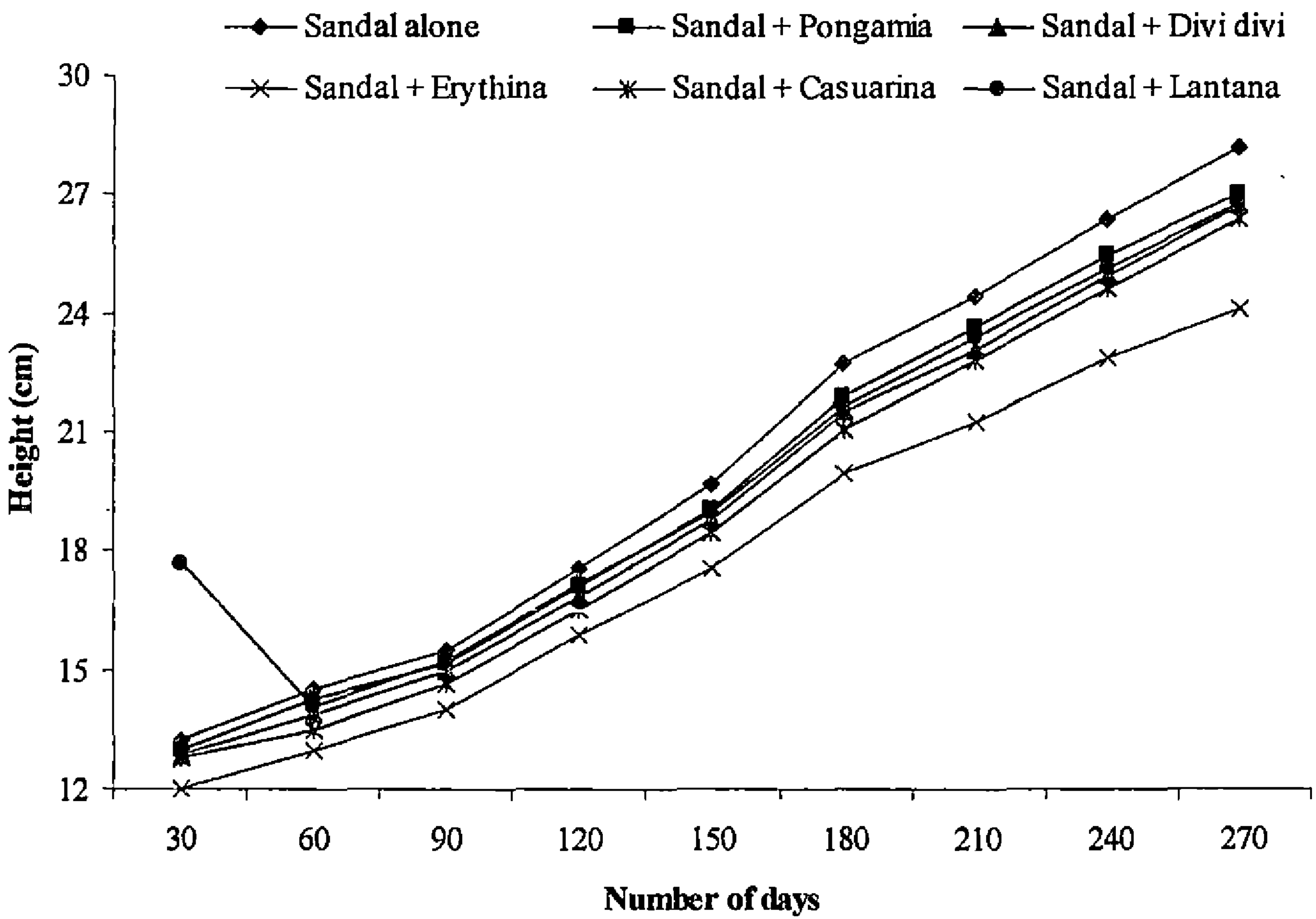

Fig. 1. Influence of different hosts on height of sandal seedlings.

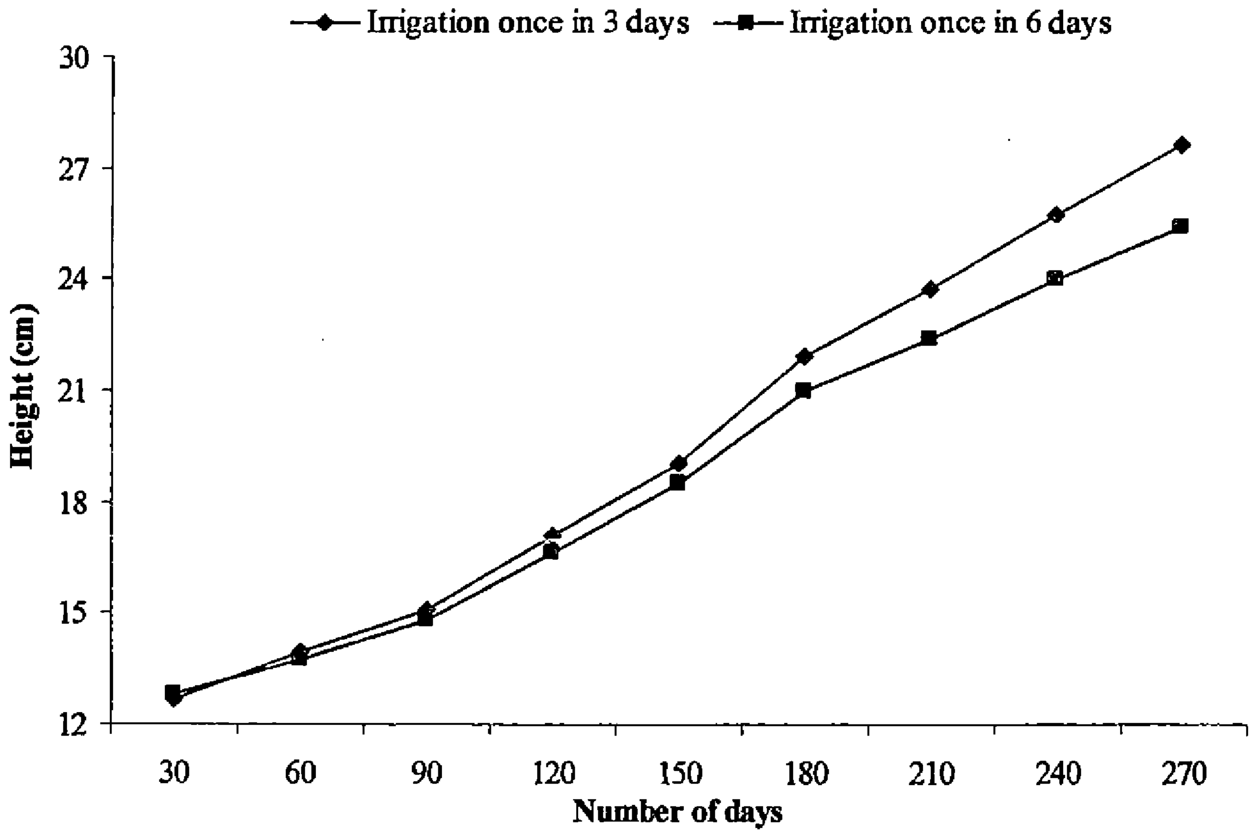

Fig. 2. Influence of soil moisture stress on height of sandal seedlings.

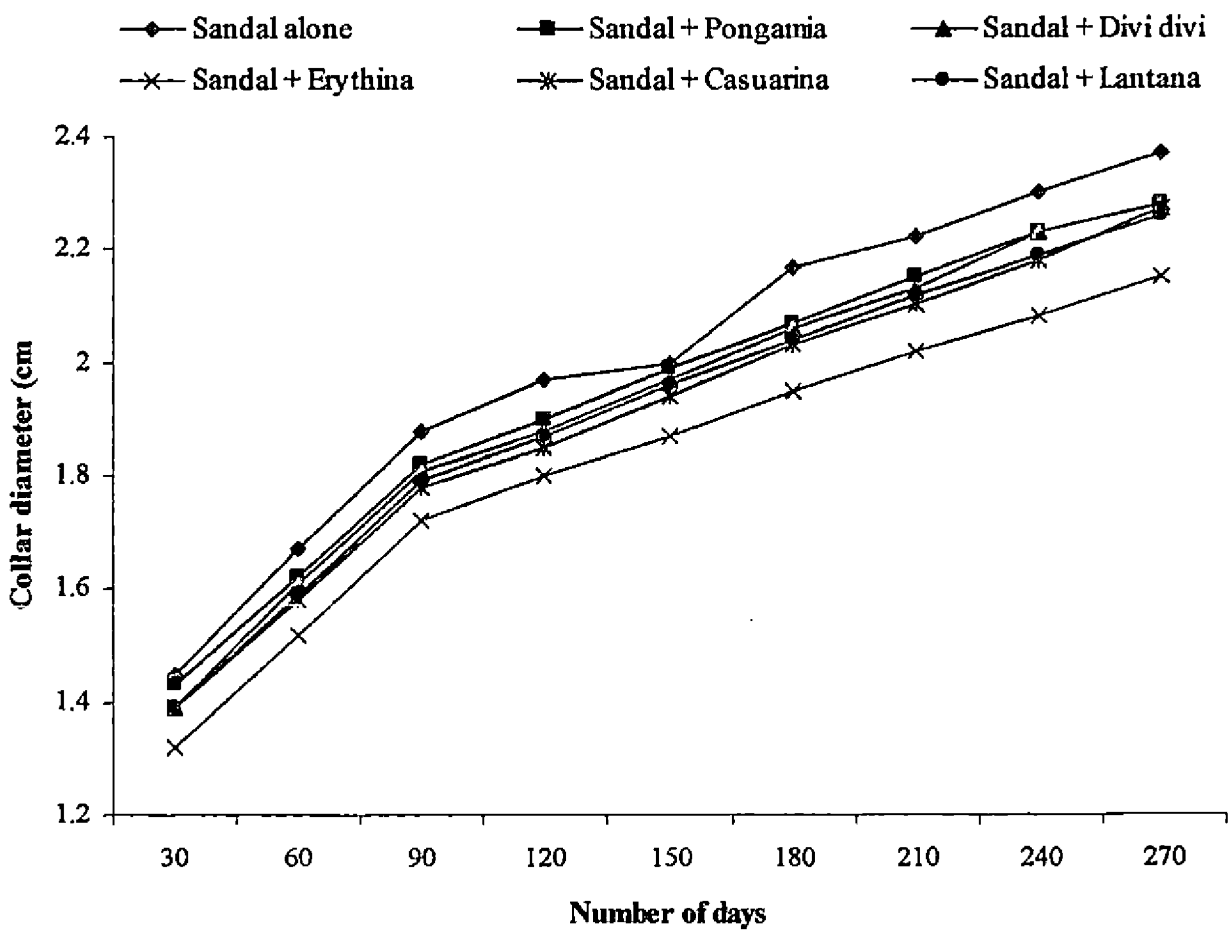

Fig. 3. Influence of different hosts on collar diameter of sandal seedlings.

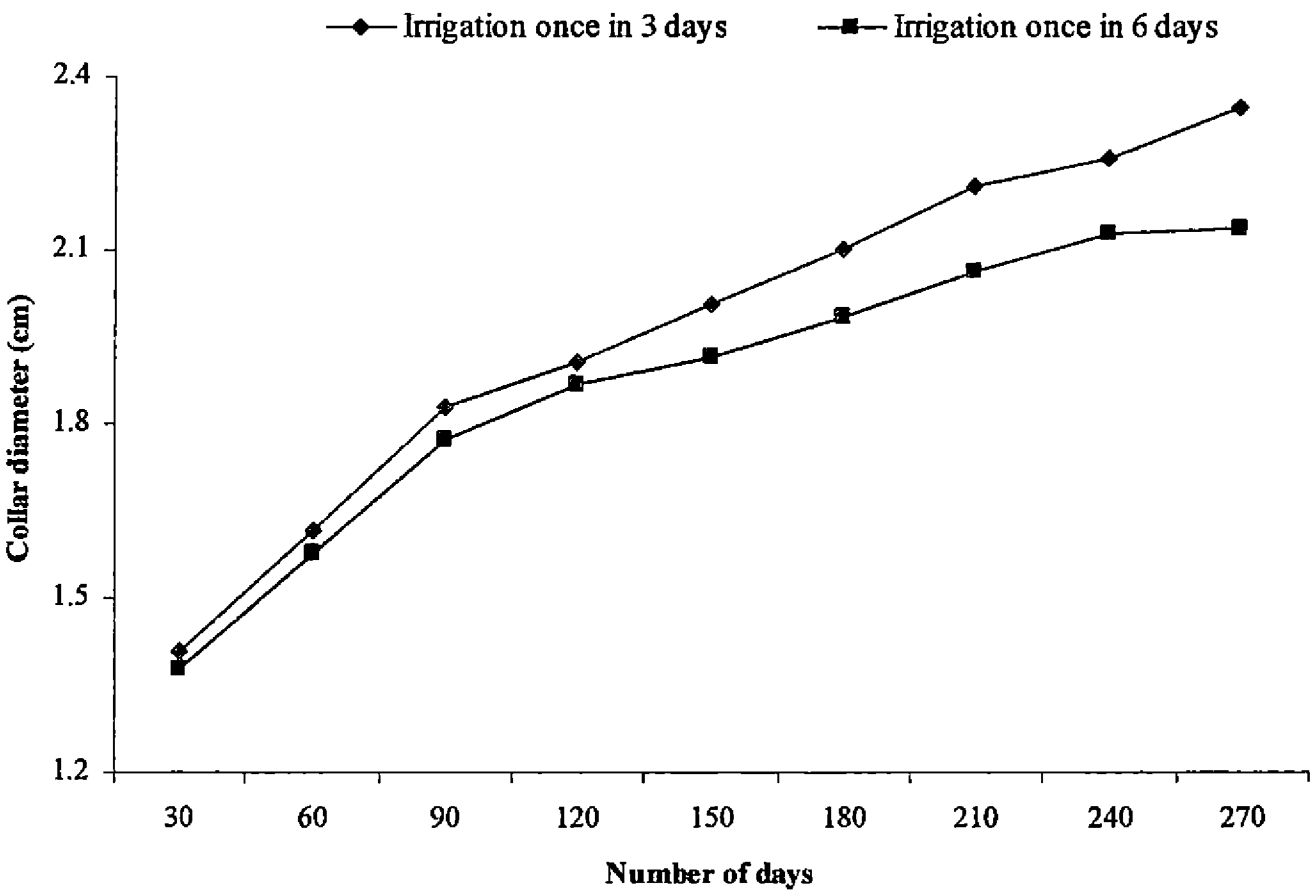

Fig. 4. Influence of soil moisture stress on collar diameter of sandal seedlings.

seedlings with *Caesalpinia coriaria* showed maximum collar diameter followed by that with *Pongamia pinnata,* which were on par with sandal seedlings alone until 210 days after planting. Sandal seedlings with *Erythrina indica* as host showed the least collar diameter growth. This was evident from 60 days after planting and the same trend continued through out the experimental period. *Casuarina equisetifolia* as host resulted in intermediary performance of sandal-collar diameter. Sandal with, Casuarina as host was superior to sandal with *Erythrina* as host, but inferior to sandal alone and sandal with hosts *Caesalpinia* and *Pongamia*. With the increase in water stress the collar diameter is found to be decreased significantly. The influence of water stress was evident from 30 days after planting itself. The same trend continued up to 270 days after planting. Irrigating once in three days was superior to irrigating once in six days.

The interaction effects of different hosts and irrigation levels on the collar diameter of sandal seedlings were not significant (Table 6).

4.1.3 Number of leaves

The number of leaves per sandal seedlings from 30 to 270 days after planting is shown in Table 7 and 8 and Fig. 5 and 6. There was no significant difference in the number of leaves of sandal seedlings with and without host. Sandal seedlings with *Lantana camara* showed the maximum number of leaves followed by that with *Casuarina equisetifolia* but they are not statistically significant The number of leaves on the sandal varied from 12-14 at 30 days after planting and it increased to 24 leaves by 270 days after planting. On an average one leaf was produced every month. As the water stress increased the number of leaves showed a significant decrease only at 120 days after planting. However, throughout the experiment the trend was same seedlings irrigated once in six days produced less leaves than the seedlings irrigated once in three days.

The interaction effects of different hosts and irrigation levels on the number of leaves of sandal seedlings were not significantly different (Table 9).

Plate 1.Effect of different hosts on the height of sandal
A. Sandal alone B. Sandal + Casuarina C. Sandal + Dividivi D. Sandal + Erythrina
E. Sandal + Lantana F. Sandal + Pongamia

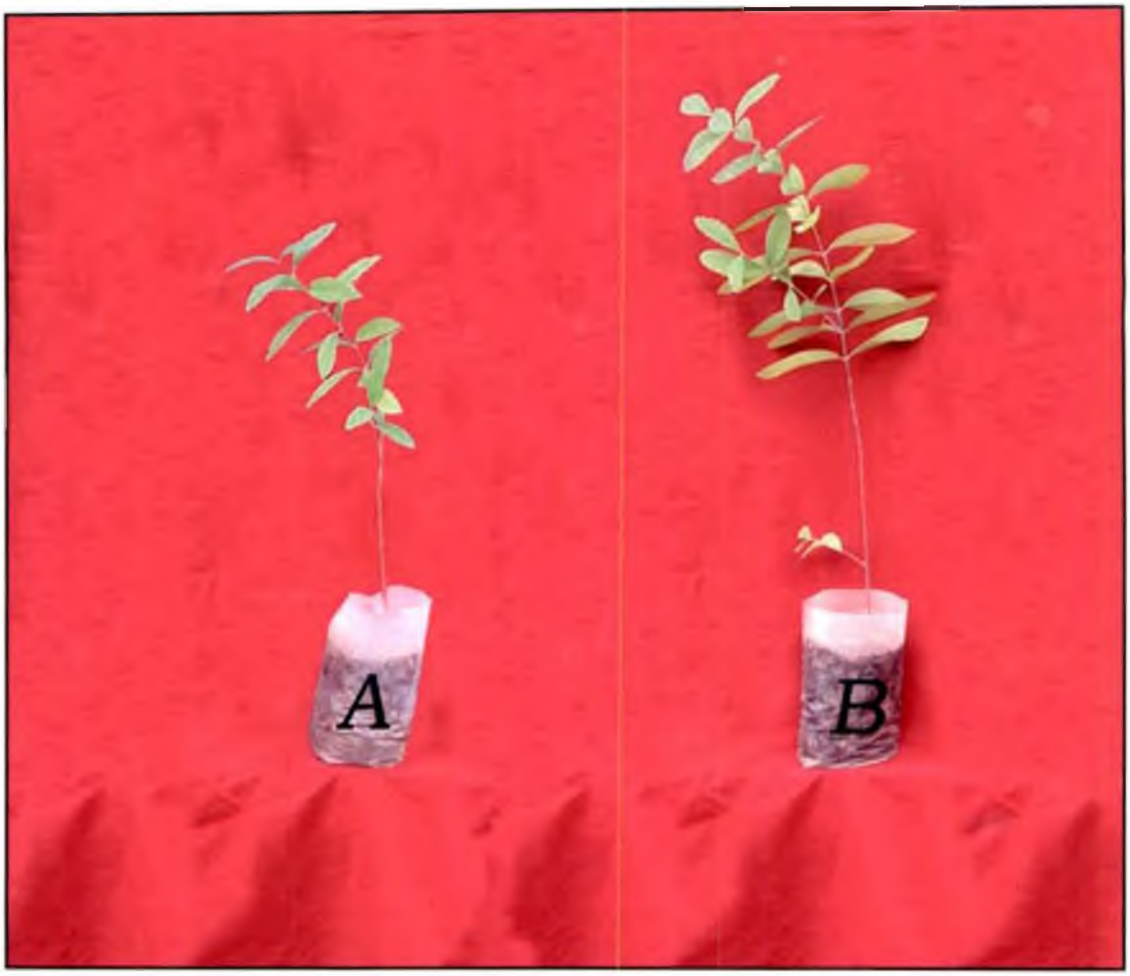

Plate 2. Effect of water stress on the height of sandal seedlings
A. Sandal irrigated once in six days
B. Sandal irrigated once in three days

Table 6. Interaction effects of different hosts and irrigation levels on the collar diameter of sandal seedlings.

	Collar diameter (mm)																	
	Days after planting																	
	30		60		90		120		150		180		210		240		270	
Irrigation	Once in 3 days	Once in 6 days	Once in 3 days	Once in 6 days	Once in 3 days	Once in 6 days	Once in 3 days	Once in 6 days	Once in 3 days	Once in 6 days	Once in 3 days	Once in 6 days	Once in 3 days	Once in 6 days	Once in 3 days	Once in 6 days	Once in 3 days	Once in 6 days
Sandal alone	1.48	1.42	1.71	1.62	1.93	1.84	2.02	1.91	2.12	2.00	2.19	2.06	2.29	2.15	2.39	2.222	2.45	2.29
Sandal+ Pongamia	1.43	1.42	1.61	1.63	1.82	1.82	1.91	1.89	2.01	1.96	2.11	2.03	2.18	2.12	2.27	2.18	2.35	2.21
Sandal+ Divi divi	1.41	1.37	1.65	1.57	1.85	1.77	1.93	1.84	2.02	1.91	2.13	1.98	2.20	2.06	2.28	2.13	2.37	2.19
Sandal+ Erythrina	1.33	1.31	1.53	1.50	1.75	1.69	1.84	1.76	1.91	1.88	2.00	1.89	2.08	1.96	2.14	2.02	2.22	2.08
Sandal+ Casuarina	1.41	1.36	1.59	1.56	1.82	1.75	1.90	1.79	1.99	1.9	2.10	1.96	2.14	2.05	2.24	2.12	2.33	2.21
Sandal+ Lantana	1.39	1.39	1.60	1.58	1.81	1.77	1.89	1.84	1.99	1.92	2.09	1.99	2.38	2.05	2.26	2.11	2.35	2.17
P	NS		NS		NS		NS		NS		NS		NS		NS		NS	
SEM ±	0.02		0.03		0.02		0.02		0.02		0.03		0.069		0.033		0.04	

Table 7. Influence of different hosts on number of leaves of sandal seedlings.

	Number of leaves								
	Days after planting								
	30	60	90	120	150	180	210	240	270
Sandal alone	13.5	15.3	17.7	19.0	20.2	20.5	21.0	21.2	22.0
Sandal+ Pongamia	12.7	14.7	17.0	18.8	20.0	20.5	21.5	21.8	22.7
Sandal+ Divi divi	13.2	14.3	16.5	18.2	19.3	20.2	20.8	21.3	22.3
Sandal+ Erythrina	13.2	15.2	17.3	18.8	20.0	20.5	21.3	21.5	22.5
Sandal+ Casuarina	14.2	16.0	18.3	19.5	20.7	21.5	22.0	22.5	23.8
Sandal+ Lantana	13.5	15.7	17.8	19.8	21.0	21.5	22.3	23.0	24.2
P	NS	NS	NS	NS	NS	NS	NS	NS	NS
SEM ±	0.680	0.674	0.670	0.701	0.736	0.776	0.656	0.624	0.767

Table 8. . Influence of soil moisture stress on number of leaves of sandal seedlings.

	Number of leaves								
	Days after planting								
	30	60	90	120	150	180	210	240	270
Irrigation once in 3 days	13.5	15.4	18.1	20.0 ^{A}	21.1	21.9	22.9	23.1	24.6
Irrigation once in 6 days	13.2	15.0	16.9	18.1 ^{B}	19.0	19.9	20.7	21.1	22.2
P	NS	NS	NS	0.05	NS	NS	NS	NS	NS
SEM ±	0.437	0.448	0.584	0.633	0.659	0.731	0.677	0.703	0.728
Figures having the same alphabet do not differ significantly									

Table 9. Interaction effects of different hosts and irrigation levels on number of leaves of sandal seedlings.

	Number of leaves																	
	Days after planting																	
	30		60		90		120		150		180		210		240		270	
Irrigation	Once in 3 days	Once in 6 days	Once in 3 days	Once in 6 days	Once in 3 days	Once in 6 days	Once in 3 days	Once in 6 days	Once in 3 days	Once in 6 days	Once in 3 days	Once in 6 days	Once in 3 days	Once in 6 days	Once in 3 days	Once in 6 days	Once in 3 days	Once in 6 days
Sandal alone	13.7	13.3	15.7	15.0	18.7	18.7	20.7	17.3	21.7	18.7	22.0	19.0	22.7	19.3	22.7	19.7	23.3	20.7
Sandal+ Pongamia	12.3	13.0	14.3	15.0	17.0	17.0	19.3	18.3	20.3	19.7	21.0	20.0	22.0	21.0	22.3	21.3	23.0	22.3
Sandal+ Divi divi	13.3	13.0	14.7	14.0	17.3	15.3	19.3	17.0	20.3	18.3	21.3	19.0	22.0	19.7	22.3	20.3	23.3	21.3
Sandal+ Erythrina	13.7	12.7	15.7	14.7	18.3	16.3	20.0	17.7	21.0	19.0	21.7	19.3	22.3	20.3	22.7	20.3	23.7	21.3
Sandal+ Casuarina	14.7	13.7	16.3	15.7	19.3	17.3	20.7	18.3	21.7	19.7	22.3	20.7	22.7	21.3	23.3	21.7	24.3	23.3
Sandal+ Lantana	13.3	13.7	15.7	15.7	18.0	17.7	20.0	19.7	21.3	20.7	21.7	21.3	22.3	22.3	23.0	23.0	24.0	24.3
P	NS		NS		NS		NS		NS		NS		NS		NS		NS	
SEM $\pm$	1.072		1.194		1.430		1.552		1.613		1.790		1.658		1.721		1.782	

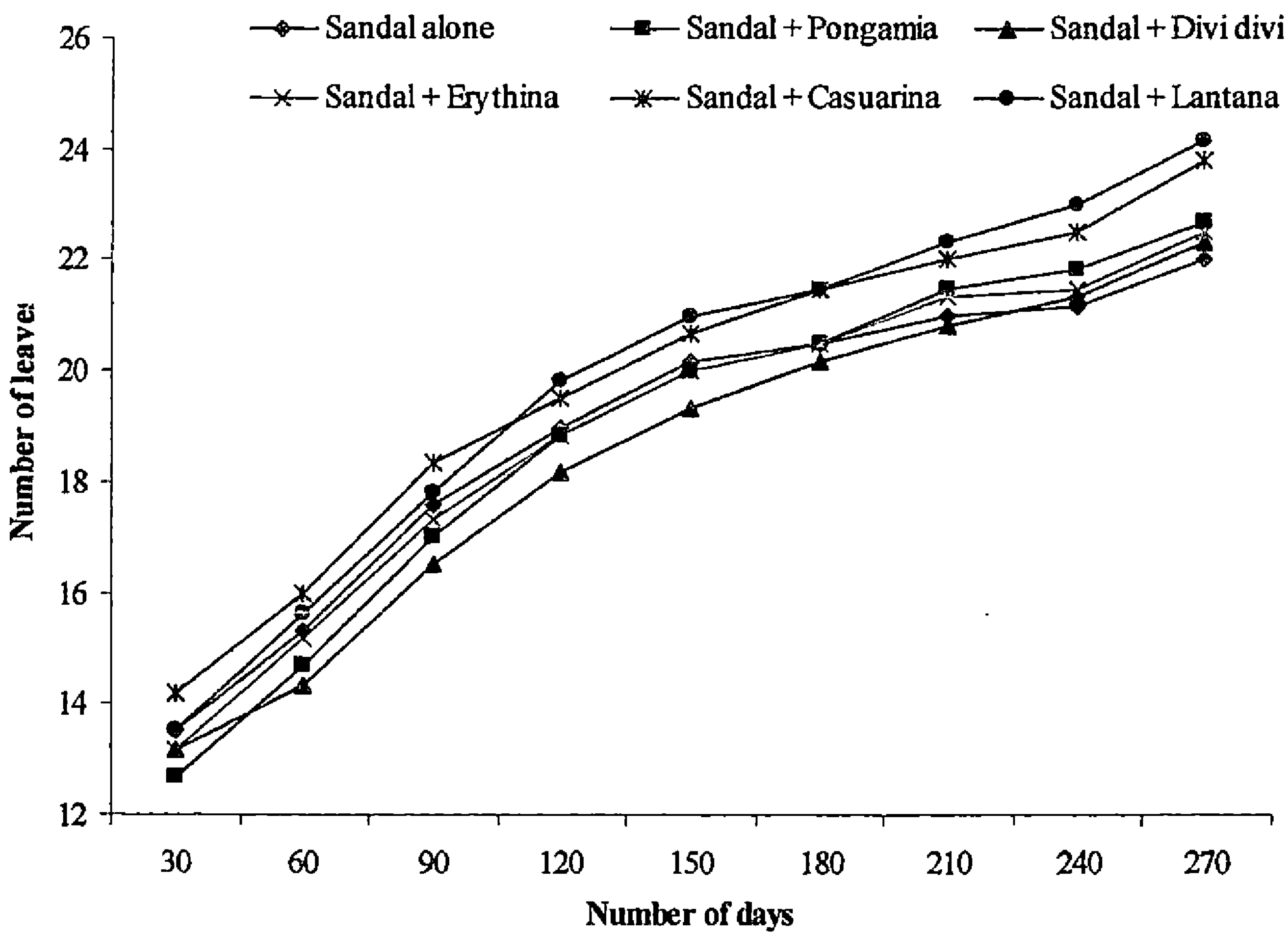

Fig.5. Influence of different hosts on number of leaves of sandal seedlings.

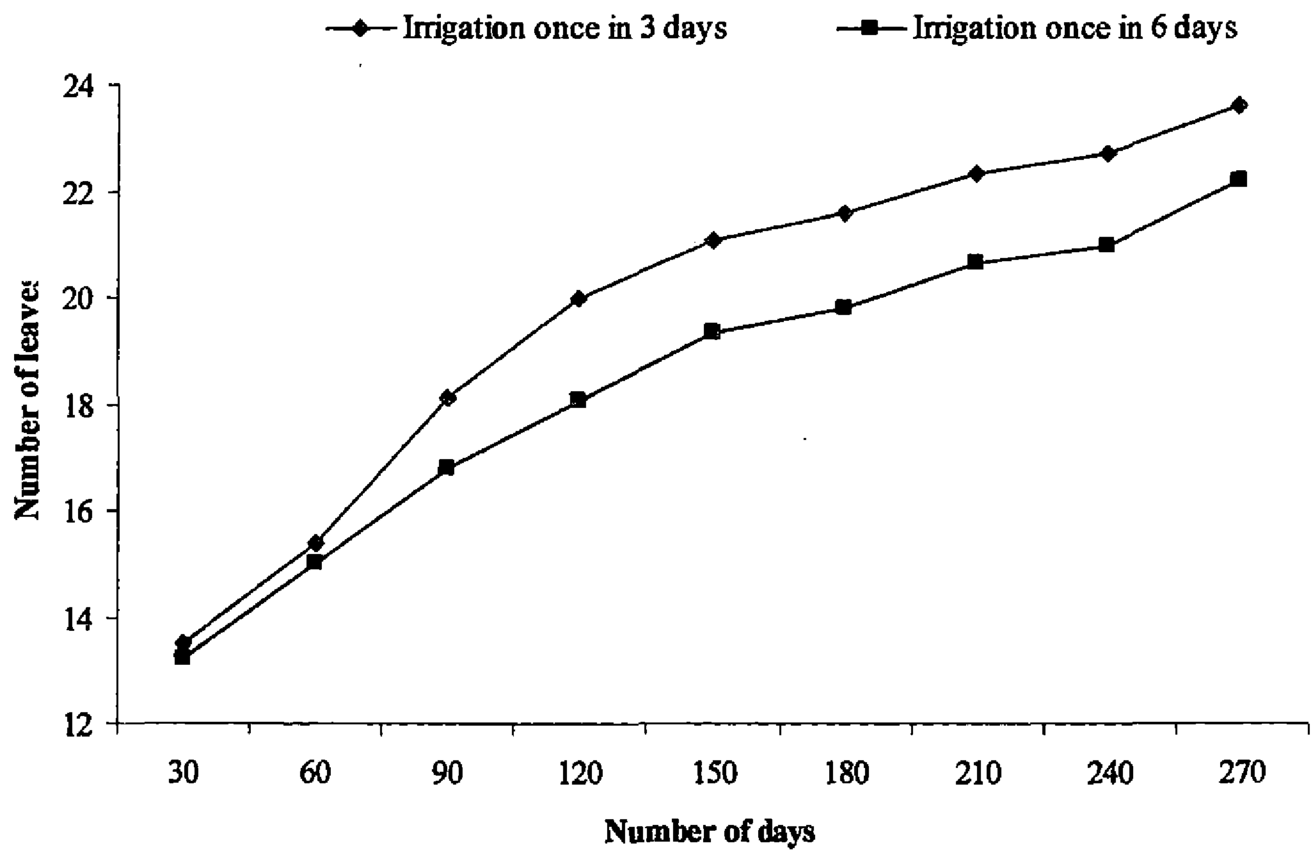

Fig.6. Influence of soil moisture stress on number of leaves of sandal seedlings.

4.1.4 Leaf area

The leaf areas of sandal seedlings at the time of destructive sampling (270 days after planting) are shown in Tables 10 and 11. There was no significant difference in the leaf area of sandal seedlings due to hosts. However, there was considerable reduction in leaf area when irrigation was given once in six days, as compared to giving irrigation once in three days.

The interaction effects of different hosts and irrigation levels on the leaf area of sandal seedlings are shown in Table 12. It was found to be non significant.

4.1.5 Root length

The root length of sandal seedlings 270 days after planting is shown in Tables 13 and 14 and Fig. 7. Sandal seedlings alone showed more root length followed by sandal seedlings with *Pongamia pinnata*, but they were not significantly different. . Sandal seedlings showed the least root length with *Erythrina indica* as host. Sandal seedlings irrigated once in six days showed more root growth compared to sandal seedlings irrigating once in three days.

The interaction effects of different hosts and irrigation levels on the root length of sandal seedlings are shown in Table 15. The interaction effect was found to be non significant.

4.1.6 Shoot dry weight

The shoot dry weight of sandal seedlings 270 days after planting is shown in Table 16 and 17 and Fig. 8. Sandal seedlings alone showed more shoot dry weight, but they were on par with sandal seedlings with *Caesalpinia coriaria,* and *Pongamia pinnata* as hosts. Sandal seedlings with *Erythrina indica* as host showed least shoot dry weight.

Table 10. Leaf area of sandal seedlings affected by different hosts (270 DAP).

	Leaf area (cm^2)
Sandal alone	98.7
Sandal+ Pongamia	93.9
Sandal+ Divi divi	91.3
Sandal+ Erythrina	95.1
Sandal+ Casuarina	100.1
Sandal+ Lantana	97.4
P	NS
SEM	3.62

Table 11. Leaf area of sandal seedlings affected by soil moisture stress (270 DAP).

Irrigation	**Leaf area (cm^2)**
Once in 3 days	101.7
Once in 6 days	90.4
P	0.003
SEM	2.19

Table 12. Interaction effects of different hosts and irrigation levels on the leaf area of sandal seedlings (270 DAP).

	Leaf area (cm^2)	
Irrigation	Once in 3 days	Once in 6 days
Sandal alone	108.6	88.8
Sandal+ Pongamia	98.4	89.4
Sandal+ Divi divi	97.8	84.7
Sandal+ Erythrina	99.6	90.5
Sandal+ Casuarina	102.8	97.4
Sandal+ Lantana	103.0	91.8
P	NS	
SEM	5.38	

Table 13. Root length of sandal seedlings affected by different hosts (270 DAP).

	Root length (cm)
Sandal alone	20.7 [A]
Sandal+ Pongamia	20.3 [AB]
Sandal+ Divi divi	18.9 [C]
Sandal+ Erythrina	16.8 [D]
Sandal+ Casuarina	19.6 [BC]
Sandal+ Lantana	18.6 [C]
P	0.00
SEM	0.29
Figures having the same alphabet do not differ significantly	

Table 14. Root length of sandal seedlings affected by soil moisture stress (270 DAP).

Irrigation	**Root length (cm)**
Once in 3 days	18.5
Once in 6 days	19.8
P	0.00
SEM	0.15

Table 15. Interaction effects of different hosts and irrigation levels on the root length of sandal seedlings (270 DAP).

	Root length (cm)	
Irrigation	Once in 3 days	Once in 6 days
Sandal alone	20.4	21.1
Sandal+ Pongamia	19.4	21.2
Sandal+ Divi divi	18.3	19.5
Sandal+ Erythrina	16.5	17.1
Sandal+ Casuarina	18.4	20.7
Sandal+ Lantana	18.0	19.2
P	NS	
SEM	0.38	

Table 16. Shoot dry weight of sandal seedlings affected by different hosts (270 DAP).

	Shoot dry weight (g)
Sandal alone	3.21^{A}
Sandal+ Pongamia	3.09^{AB}
Sandal+ Divi divi	3.10^{AB}
Sandal+ Erythrina	2.92^{C}
Sandal+ Casuarina	3.08^{B}
Sandal+ Lantana	2.93^{C}
P	0.001
SEM	0.037

Figures having the same alphabet do not differ significantly

Table 17. Shoot dry weight of sandal seedlings affected by soil moisture stress (270 DAP).

Irrigation	**Shoot dry weight (g)**
Once in 3 days	3.10
Once in 6 days	3.01
P	0.007
SEM	0.021

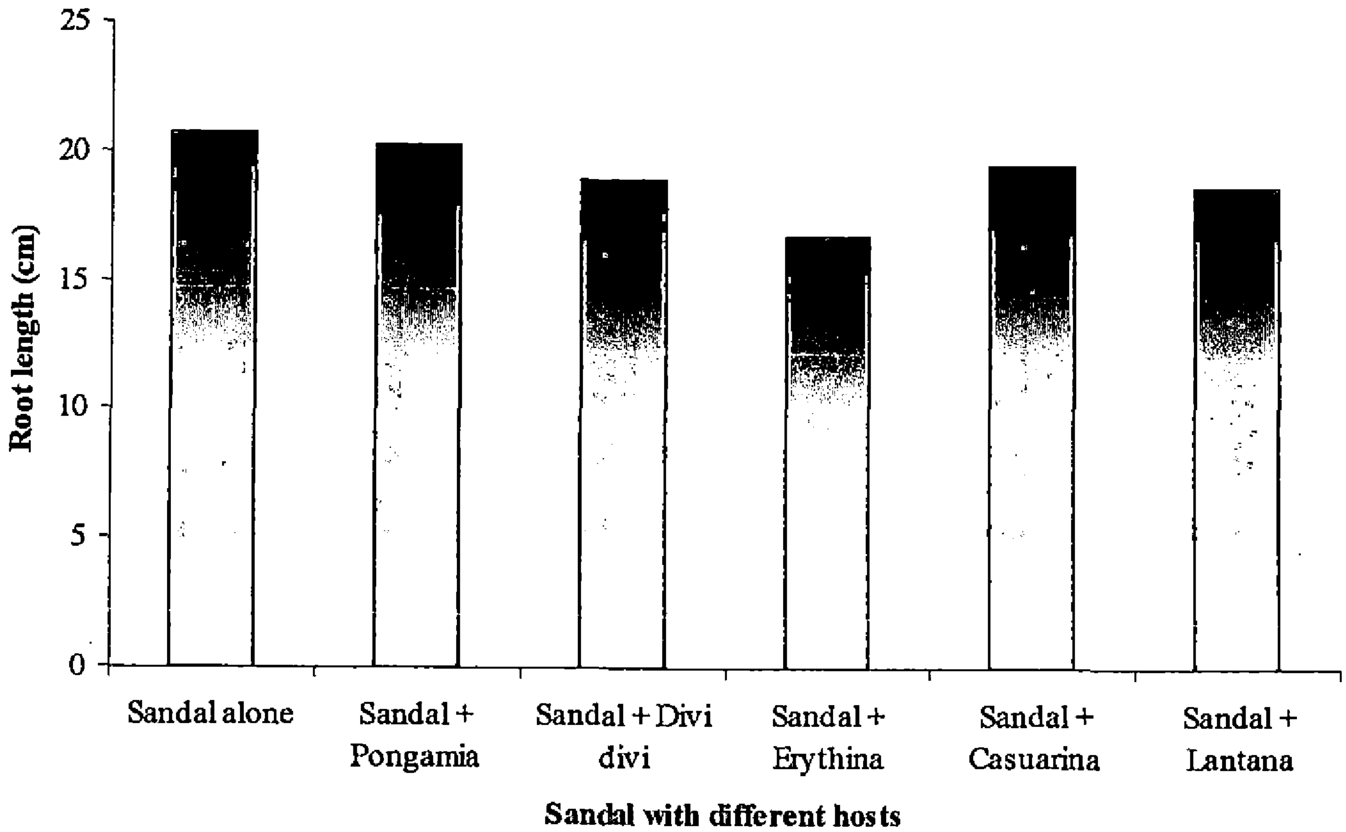

Fig.7. Influence of different hosts on root length of sandal seedlings.

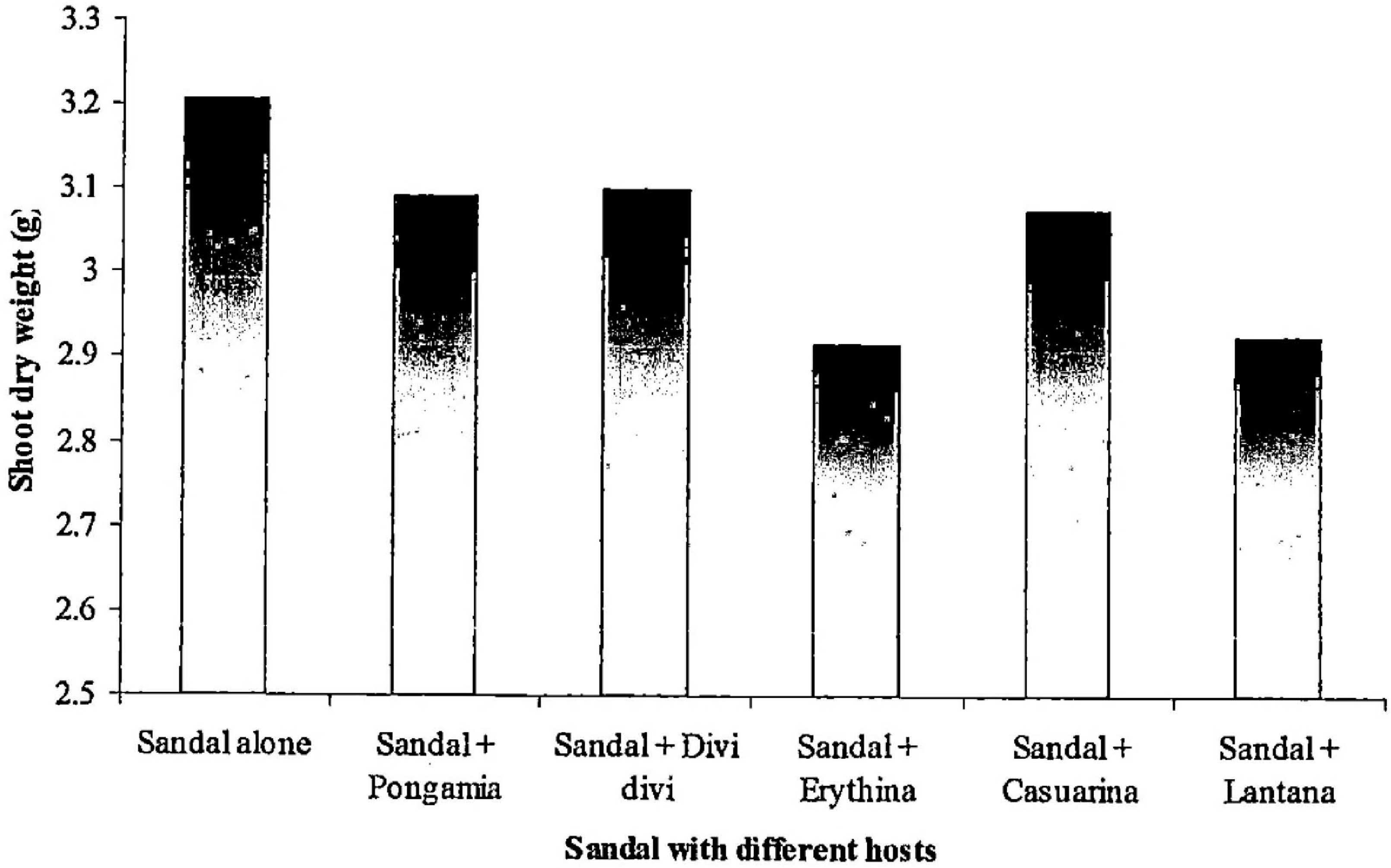

Fig.8. Influence of different hosts on shoot dry weight of sandal seedlings.

Sandal seedlings irrigated once in three days showed significant increase in shoot dry weight compared to sandal seedlings irrigated once in six days. The interaction effects of different hosts and irrigation levels on the shoot dry weight of sandal seedlings is shown in Table 18. The interaction effects were found to be not significant.

4.1.7 Root dry weight

The root dry weight of sandal seedlings 270 days after planting is shown in Table 19 and 20 and Fig. 9. Sandal seedlings alone showed more root dry weight followed by sandal seedlings with *Pongamia pinnata* as host. Sandal seedlings showed least root dry weight with *Erythrina indica* as host, but were on par with *Casuarina* and *Lantana* as hosts.

Sandal seedlings irrigated once in three days showed lesser root dry weight compared to sandal seedlings irrigated once in six days (Table.20). The interaction effects of different hosts and irrigation levels on the root dry weight of sandal seedlings (Table 21) were not significant.

4.1.8 Total dry weight

The total dry weight of sandal seedlings 270 days after planting is shown in Table 22 and 23 and Fig. 10. Sandal seedlings alone showed more total dry weight followed by sandal seedlings with *Pongamia pinnata, Caesalpinia coriaria* and *Casuarina equisetifolia* as hosts. Sandal seedlings showed least value of total dry weight with *Erythrina indica* as host, which was on par with *Lantana.*

Sandal seedlings irrigated once in three days showed more total dry weight compared to sandal seedlings irrigated once in six days. The interaction effects of different hosts and irrigation levels on the total dry weight of sandal seedlings is shown in Table 24 and it was found to be non significant.

Table 18. Interaction effects of different hosts and irrigation levels on the shoot dry weight of sandal seedlings (270 DAP).

	Shoot dry weight (g)	
Irrigation	Once in 3 days	Once in 6 days
Sandal alone	3.31	3.10
Sandal+ Pongamia	3.16	3.03
Sandal+ Divi divi	3.12	3.08
Sandal+ Erythrina	2.98	2.86
Sandal+ Casuarina	3.08	3.07
Sandal+ Lantana	2.96	2.89
P	NS	
SEM	0.509	

Table 19. Root dry weight of sandal seedlings affected by different hosts (270 DAP).

	Root dry weight (g)
Sandal alone	2.08^{A}
Sandal+ Pongamia	1.99^{A}
Sandal+ Divi divi	1.89^{B}
Sandal+ Erythrina	1.78^{C}
Sandal+ Casuarina	1.87^{BC}
Sandal+ Lantana	1.86^{BC}
P	0.000
SEM	0.030
Figures having the same alphabet do not differ significantly	

Table 20. Root dry weight of sandal seedlings affected by soil moisture stress (270 DAP).

Irrigation	**Root dry weight (g)**
Once in 3 days	1.89
Once in 6 days	1.94
P	0.003
SEM	0.011

Table 21. Interaction effects of different hosts and irrigation levels on the root dry weight of sandal seedlings (270 DAP).

	Root dry weight (g)	
Irrigation	Once in 3 days	Once in 6 days
Sandal alone	2.01	2.15
Sandal+ Pongamia	1.99	2.00
Sandal+ Divi divi	1.88	1.91
Sandal+ Erythrina	1.76	1.79
Sandal+ Casuarina	1.83	1.89
Sandal+ Lantana	1.84	1.88
P	NS	
SEM	0.026	

Table 22. Total dry weight of sandal seedlings affected by different hosts (270 DAP).

	Total dry weight (g)
Sandal alone	5.29 ^{A}
Sandal+ Pongamia	5.09 ^{B}
Sandal+ Divi divi	4.99 ^{B}
Sandal+ Erythrina	4.69 ^{D}
Sandal+ Casuarina	4.94 ^{BC}
Sandal+ Lantana	4.79 ^{CD}
P	0.000
SEM	0.058
Figures having the same alphabet do not differ significantly	

Table 23. Total dry weight of sandal seedlings affected by soil moisture stress (270 DAP).

Irrigation	**Total dry weight (g)**
Once in 3 days	5.12
Once in 6 days	4.08
P	0.14
SEM	0.018

Table 24. Interaction effects of different hosts and irrigation levels on the total dry weight of sandal seedlings (270 DAP).

	Total dry weight (g)	
Irrigation	Once in 3 days	Once in 6 days
Sandal alone	5.32	5.25
Sandal+ Pongamia	5.15	5.03
Sandal+ Divi divi	5.00	4.99
Sandal+ Erythrina	4.74	4.65
Sandal+ Casuarina	4.91	4.97
Sandal+ Lantana	4.80	4.77
P	NS	
SEM	0.046	

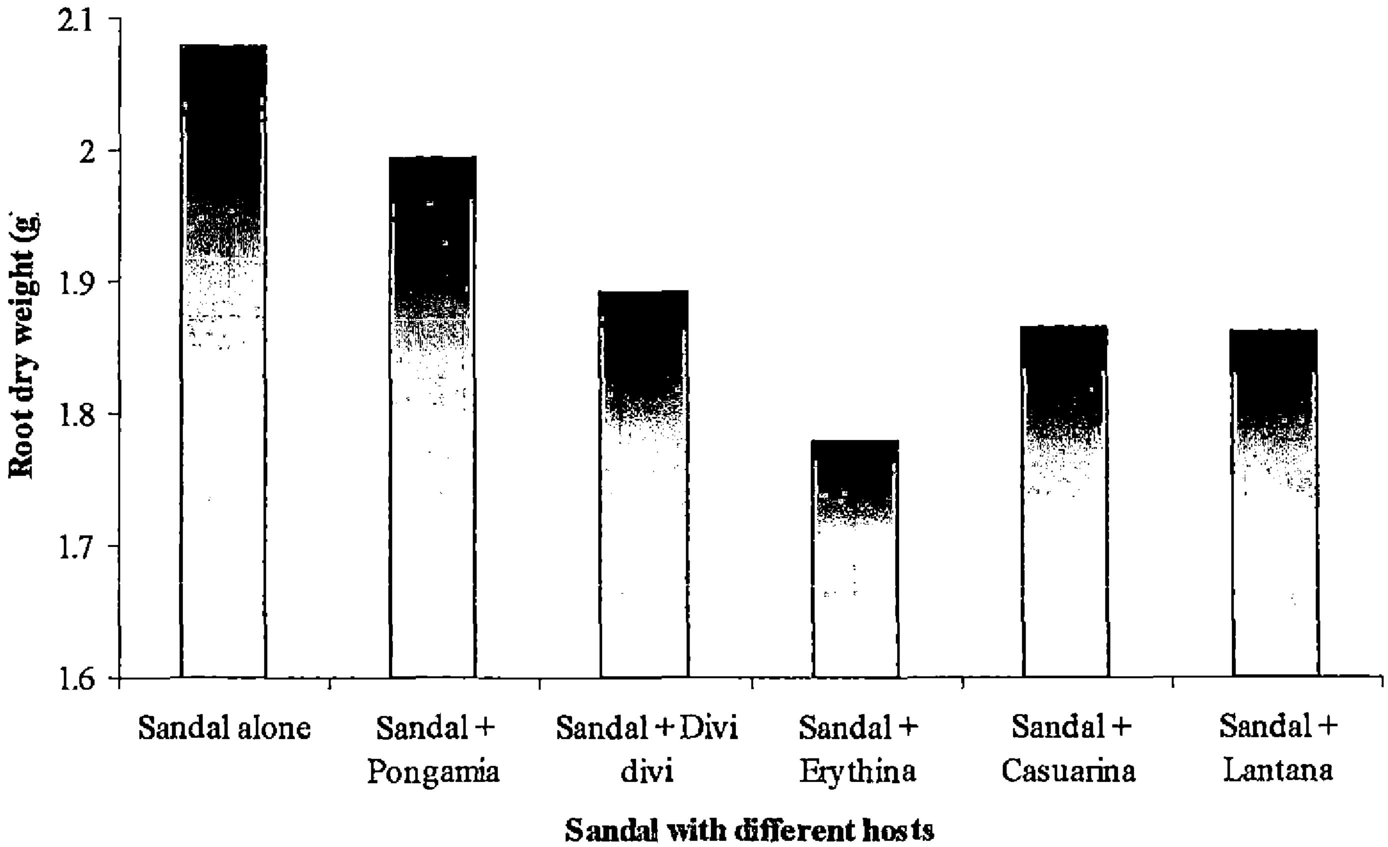

Fig.9. Influence of different hosts on root dry weight of sandal seedlings.

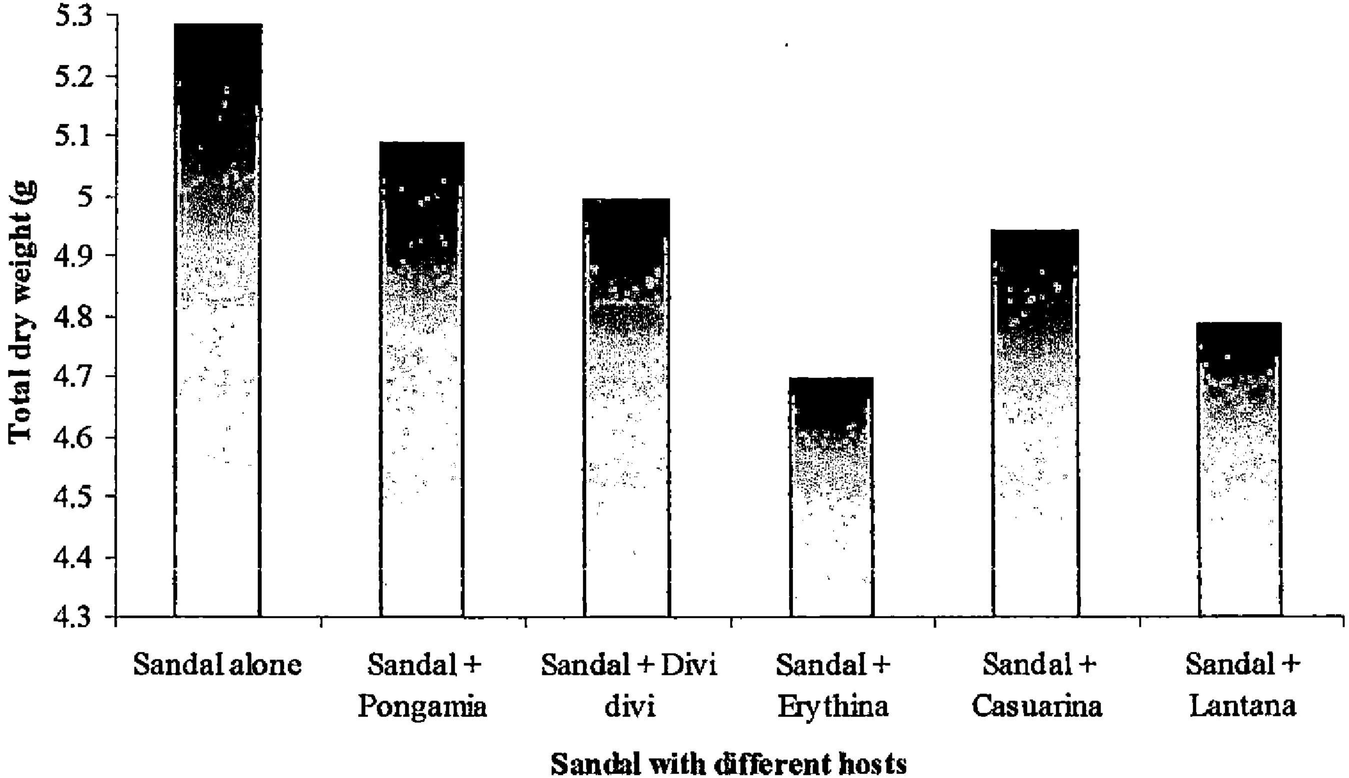

Fig. 10. Influence of different hosts on total dry weight of sandal seedlings.

4.1.9 Haustorial connections

The sandal seedlings with hosts were removed from the polybags and washed with water to remove the soil. The roots were examined visually for haustorial connections. No haustorial connections were observed during the period from 30 to 270 days after planting

4.2 PHYSIOLOGICAL PARAMETERS OF SANDAL

4.2.1 Pre-dawn water potential

The pre-dawn water potential of sandal seedlings after 270 days after planting are shown in Table 25 and 26 and Fig. 11. Sandal seedlings alone showed the highest value for pre-dawn water potential which was on par with *Casuarina equisetifolia* as host. This was followed by sandal seedlings with *Pongamia* or *Caesalpinia* or *Lantana* as hosts. The least pre dawn water potential was shown by sandal seedlings with *Erythrina indica* as host.

Sandal seedlings irrigated once in three days showed significantly high pre-dawn water potential compared to sandal seedlings irrigated once in six days. The interaction effects of different hosts and irrigation levels on pre-dawn water potential of sandal seedlings (Table 27.) were not significantly different.

4.2.2 Transpiration rate

The transpiration rate of sandal seedlings at 8:00 hrs was found to vary significantly during 30 and 60 days after planting, with different hosts. The transpiration rate at 8:00 hrs from 30 to 270 days after planting is shown in Table 28 and 29 and Fig. 12. At 30 days after planting, highest transpiration rate was when the host was *Casuarina equisetifolia* which was on par with the sandal seedlings with hosts *Pongamia, Caesalpinia, Lantana* and sandal seedlings without host. At 60 days after planting,

Table 25. Pre- dawn water potential of sandal seedlings affected by different hosts (270 DAP).

	Pre dawn water potential (MPa)
Sandal alone	1.89 [D]
Sandal+ Pongamia	2.02 [C]
Sandal+ Divi divi	2.01 [C]
Sandal+ Erythrina	2.31 [A]
Sandal+ Casuarina	1.93 [D]
Sandal+ Lantana	2.22 [B]
P	0.000
SEM	0.022
Figures having the same alphabet do not differ significantly	

Table 26. Pre- dawn water potential of sandal seedlings affected by soil moisture stress (270 DAP).

Irrigation	**Pre dawn water potential (MPa)**
Once in 3 days	1.93
Once in 6 days	2.20
P	0.000
SEM	0.018

Table 27. Interaction effects of different hosts and irrigation levels on the pre dawn water potential of sandal seedlings (270 DAP).

	Pre dawn water potential (MPa)	
Irrigation	Once in 3 days	Once in 6 days
Sandal alone	1.78	2.01
Sandal+ Pongamia	1.85	2.19
Sandal+ Divi divi	1.93	2.09
Sandal+ Erythrina	2.17	2.44
Sandal+ Casuarina	1.81	2.05
Sandal+ Lantana	2.02	2.43
P	NS	
SEM	0.043	

Table 28. Influence of different hosts on transpiration rate at 8:00 hrs of sandal seedlings.

	Transpiration (µg H_2O $cm^{-2}s^{-1}$)								
	Days after planting								
	30	60	90	120	150	180	210	240	270
Sandal alone	1.04^{AB}	1.10^{B}	1.17	1.47	2.12	1.95	1.84	1.71	3.71
Sandal+ Pongamia	1.04^{AB}	0.99^{B}	0.98	1.85	1.93	2.02	1.67	1.63	3.64
Sandal+ Divi divi	1.01^{AB}	2.01^{A}	1.05	1.98	1.49	1.84	1.39	2.62	3.91
Sandal+ Erythrina	0.82^{B}	1.09^{B}	1.19	1.58	1.44	1.94	1.49	1.84	3.54
Sandal+ Casuarina	1.18^{A}	1.30^{B}	1.07	1.91	1.40	1.47	1.44	1.76	3.77
Sandal+ Lantana	1.02^{AB}	1.01^{B}	1.29	1.79	2.02	1.72	2.03	1.95	3.69
P	0.052	0.003	NS	NS	NS	NS	NS	NS	NS
SEM ±	0.066	0.149	0.167	0.185	0.353	0.266	0.224	0.245	0.293

Figures having the same alphabet do not differ significantly

Table 29. Influence of soil moisture stress on transpiration rate at 8:00 hrs of sandal seedlings.

	Transpiration (µg H_2O $cm^{-2}s^{-1}$)								
	Days after planting								
	30	60	90	120	150	180	210	240	270
Irrigation once in 3 days	1.39 ^{A}	1.73 ^{A}	1.52 ^{A}	2.51^{A}	2.27 ^{A}	1.95 ^{A}	2.12 ^{A}	2.17 ^{A}	4.15 ^{A}
Irrigation once in 6 days	0.65 ^{B}	0.78 ^{B}	0.73 ^{B}	1.02 ^{B}	1.19 ^{B}	2.6 ^{B}	1.17 ^{B}	1.66 ^{B}	3.28 ^{B}
P	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.011	0.000
SEM ±	0.039	0.087	0.101	0.113	0.101	0.133	0.110	0.119	0.127

Figures having the same alphabet do not differ significantly

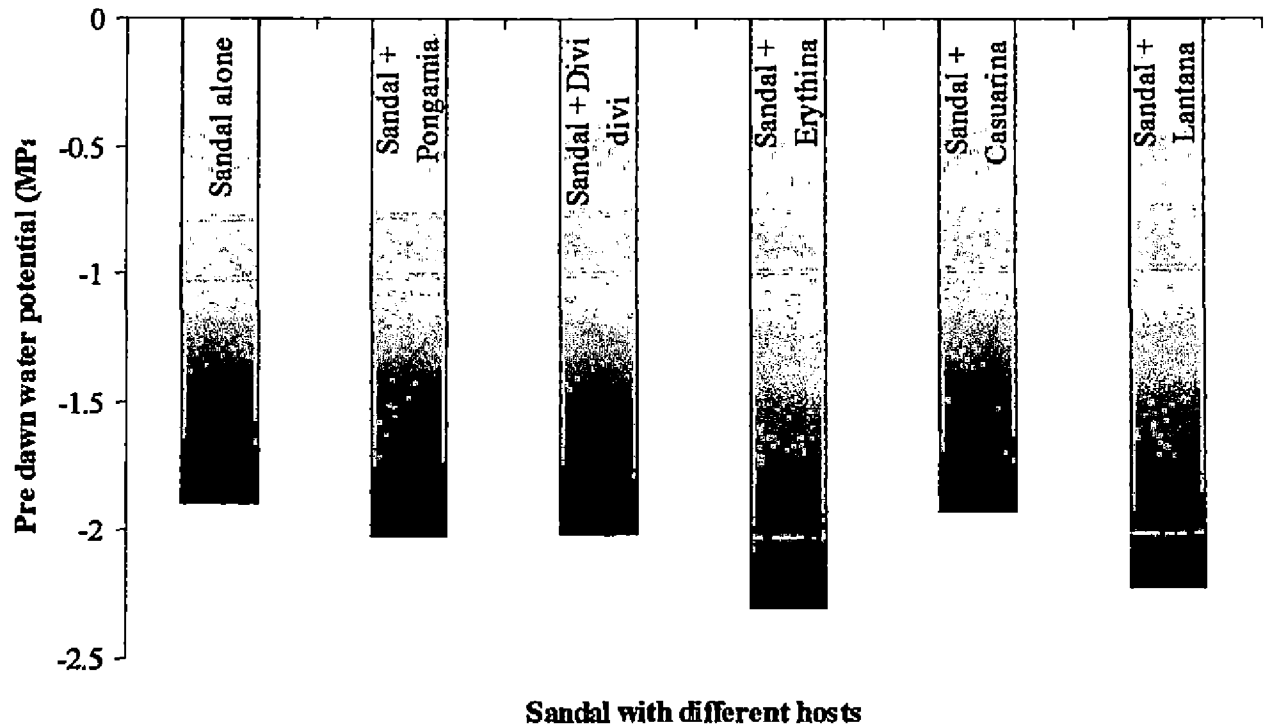

Fig. 11. Influence of different hosts on pre dawn water potential of sandal seedlings.

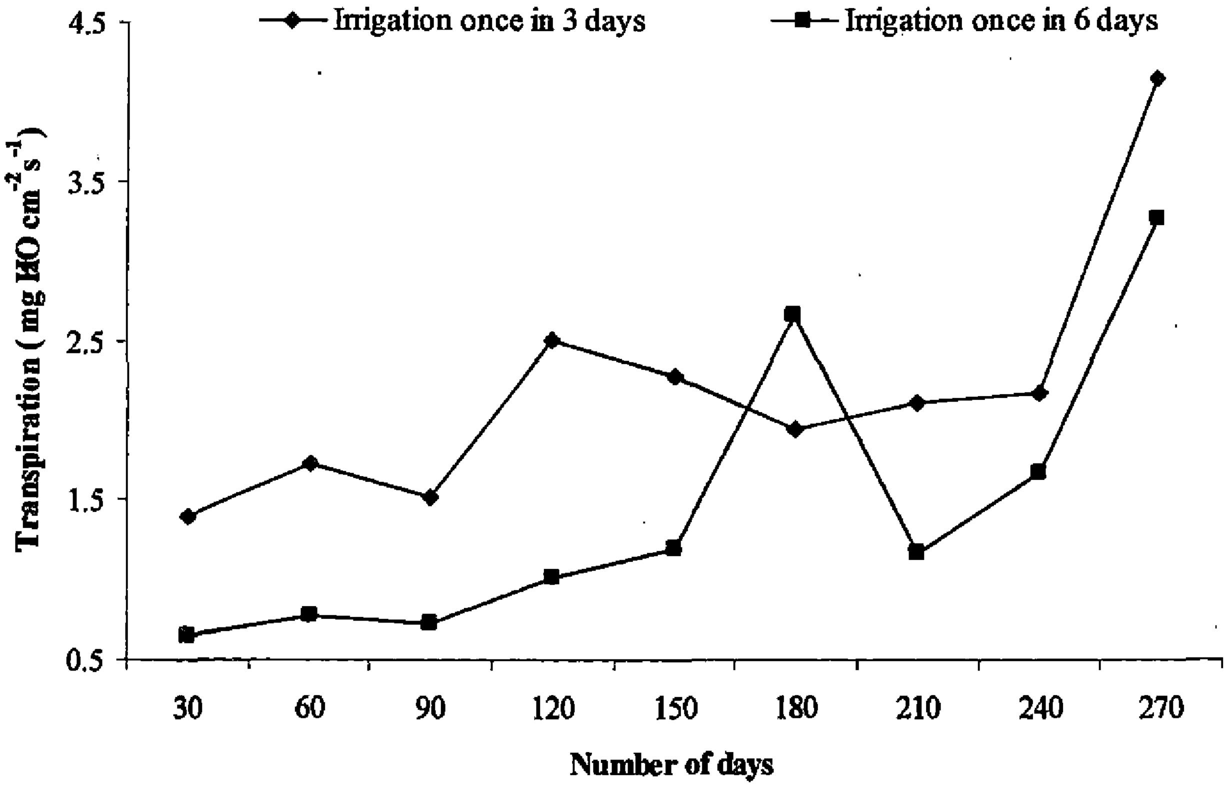

Fig. 12. Influence of soil moisture stress on transpiration rate of sandal seedlings at 8:00 hrs.

maximum transpiration rate was observed when the host was *Caesalpinia*. Transpiration rate of sandal seedlings with other hosts and sandal seedlings were on par. However, from 90 to 270 days after planting transpiration rate of sandal seedlings was not influenced by the host. In sandal seedlings, the value of transpiration rate at 8:00 hrs was significantly more in seedlings irrigated once in three days than that irrigated once in six days during the entire period from 30 to 270 days after planting.

The interactions of different hosts and irrigation levels on the transpiration rate at 8:00 hrs of sandal seedlings is shown in Table 30. The interaction effects were found to be significant only at 60^{th} day after planting. Sandal seedlings with *Caesalpinia coriaria* as host and irrigated once in three days showed more transpiration rate.

The transpiration rate at 14:00 hrs, from 30 to 270 days after planting is shown in Tables 31 and 32 and Fig. 13. The transpiration rate at 14:00 hrs was found to be significantly different for sandal seedlings with different hosts only at 240^{th} day after planting. The transpiration rate at 14:00 hrs was more in seedlings irrigated once in three days than that irrigated once in six days.

The interaction effects of different hosts and irrigation levels on the transpiration rate of sandal seedlings at 14:00 hrs is shown in Table 33. The interaction effects were not found to be significant.

Table 30. Interaction effects of different hosts and irrigation levels on the transpiration rate at 8:00 hrs of sandal seedlings.

	Transpiration (µg H_2O $cm^{-2}s^{-1}$)																	
	Days after planting																	
	30		60		90		120		150		180		210		240		270	
Irrigation	Once in 3 days	Once in 6 days	Once in 3 days	Once in 6 days	Once in 3 days	Once in 6 days	Once in 3 days	Once in 6 days	Once in 3 days	Once in 6 days	Once in 3 days	Once in 6 days	Once in 3 days	Once in 6 days	Once in 3 days	Once in 6 days	Once in 3 days	Once in 6 days
Sandal alone	1.44	0.66	1.43^{BC}	0.77^{CDE}	1.46	0.88	2.00	0.94	2.58	1.66	2.86	1.03	2.44	1.23	1.89	1.52	4.18	3.25
Sandal+ Pongamia	1.45	0.63	1.33^{BCDE}	0.67^{DE}	1.31	0.64	2.36	1.34	2.30	1.56	2.97	1.06	2.46	0.89	1.85	1.40	3.86	3.42
Sandal+ Divi divi	1.47	0.55	3.17^{A}	0.86^{CDE}	1.54	0.56	2.90	1.11	2.14	0.9	2.81	0.87	1.79	1.00	1.98	2.26	4.34	3.49
Sandal+ Erythrina	1.21	0.44	1.46^{BC}	0.74^{CDE}	1.51	0.87	2.24	0.91	2.00	0.9	2.87	1.01	1.78	1.20	2.21	1.47	3.99	3.10
Sandal+ Casuarina	1.42	0.94	1.68^{A}	0.99^{BCDE}	1.30	0.83	2.77	1.06	2.03	0.8	2.08	0.86	1.84	1.03	1.98	1.53	4.36	3.18
Sandal+ *Lantana*	1.35	0.69	1.38^{BCD}	0.63^{E}	1.99	0.61	2.81	0.79	2.58	1.4	2.38	1.06	2.39	1.67	2.09	1.80	4.17	3.22
P	NS		0.034		NS		NS		NS		NS		NS		NS		NS	
SEM ±	0.09		0.21		0.24		0.28		0.25		0.32		0.27		0.29		0.31	
Figures having the same alphabet do to differ significantly																		

Table 31. Influence of different hosts on transpiration rate at 14:00 hrs of sandal seedlings.

	Transpiration rate (µg H_2O $cm^{-2}s^{-1}$)								
	Days after planting								
	30	60	90	120	150	180	210	240	270
Sandal alone	3.00	2.52	2.67	3.61	3.65	2.60	3.06	3.29^{A}	4.00
Sandal+ Pongamia	3.15	2.47	1.89	3.01	3.20	2.47	2.79	3.11^{A}	4.16
Sandal+ Divi divi	2.73	2.98	2.23	3.00	2.29	2.62	3.67	2.28^{B}	4.05
Sandal+ Erythrina	2.30	3.14	2.51	2.99	3.02	2.89	3.01	3.01^{A}	3.92
Sandal+ Casuarina	2.53	3.22	2.34	3.64	2.07	2.68	2.89	2.94^{A}	3.76
Sandal+ Lantana	2.59	2.74	2.51	3.23	2.76	2.92	3.21	3.16^{A}	3.95
P	NS	NS	NS	NS	NS	NS	NS	0.02	NS
SEM $\pm$	0.233	0.256	0.292	0.203	0.372	0.199	0.266	0.179	0.263
Figures having the same alphabet do to differ significantly									

Table 32. Influence of soil moisture stress on transpiration rate at 14:00 hrs of sandal seedlings.

	Transpiration (µg H_2O $cm^{-2}s^{-1}$)								
	Days after planting								
	30	60	90	120	150	180	210	240	270
Irrigation once in 3 days	3.39	3.69	3.49	4.21	4.21	4.14	4.03	3.67	4.14
Irrigation once in 6 days	2.04	1.99	1.23	2.28	1.67	1.24	2.19	2.27	3.81
P	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	NS
SEM ±	0.195	0.129	0.157	0.184	0.139	0.136	0.187	0.154	0.140
Figures having the same alphabet do to differ significantly									

Table 33. Interaction effects of different hosts and irrigation levels on the transpiration rate at 14:00 hrs of sandal seedlings.

	Transpiration (µg H_2O $cm^{-2}s^{-1}$)																	
	Days after planting																	
	30		60		90		120		150		180		210		240		270	
Irrigation	Once in 3 days	Once in 6 days	Once in 3 days	Once in 6 days	Once in 3 days	Once in 6 days	Once in 3 days	Once in 6 days	Once in 3 days	Once in 6 days	Once in 3 days	Once in 6 days	Once in 3 days	Once in 6 days	Once in 3 days	Once in 6 days	Once in 3 days	Once in 6 days
Sandal alone	3.60	2.39	3.51	1.52	3.98	1.34	4.63	2.58	4.95	2.34	3.98	1.22	3.82	2.30	4.00	2.59	4.59	3.41
Sandal+ Pongamia	4.02	2.27	3.49	1.44	2.84	0.95	3.95	2.07	4.24	2.16	4.00	0.94	3.81	1.78	4.12	2.10	4.08	4.22
Sandal+ Divi divi	3.68	1.77	3.97	1.98	3.33	1.12	4.11	1.88	4.40	1.44	3.70	1.53	4.41	2.93	2.85	1.72	4.20	3.90
Sandal+ Erythrina	2.81	1.79	3.44	2.80	3.55	1.47	3.81	2.17	4.41	1.62	4.83	0.92	3.84	2.18	3.37	2.64	3.81	4.02
Sandal+ Casuarina	3.12	1.93	4.23	2.20	3.47	1.19	4.63	2.63	3.22	0.91	4.09	1.26	4.03	1.75	3.70	2.17	4.02	3.49
Sandal+ Lantana	3.11	2.08	3.50	1.98	3.73	1.29	4.10	2.35	4.01	1.50	4.25	1.58	4.23	2.18	3.95	2.38	4.09	3.80
P	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
SEM ±	0.48		0.32		0.38		0.45		0.34		0.33		0.459		0.376		0.34	

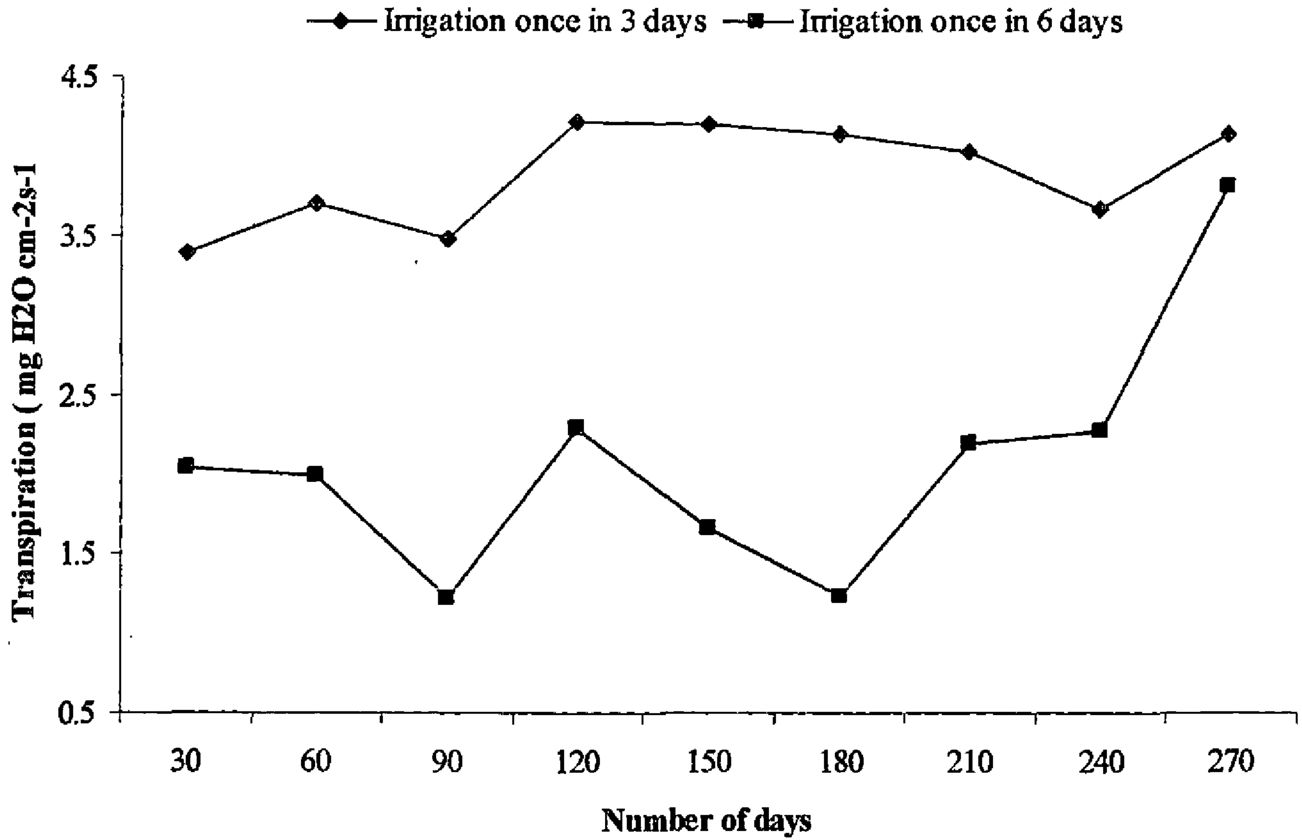

Fig. 13. Influence of soil moisture stress on transpiration rate of sandal seedlings at 14:00 hrs.

DISCUSSION

5. DISCUSSION

Sandal is considered to be a hemi-parasite, which requires the support of a host plant for its establishment and normal growth. The interaction effects of sandal and host plants are so complex that the role of host plants on the growth of sandal seedlings is not yet understood unambiguously. The influence of different host plants on the growth of sandal seedlings is one criterion that is studied in this project. The other aspect is the effect of soil moisture stress on the growth of sandal seedlings.

Complimentary effects of host plants on sandal nutrition were dealt in most of the earlier studies (Iyengar (1965), Ananthapadmanabha (1984), Rangaswamy *et al.* (1986) and Varghese (1996)). However, the result obtained were not enough to have a common conclusion. The role of host plants on the water balance of sandal investigated by Hiremath (2004). The interactive effects of different hosts and soil moisture stress on the growth of sandal seedlings were not investigated in detail. The differences in response of sandal seedlings with different hosts like *Pongamia pinnata, Caesalpinia coriaria, Erythrina indica, Casuarina equisetifolia* and *Lantana camar*a are discussed with regard to the results obtained.

Growth parameters

The growth of sandal seedlings with and without hosts was similar in most cases. However, significant variations were observed in the growth characters of sandal, like height, collar diameter, shoot dry weight, leaf area and root growth due to the influence of some of the hosts and water stress. As no haustorial connections were seen up to 270 days after planting, the variations obtained cannot be attributed to host parasitic relationships, but to the above ground or below ground competition for nutrients and water.

The decrease in the growth parameters of sandal seedlings observed with some of the hosts compared to sandal seedlings alone can be attributed to the competition from the host. The failure in haustoria may be because of the very low light conditions prevailed inside the glass house. Hiremath (2004) also observed haustorial connections only after 300 days after planting. Kamalolbhavan (2002) observed that the number of leaves of sandal were least when grown under 75 per cent shade.

Sandal seedlings showed more collar diameter when grown alone compared to sandal seedlings grown with different hosts. Sandal seedlings grown with *Erythrina indica* showed the least diameter growth. This clearly shows that the above ground competition of sandal with host decreases the collar diameter.

Observations made on the root length showed the significant difference with different hosts. Maximum root length was shown by sandal alone. The decrease in root length is due to the competition from host plants. Hiremath (2004) also recorded a decrease in root length due to the influence of host. Lott *et al.* (2000) reported a decrease in root length due to competition from component plants in a multi-cropping system involving grevellia and maize. Divakara *et al.* (2001) reported decrease in root length due to root competition in a system involving bamboo, vateria and teak and Thomas *et al.* (1998) in a system involving ginger and *Ailanthus triphysa*. Tilman (1982) suggested that competition from adjoining roots for the resources could result if roots of one plant deplete the soil resources more quickly than roots of others.

There was significant variation in the shoot dry weight with different hosts. Sandal seedlings alone showed more shoot dry weight. As there was no haustorial connection, the difference in shoot dry weight was due to the competitive interactions. The trend was same with root dry weight and total biomass.

As the levels of water stress increased, the sandal seedlings showed a significant decrease in height, with all host species. Reduction in plant height of sandal due to water stress was observed by Hiremath, 2004. Cannel *et al.* (1978) observed reduction in stem elongation due to water stress in loblolly pine. Rajesh (1996) reported a reduction in shoot elongation rate due to water stress in *Ailanthus triphysa, Acacia mangium, Switenia macrophylla, Pterocarpus marsupium* and *Tectona grandis.*

Rajesh (1996) observed that there was decrease in the number of leaves and leaf area with increasing levels of water stress in *Ailanthus triphysa, Acacia mangium, Switenia macrophylla, Pterocarpus marsupium* and *Tectona grandis.* Wiley (1982) reported that when more than one plant species is grown on the same unit of land there are chances of both complementary and competitive responses. As no haustorial connections were observed between hosts and sandal the reduction in leaf number and area may be attributed to the competition for light. Reduction in number of leaves was observed in *Eucalyptus* spp. (Myers and Landsberg, 1989) and *Fagus sylvatica* (Cermack *et al.* 1993) with reduction in light.

As the levels of water stress increased, the collar diameter deceased. Hiremath (2004) also observed the same trend. Kallarackal and Soman (1992) reported adverse interference on cambial growth of *Acacia auriculiformis* due to water stress. Zahner (1968) also observed variation in the xylem increment of forest trees due to water deficit.

With the increase in water stress, root length increased. The water stress might have induced the root to grow more in search of water. Awang and Dechavez (1993) observed similar responses in *Acacia mangium.* There were significant decreases in the shoot dry weight, root dry weight and total biomass with increase in water stress.

So in the wake of the results of the present experiment, the recommendation of the requirement of a host species right from the seedling stage needs further investigation. As there was no haustorial connection up to 300 days after planting, there should a separate study on the influence of light conditions and haustorial formation.

Physiological parameters

There was significant difference in the transpiration rate when sandal is planted with different hosts during 30, 60 and 240 days after planting. Transpiration at 14:00 hrs was more compared to that at 8:00 hrs. This may be because the stomata of sandal may be opening more in the after noon hours. Kozlowski *et al.* (1999) reported that stomatal opening and closing in plants are influenced by solar radiation, temperature and humidity. There was a significant decrease in the transpiration rate with increased water stress. Kozlowski (1982) reported partial closure of stomata in many tree species in response to water stress. Landsberg and Jarvis (1976) reported that water stress becomes a factor for closure of stomata, when the water potential falls quiet low.

Sandal seedlings alone showed more water potential. Lower water potential enhanced the efficiency of plant in extracting soil moisture during drought. Tennakoon *et al.* (2000) reported more negative water potential for sandal than that with the hosts. Taide (1992) reported probability of host plants contributing to maintaining the internal water balance of sandal. Water stress decreased the water potential. Rajesh (1996) observed lower water potential in *Pterocarpus marsupium* and *Acacia mangium* subjected to water stress. Lower water potential observed in sandal seedlings grown with hosts may be due to competition between sandal and host.

The results obtained from the present study shows no positive influence of hosts on the growth parameters of sandal during its early stages of growth. As the sandal seedlings survived 270 days after planting without any haustorial connection, the species may be autotrophic evolutionary during the early phase. The interactions between host and sandal seedlings need to be more carefully investigated after the haustorial formation. The influence of light on the haustorial formation also has to be investigated. So the necessity of host species is questionable at the earlier stages of sandal growth.

SUMMARY AND CONCLUSIONS

6. SUMMARY AND CONCLUSIONS

Experiments were conducted at College of Forestry, Kerala Agricultural University, Vellanikkara during 2004-05 to study the influence of different hosts and soil moisture stress on the growth and water relation in sandal (*Santalum album* Linn). The salient features of the study are summarized below.

1. Sandal seedlings with and without host showed similar height increment, except when erythrina was the host.
2. The host plant had no influence on most of the growth parameters of sandal seedlings.
3. Erythrina as host decreased the height of sandal seedlings.
4. The collar diameter of sandal seedlings with and without host was on par during the early seedling stage and by 270 DAP sandal alone showed the highest collar diameter.
5. Water stress decreased the seedling height, collar diameter, number of leaves, leaf area, shoot dry weight and total dry weight of sandal seedlings.
6. Fully irrigating the pots once in three days resulted in better growth of sandal seedlings as compared to irrigation once in six days.
7. Water stress increased the root length and root dry weight.
8. Root length was found to be more for sandal seedlings which were irrigated once in six days compared to that irrigated once in three days.
9. Leaf area does not show any significant difference with different hosts.
10. Water stress decreased leaf area of sandal seedlings.
11. Haustorial connections were not observed between the roots of sandal and hosts up to 270 DAP.
12. Transpiration rate at 14:00 hrs was found to be more than the transpiration at 8:00 hrs.
13. Transpiration rate decreased with increase in soil moisture stress.
14. Pre dawn water potential was lower for sandal seedlings irrigated once in six days compared to that irrigated once in three days.

CONCLUSIONS

The sandal seedlings without host performed on par or better compared to sandal seedlings with hosts. The water stress substantially reduced most growth parameters of sandal seedlings. The haustorial connections were not observed up to 270 days after planting. So the necessity for the host during early phase for the sandal seedlings needs review. As the experiment was conducted in a shade house which receives 25% of the sun light, the influence of light on haustorial formation has to be studied. The conclusion about the necessity of the host plant can be arrived at only after the studies of the performance of sandal seedlings with different hosts in field conditions. Even if we are going for host, the host should be selected in such a way as to reduce the competition for scarce resources, as the over head competition for light and below ground competition for water and nutrients with the host decrease the sandal growth.

REFERENCES

REFERENCES

Alberte, R.S., Thombee, J.P. and Fiscus, E.L. 1977. Water stress effects on the content and organization of chlorophyll in mesophyll and bundle sheath chloroplasts of maize. *Plant Physiol.* 59: 351-353.

Ananthapadmanabha, H.S., Rangaswamy, C.R., Sharma, C.R., Nagaveni, B.C., Jain, H.C. and Krishnappa, B.P. 1984. Host requirement of sandal. *Indian For.* 84: 264-268.

Awang, K. and Dechavez, C.G. 1993. Effect of root wrenching and controlled watering on growth, drought resistance and quality of bare rooted seedlings of *Acacia mangium. J Trop. For. Sci.* 5: 309-321.

Balasundaran, M. 1998. A method for clonal propagation of sandal. In: Radomiljac, A. M., Ananthapadmanabha, B.S., Welbourn, R.M. and SatyanarayanaRao, K. (Ed.). *Proc. of ACIAR conference on sandal at Institute of Wood Science and Technology, Bangalore, India from* 18th to 19th December, 1997. No. 84. pp 126-129.

Barber, C.A. 1902. The natural history of the sandal tree. *Indian For.* 29: 386-389.

Barber, C.A. 1907. Studies in root parasitism. Mem. Deptt. Agric., *Indian Bot.* 1: 1-58.

Batten, D.J., Mc Conchie, C.A. and Lloyd, J. 1994. Effects of soil water deficit on gas exchange characteristics and water relations of orchard lychee *(Litchi chinesis* Sonn.) trees. *Tree Physiol.* 14: 1177- 1189.

Beda, N., Cochard, H., Dreyer, E. and Granier, A. 1993. Water transfer in a mature oak stands *(Quercus petaea)* seasonal evolution and effect of severe drought. *Can.* 1. *For. Res.* 23: 1136-1143.

Cannel, M., Bridewater. F. and Greenwood, M. 1978. Seedlings growth rates, water stress response and root shoot relationships related to eight year volumes among families of *Pinus taeda* L. *Silvae genet.* 27: 273-248.

Cermak, J. Matyssek, R. and Kucera, J. 1993. Rapid response of large drought stressed beech trees to irrigation. *Tree Physiol.* 12: 281-290.

Chung, H.H. and Kramer, P.J. 1975. Absorption of water and ^{32}P through suberised and unsuberised roots of loblolly pine. *Can. J. For. Res.* 5: 229-235.

Davies, W.J., Kozlowski, T.T. and Pereira, J. 1974. Effect of wind on transpiration and stomatal aperture of woody plants. Mechanisms of regulation of plant growth. In: Bieleski, R.L., Ferguson, A.R. and Cresswell, M.M. (Ed.). *Bull. Royal Soc. New Zealand. No.* 12: 433-438.

Divakara, B.N., Kumar, B.M., Balachandran, P.V. and Kamalam, N.V. 2001. Bamboo hedgerow systems in Kerala, India: Root distribution and competition with trees for P. *Agrofor. Syst.* 51: 189-200.

Driessche, V.D.R. 1991. Influence of container nursery regimes on drought resistance of seedlings following planting. II. Stomatal conductance, SLA and root growth capacity. *Can. J. For. Res.* 21: 566-572.

Ellsworth, D.S. and Reich, P.B. 1992. Water relations and gas exchange of *Acer saccharum* seedlings in contrasting natural light and water regimes. *Tree Physiol.* 10: 1-20.

Evans, J.R. 1983. Nitrogen and photosynthesis in the flag leaf of wheat (*Triticum aestivum L.*). *Plant physiol.* 72:297-302.

Fox J.E.D., Brand, J.E., Barret, D.R. 1994. Silvicultural characteristics associated with the ecology and parasitic habit of sandalwood. Sandalwood workshop, August, New Caledonia. CIRAD/FAO, Rome. pp 104-125.

Fox, J.E.D., Surata, I.K. and Sutarjo, S. 1990. Nursery potting mixture for sandal in Timor. *Mulga Res. Cent. J.* 10: 38-44.

Freed, R. 1986. MST A T Version 1.2. Department of Crop and Soil Sciences. Michigan State University, USA.

Giles, K.L., Beardsell, M.F. and Cohen, D. 1974. Cellular and ultra structural changes in mesophyll and bundle sheath cell of maize in response to water stress. *Plant Physiol.* 54: 208- 212.

Guehl, J.M., Aussenace, G., Bouachrine, J., Zimmeramann, R., Pennes, J.M., Ferhi, A. and Griev, P. 1991. Sensitivity of leaf gas exchange to atmoSpheric drought, soil drought and water use efficiency in some Mediterranean *Abies* spp. *Can. J. For. Res.* 21: 1507-1515.

Hirmath, V.J. 2004. Influence of soil moisture regimes and stage of host introduction on the seedling growth of sandal provinces. MSc thesis, Kerala Agricultural University, Thrissur, Kerala. p 149.

Iyengar, A.U. 1965. The physiology of the root parasitism in sandal (*Santalum album* Linn). *Indian For.* 91: 246-256.

Jain, S.H., Angadi, V.G., Rajeevalochan, A.N., Shankarnarayana, K.H., Theagarajan, K.S. and Rangaswamy, C.R. 1998. Identification of provenances of sandal in India for genetic conservation. *Proc. of ACIAR conference on sandal at Institute of Wood Science and Technology, Bangalore, India from 18th to 19th December, 1997.* No. 84. pp 117-120.

Kallarackal, J. and Somen, C.K. 1992. Water use of selected indigenous and exotic tree species. KFRI Research Report No. 86. Kerala Forest Research Institute, Peechi, Thrissur, Kerala. India.

Kamalolbhavan, B.N. 2002. Response of sandal (*Santalum album* Linn.) seedlings to shade and mycorrhizal association. MSc thesis, Kerala Agricultural University, Thrissur, Kerala. p 64.

Kireger, E.K and Blake. T.J. 1994. Genetic variation in dry matter production, water use efficiency and survival under drought in four *Acacia* species studied in Baringo, Kenya. In: Bryan, RB. (Ed.) Soil erosion, land degradation and soil transition: geological analysis of semi arid tropical region. pp 195-204.

Kozlowski, T.T. 1976. Water relations and tree improvement. In: Cannel, M. and Last, F.T. (Ed.). Tree physiology and yield improvement. Academic Press, London. pp 307-327.

Kozlowski, T.T. 1982. Water supply and tree growth. Part 1. Water deficits. *For. Absl.* 43: 57-95

Kozlowski, T.T., Kramer, P.I. and Pallardy, S. G. 1991. The physiological ecology of woody plants. Academic Press Inc., San Diego, California. p 657.

Kozlowski, T.T. and Pallardy, S. G. 1979. Effects of low temperatures on leaf diffusion resistance of *Ulmus americana* and *Fraxinus pennsylvanica* seedlings. *Can. J Bot.* 57: 2466-2470.

Kramer, P.J. 1969. Plant and soil water relationships: A modem synthesis. Mc Grew and Hill, New York. p 251.

Kramer, P.J. 1980. Drought stress and the origin of adaptations. In: Turner, N.C and Karmer, P.J (Ed.). Adaptations of plants to water and high temperature stress. Wiley, New York. Pp 7-20.

Kramer, P.J. 1983. Water relations of plants. Academic Press, New York. p 259.

Kramer, P.J. and Kozlowski, T.T. 1979. Physiology of woody plants. Academic Press. New York. p 469.

Landsberg, J.J. and Jarvis. P.G. 1976. A numerical investigation of the momentum balance of a spruce forest. *J. Appl. Ecol.* 10:645-655.

Lange, O.L., Ullmann, J.D., Tenhunen, J.D. and Bannister, P. 1987. Stomatal conductance and transpiration of two faces of *Acacia* phyllodes. *Trees* 1: 110- 122.

Lott, J. E., Howard, S. B., Ong, C. K. and Black, C. R. 2000. Long term productivity of a *Grivellia robusta* based over storey agro forestry system in semi-arid Kenya. II Crop growth and system performances. *For. Ecol. Manage.* 139: 187-201.

Lushington, P.M. 1904. Notes on sandal. *Indian For.* 30: 13-15.

Mathew, T.K. 1995. Sandalwood in Kerala-past, present and future. Recent advances in research and management of sandal in India. In: R.A, Srimathi., H.D, Kulkarni, and K.R. Venketesan (Eds.) Associated Publishing Company. New Delhi. pp 53-57.

Momen, B., Menre. J.W. and Welker, J.M. 1992. Tissue water relations of *Quercus wiblizeni* seedlings: drought resistance in California evergreen oak. *Acta. Decal.* 13: 127-136.

Myers, B.J. and Landsberg, J.J. 1989. Water stress and seedlings growth of two eucalypt from contrasting habitats. *Tree Physiol.* 5: 207-218.

Pallardy, S.G. and Kozlowski, T.T. 1979. Relationship of leaf diffusion resistance of Populus clones to leaf water potential and environment. *Oecologia* 40: 371-380.

Pessin, L.J. 1939. Density of stocking and character of ground cover a factor in long leaf reproduction. *J. For.* 37: 255-258.

Phillips, J.G. and Riha, S.J. 1993. Canopy development and solar conversion efficiency in *Acacia auruclifornis* under drought stress. *Tree Physiol.* 12: 137-149.

Pilger, R. 1935. *Santalaceae.* In: Engler, A. and Prantl, K. (Eds). Die naturalichen pflanzen familien, Leipzig.

Radomiljac, A.M. 1994. Research trends in *Santalum* species –an emphasis in germplasm conservation and plantation establishment, Sandalwood workshop, August, New Caledonia . CIRAD/FAO, Rome.

Radomiljac. A.M. 1998. The influence of pot host species, seedling age and supplementary nursery nutrition on *Santalurn album* Linn. (Indian sandalwood). Plantation establishment, Ord river irrigation area, Western Australia. *For. Ecol. Manage.* 102: 193-202.

Rai, S.N. 1990. Status and cultivation of sandalwood in India. In: Hamilton, Land Gornad, C.E. (ed.). *Proc. of the symposium of sandalwood in the pacific from 9th to 11th April 1990; Honolulu, Hawaii.* PSW -122. pp 66-71.

Rai, S.N. and Kulkarni, H.D. 1986. Sandal wood plantations. In: Srivastava, H.C., Bharatendu,V. and Menon, K.K.G. (Eds). Plantation crops Vol.1. Opportunities and constraints. Oxford and IBH publishing Co., New Delhi. pp 295-300.

Rai, S.N. and Sarma, C.R. 1986. Relationship between height and diameter increment of sandal (*Santalum album* Linn.) *Van Vigyan* 24: 105-138.

Rajesh, N. 1996. Response of selected forestry and agro forestry tree seedlings to water stress. M.Sc thesis, Kerala Agricultural University, Thrissur, Kerala. p 155.

Rangaswamy, C.R, Jain, S.H. and Parthasarathi, K. 1986. Soil properties of some sandal bearing areas. *Van Vigan.* 24: 61-68.

Rao, L.N. 1942. Parasitism in Santalaceae. *Ann. Bot.* 6: 131-150.

Rao, M.R. 1903. Root parasitism of sandal trees. *Indian For.* 29: 386-389.

Rao, M.R. 1911. Host plants of the sandal tree *Indian For. Rec.* 2: 159-207.

Rao, M.R 1918. Host plants of *Santalum album. Indian For.* 44: 58.

Rhizopoulou, S. and Davies, W.J. 1993. Leaf and root growth dynamic in *Eucalyptus globulus* seedlings grown in dry soil. *Trees.* 8: 1-18.

Scot, J. 1871. Notes of Horticulture in Bengal. No.2. Loranthaceae the mistletoe order of their germination and mode of attachment. *J. Agric. Hort. Soc. Indian* 2: 287.

Seiler, J.R. 1985. Morphological and physiological changes in black alder induced by water stress. *Plant Cell Environ.* 8: 219-222.

Shinde, S.R., Ghatge, RD. and Mehetre, S.S.1993. Growth and development of sandalwood and its host *(Casuarina)* with teak in mixed plantation *Indian. J For.* 22: 253-257.

Sindhuveerendra, H.C. Ramalakshmi, S. Mallesha, B.B., Ananthapadmananbha, H.S. and Rangaswamy, C.R. 1998. Variation in seed characters in provenances of sandal (*Santulam album* Linn). *Proc. of ACIAR conference on sandal at Institute of Wood Science and Technology, Bangalore, India from 18th to 19th December, 1997.* No. 84. pp 123-125.

Slatyer, R.O. 1967. Plant water relationships. Academic Press. NewYork. p 336.

Slavik, B. 1974. Methods of studying plant water relations. Springer Verley. New York. p 449.

Srimathi, R.A., Babu, D.R.C. and Sreenivasaya, M. 1961. Influence of host plants on the amino acid make up of *Santalum album* Linn. *Current Sci.* 30: 417.

Srinivasan, V.V., Shivaramakrishan, V.R., Rangaswamy, C.R., Ananthapadmanabha, H.S. and Shankaranarayan, K. 1992. SANDAL (*Santalum album* Linn). Monograph by the Institute of Wood Science and Technology (ICFRE), Malleshwaram, Bangalore, India. p 233.

Stoneman, G.L, Turner, N.C. and Dell, B. 1994. Leaf growth, photosynthesis and tissue water relations of greenhouse grown *Eucalyptus marginata* seedlings in response to water deficits. *Tree Physiol.* 14: 633-646.

Surendran, C., Parthiban, K.L., Bhuvaneshwaram, C. and Murugesh, M. 1998. Silvicultural strategies for augmentation of sandal regeneration. *Proc. of ACIAR conference on sandal at Institute of Wood Science and Technology, Bangalore, India from 18th to 19th December, 1997.* No. 84. pp 69-73.

Taide, Y.B. 1991. Biology of the seedling of sandalwood (*Santalum album* Linn). M.Sc thesis. Kerala Agricultural University, Thrissur. p 69.

Tennakoon, K.U., Ekanayake, S.P. and Etampawala, E.R.L.B. 2000. An overview of *Santalumalbum* research in Sri Lanka. *Sandal wood Research Newsletter.* 11: 1- 4.

Thomas, J., Kumar, B.M., Wahid, P.A., Kamalam, N.V. and Fisher, R.F. 1998. Root competition for P between ginger and *Ailanthus triphysa* in Kerala, India. *Agrofor. Syst.* 41: 293-305.

Tilman, D. 1982. Resource competition and community structure. Princeton University Press. p 214.

Turner, N.C. and Kramer, P.J. 1980. Adaptation of plants to water and high temperature stress. John Wiley and sons. New York. p 52.

Turner, N.C., Otode, J.C., Cruz, R.T., Yanbao, E.B., Ahmad, S., Namuco, O.S. and Dihgkuhn, M. 1986. Response of seven diverse rice cultivars to water deficits, II. Osomotic adjustment, leaf elasticity, leaf extension, leaf death, stomatal conductance and photosynthesis. *Field Crops Res.* 13: 273-286.

Vance, N.C. and Running, S.W. 1985. Light reduction and moisture stress: effects of growth and water relations of western larch seedlings. *Can. J. For. Res.* 15: 72- 77.

Varghese, S. 1996. Parasitic interference of sandal *(Santalurn album* Linn.) on common agricultural crops from the homesteads. M.Sc thesis. Kerala Agricultural University, Thrissur. p 66.

Venkatesan, K.R. 1995. Sandal and social forestry. In: Srimathi, R.A., Kulkami, H.D. and Venkatesan, K.R. (Eds.). Recent advances in research and management of *Santalum album L.* in India. Associated Publishing Co. New Delhi. pp 199-206.

Waring, R.H. and Schlesinger, W.H. 1985. Forest ecosystems. Academic Press, Orlando, FL.

Wiley, R W. 1982. Intercropping and its importance and research needs - Part 1. Competition and yield advantages. *Field Crops Abst.*, 32: 1-10.

Zahner, R. 1968. Water deficits and growth of trees. In: Water deficits and plant growth. Vol. II. Kozlowski, T. T. (Ed.). Academic Press, London. pp 191-254.

APPENDICES

APPENDIX. I

Abstract of ANOVA table for height of sandal seedlings

Source	Degrees of freedom	Mean square								
		30 days	60 days	90 days	120 days	150 days	180 days	210 days	240 days	270 days
Hosts	5	1.034	1.808	1.761	2.185	3.074	5.233	6.872*	8.219**	10.992**
Irrigation	1	0.111	0.340	0.840	1.822*	2.778**	7.934**	16.538*	27.563**	120.855**
Error	12	2.277	2.422	2.519	2.547	2.436	2.451	2.81	2.133	2.124

* denotes significance at 5% level
** denotes significance at 1%level

APPENDIX. II

Abstract of ANOVA table for collar diameter of sandal seedlings

Source	Degrees of freedom	Mean square								
		30 days	60 days	90 days	120 days	150 days	180 days	210 days	240 days	270 days
Hosts	5	0.012	0.015**	0.017*	0.018**	0.023**	0.020**	0.033	0.032**	0.030**
Irrigation	1	0.008**	0.014*	0.028**	0.052**	0.070**	0.125**	0.198**	0.156**	0.221**
Error	12	0.004	0.003	0.004	0.004	0.004	0.003	0.015	0.005	0.004

* denotes significance at 5% level
** denotes significance at 1%level

APPENDIX. III

Abstract of ANOVA table for number of leaves of sandal seedlings

Source	Degrees of freedom	Mean square								
		30 days	60 days	90 days	120 days	150 days	180 days	210 days	240 days	270 days
Hosts	5	1.494	2.294	2.511	2.028	2.028	1.978	2.000	3.111	4.583
Irrigation	1	0.694	1.361	16.00	34.028*	26.694	28.444	25.00	25.00	17.361
Error	12	2.778	2.722	2.694	2.944	3.250	3.611	2.583	2.333	3.528

* denotes significance at 5% level

APPENDIX. IV

Abstract of ANOVA table for transpiration at 8 hours of sandal seedlings

Source	Degrees of freedom	Mean square								
		30 days	60 days	90 days	120 days	150 days	180 days	210 days	240 days	270 days
Hosts	5	0.080*	0.901**	0.080	0.235	0.627	0.244	0.379	0.790	0.094
Irrigation	1	4.928**	8.189**	5.554**	20.160**	10.368**	25.469**	8.075**	2.275**	6.86**
Error	12	0.026	0.134	0.168	0.204	0.749	0.423	0.302	0.362	0.514

* denotes significance at 5% level
** denotes significance at 1%level

APPENDIX. V

Abstract of ANOVA table for transpiration at 14 hours of sandal seedlings

Source	Degrees of freedom	Mean square								
		30 days	60 days	90 days	120 days	150 days	180 days	210 days	240 days	270 days
Hosts	5	0.583	0.604	0.451	0.555	1.637	0.179	0.577	0.761*	0.110
Irrigation	1	16.484**	26.197**	45.901**	33.486**	58.166**	75.690**	30.360**	17.584**	0.951
Error	12	0.326	0.393	0.51	0.247	0.830	0.237	0.424	0.193	0.416

* denotes significance at 5% level

** denotes significance at 1%level

APPENDIX. VI

Abstract of ANOVA table for shoot dry weight of sandal seedlings

Source	Degrees of freedom	Mean square
Hosts	5	0.076
Irrigation	1	0.082
Error	12	0.008

APPENDIX. VII

Abstract of ANOVA table for root dry weight of sandal seedlings

Source	Degrees of freedom	Mean square
Hosts	5	0.069**
Irrigation	1	0.026**
Error	12	0.006

** denotes significance at 1%level

APPENDIX. VIII

Abstract of ANOVA table for total biomass of sandal seedlings

Source	Degrees of freedom	Mean square
Hosts	5	0.269**
Irrigation	1	0.016*
Error	12	0.020

* denotes significance at 5% level

** denotes significance at 1%level

APPENDIX. IX

Abstract of ANOVA table for root length of sandal seedlings

Source	Degrees of freedom	Mean square
Hosts	5	11.900**
Irrigation	1	15.603**
Error	12	0.527

** denotes significance at 1%level

APPENDIX. X

Abstract of ANOVA table for pre dawn water potential of sandal seedlings

Source	Degrees of freedom	Mean square
Hosts	5	0.162**
Irrigation	1	0.675**
Error	12	0.003

** denotes significance at 1%level

APPENDIX. XI

Abstract of ANOVA table for leaf area of sandal seedlings

Source	Degrees of freedom	Mean square
Hosts	5	64.77
Irrigation	1	1144.35*
Error	12	78.662

* denotes significance at 5% level

INFLUENCE OF HOST PLANTS AND SOIL MOISTURE STRESS ON THE WATER RELATIONS IN SANDAL

By

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ABSTRACT OF THESIS

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ABSTRACT

The influence of host plants and soil moisture stress on water relations in sandal was investigated in a pot culture experiment at College of Forestry, Kerala Agricultural University, Vellanikkara. Five host plants, Divi divi (*Caesalpinia coriaria* Jacq.), Casurina (*Casuarina equisetifolia* J.R & H.G. Forst), Pongamia (*Pongamia pinnata* (L.) Pierre), Lantana (*Lantana camara* L.) and Erythrina (*Erythrina indica* Lamk.) were selected for this study.

The results showed that Sandal seedlings with and without host showed similar height increment, except when erythrina was the host. The host plant had no influence on most of the growth parameters of sandal seedlings. The collar diameter of sandal seedlings with and without host was on par during the early seedling stage and by the end of the experimental period it showed a significant difference. There was no significant difference in the number of leaves, leaf area and root length of sandal with different hosts. Haustorial connections were not recorded even after the experimental period. Sandal seedlings with *Erythrina indica* as host decreased the pre dawn water potential.

Water stress decreased the seedling height, collar diameter, number of leaves, leaf area, shoot dry weight and total dry weight of sandal seedlings. Fully irrigating the pots once in three days resulted in better growth of sandal seedlings as compared to irrigation once in six days. Water stress increased the root length and root dry weight. Root length was found to be more for sandal seedlings which were irrigated once in six days compared to that, irrigated once in three days. Water stress decreased leaf area of sandal seedlings.

Transpiration rate at 14:00 hrs was found to be more than that of transpiration at 8:00 hrs. Transpiration rate decreased with increase in soil moisture stress. Pre dawn water potential was lower for sandal seedlings irrigated once in six days compared to that irrigated once in three days.

As the haustorial connections were not observed even after 270 days after planting it can be concluded that the difference in the seedling growth parameters of sandal with some of the hosts is due to the above and below ground competition for sun light, water and nutrients.