PARASITIC INTERFERENCE OF SANDAL (*SANTALUM ALBUM* LINN.) ON COMMON AGRICULTURAL CROPS FROM THE HOMESTEADS

By

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THESIS

Submitted in partial fulfilment of the requirement for the degree

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DECLARATION

I hereby declare that this thesis entitled **"Parasitic interference of sandal (*Santalum album* Linn.) on common agricultural crops from the homesteads"** *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 other University or Society.*

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Dedicated to

my parents

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

Introduction

INTRODUCTION

The sandal wood tree (*Santalum album* Linn.) belonging to the family Santalaceae is a semiroot parasite with considerable economic importance by virtue of its scented wood and oil. Santalaceae consists of three genera : *Santalum, Ozyris* and *Thesium*. The genus *Santalum* includes many species like *S. yasi* (in Fiji), *S. lanceolatum* (North west Australia), *S. austrocaledonium* etc. and most of them possess scented wood oil. But the oil of prime quality is obtained from *S. album* and is known in trade and commerce as East Indian Sandal Wood Oil. The oil found in the root and heart wood of sandal is acknowledged as one of the most precious perfumery items from antiquity down to modern times (Srinivasan *et al.*, 1992).

Santalum album is mainly distributed in South India and the Indonesian islands. The other species of *Santalum* occur in parts of Australia, Caledonia and Polynesia. In India sandal is found mainly in the Deccan plateau and its extension. The species is found in small numbers in almost all parts of India except the Himalayas. Large natural stands of sandal occur in Karnataka (5,245 km^2) and Tamil Nadu (3,040 km^2) accounting for nearly 90 per cent of sandal in India (Venkatesan, 1980).

India enjoys a virtual monopoly of world sandal wood oil trade meeting about 90% of the demand and earning considerable foreign exchange (Husain and Punnuswamy, 1982). But there are evidences that production of sandal wood in India is declining sharply. For instance, in Karnataka, one of the major sandal production areas in India, production dropped at the rate of seven per cent per year whereas price increased at the rate of ten per cent per year per tonne during the period from 1964-1986 (Rai and Sarma, 1990). The reasons cited include spike disease, illicit felling and failure in regeneration efforts.

The diminishing supplies of sandal wood from its natural habitat and its increasing demand make it imperative that sandal now may also be grown outside the forest areas. Its high economic value provides sufficient incentives to farmers and land holders for its commercial cultivation. Traditionally sandal is grown in some homesteads of Kerala, especially towards the northern parts of the state.

Being a semiroot parasite, the presence of suitable hosts is a pre requisite for successful growth of sandal in the homesteads. However, in the homesteads or other agricultural lands, there is the possibility of sandal parasitising the agricultural crops and adversely affecting the yield of components crops. The parasitisation behaviour of sandal on common agricultural crop species grown in homesteads of Kerala is not much investigated. The information available on the selective translocation of minerals and carbon between sandal and hosts are also ambiguous. So it was proposed to conduct experiments with the following objectives.

1. To elucidate the parasitisation behaviour of sandal on selected horticultural/agricultural crops occurring in the homesteads of Kerala

2. To study the effect of supplementing manures and fertilizers to specific sandal-host combinations

3. To study the translocation of minerals and photosynthates between sandal and hosts using radioisotopes.

Review of Literature

REVIEW OF LITERATURE

2.1 The tree

The sandal wood tree *Santalum album* Linn. is a small to medium sized, evergreen semiparasitic tree with slender, erect as well as drooping branches, sometimes reaching upto 10-15 m height and 1-2.4 m girth (Parthasarathi and Rai, 1989).

Leaves are opposite and decussate, some times showing whorled arrangement. The shape of leaves vary considerably and six morphological types have been widely recognised viz. ovate, lanceolate, elliptic, linear, big and small (Kulkarni and Srimathi, 1982). The bark is reddish brown or dark brown and the wood is diffuse porous, close grained, hard and oily. Sapwood is white and scentless whereas the heart wood is yellowish to brown and strongly scented.

The tree starts flowering at an early age of 2-3 years. Flowers are purplish brown, unscented, borne in axillary or terminal cymose panicles and are tetra or pentamerous. Most trees flower twice a year (March to May and September to December) and some once in a year. Overlapping of flowering and fruiting seasons will some times result in occurrence of different stages from flower initiation to mature fruits in the same tree. Fruit is a drupe, single seeded. Seeds lack testa and a false seed coat is formed of stony endocarp (Srinivasan *et al.*, 1992).

2.2 Habitat

Generally sandal is considered as a species of the dry zone. Champion and Seth (1968) have listed sandal as a component of southern tropical dry mixed deciduous forest (5A/C-3). Rainfall of the natural sandal tracts are in the range of 600 mm to 1600 mm. Though the tree occurs in an altitudinal range of sea level to 1800 m, the most favourable range is 600-1050 m (Kulkarni, 1994).

Though initially shade tolerant, mature tree does not tolerate overhead shade. Sandal grows on a variety of soil types and Rangaswamy and Jain (1986) found out that it is mostly prevalent on red loams and it can grow under varying conditions of pH. The tree does not come up well in saline and calcareous soils. Those trees grown on poor soils especially stony or gravelly soils are said to be producing more scented wood giving a better yield of oil (CSIR, 1972).

The tree needs good drainage and does not withstand waterlogging. It is extremely sensitive to fire and frost. Root suckers are freely produced when the roots are exposed or injured and it coppices well in the young stages only.

2.3 Parasitism of sandal

The fact that sandal is a root parasite was first noticed by John Scott (1871), Curator of Royal Botanical Gardens, Calcutta. He observed large number of root connections between sandal and other plants. Later on Barber (1902) and Lushington (1904) also observed the presence of haustoria in sandal roots through which roots remain attached to those of other plants.

Barber's studies (1903; 1906) in connection with spike disease provided detailed examinations of sandal roots. He observed that haustoria formation was seen on certain roots only and not on all roots and where haustoria are formed there is a row of them on host roots. Barber noted the presence of root hairs in sandal seedling roots and commented that haustoria arise from external layers of rootlets whereas lateral rootlets arise from deep in its tissues. Haustoria are not fixed or permanent structures. Old ones die leaving scars behind and new ones are often formed from the tiny roots. A large number of haustoria may remain unattached also.

The haustoria when attached with host roots assumes the shape of a flattened bell (Barber, 1906). The presence of vascular strands was also observed in them.

Taide (1991) in an anatomical study of the sandal haustorium found that young haustorium appears as a small hemispherical outgrowth consisting of a narrow neck, a massive parenchymatous body and a broad apex. The parenchymatous body of the haustorium by its spreading growth produces clasping folds around the host root. Penetration is effected by the glandular activity of the surface layers of the haustorium. The parent root and the host show direct vascular connections with that of the haustorium which later undergoes secondary growth. The vascular connections between the host and the sandal becomes so intimate that the host root and the parasite root become almost a single physiological unit.

2.4 Extent of parasitism

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. Howard (1919) regarded root connections between sandal and other plants as symbiosis rather than parasitism. 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 to others it was not so (Iyengar, 1965).

Sreenivasa Rao (1933) after studying the parasite with and without host *Acacia farnesiana* concluded that sandal depends on its hosts for N, P & K while Ca & Fe appear to be directly derived from soil. Venkata 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. After studying soils under healthy and spiked sandal Iyengar (1965) concluded that sandal depends on the hosts for N & P while Ca & 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.

Tracer technique studies have shown that calcium could be absorbed by the roots of sandal seedlings, while phosphate, organic substances, aminoacids, sugar and mineral phosphates were drawn from the host plant (Kunda *et al.*, 1974a,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 phosphorus, potassium and magnesium 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 potculture studies with sandal, *Cajanus cajan* and *Pongamia pinnata,* it was confirmed and the number of nodules and the nitrogen content of plants decreased in parasitized nodulating species with corresponding increase in nitrogen 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 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 phosphorous, calcium, magnesium and nitrogen. This increase in the mineral elements in the hosts, when found associated with sandal might be possible by reverse transfer or by antagonistic processes, which makes us believe that the haustorial connections may serve as two way traffic.

2.5 Self-parasitism in sandal

It is the phenomenon in which a sandal plant forms root connections with another sandal. The high density of population of sandal in an area may be the reason for this and growth of sandal will be adversely affected in such areas (Iyengar, 1965).

2.6 Hosts

Though sandal's parasitism was discovered in 1871, its importance was fully realised only when Barber (1902) stressed that sufficient attention must be given for the aspect of root connections between sandal and other trees in the artificial regeneration of the species. Barber (1906) observed that rate of attack by sandal roots depended upon the host species, so that a certain amount of selectivity or preference by the parasite is evident. Thus according to Barber, members of Anonaceae are not parasitised at all.

Rama Rao (1910) stated that sandal haustoria have a selective power and attacked good hosts extensively and bad hosts only very sparingly. On this basis he attempted a classification of hosts as good, moderately good and bad. Rangaswami and Griffith (1939) made a classification of hosts of sandal based upon haustorial connections of 3 years old sandal plants grown with 95 different hosts, viz., < 25 connections - poor host, 25-100-medium and > 100 connections per combination - good host.

Venkata Rao (1938) was of the opinion that good and bad hosts of sandal can only be differentiated when grown individually with sandal. It cannot be based on the selective tendency of the haustorium alone, as good and bad hosts are equally well attacked. Iyengar (1965) observed that haustoria formation is an inherent capacity of sandal and in the field haustoria can be seen attached even to pebbles, charcoal and dead wooden parts. Venkata Rao (1938) examined sandal plants grown in pots with 108 different host species. The hosts were grouped into three classes based on their capability to help the parasite to grow, viz., (a) vigorously (b) normally and (c) poorly. He also cited instances where hosts are killed by sandal and toxic hosts which can kill sandal.

Based on the differential response in the cation exchange capacity (CEC) of roots of host plants, Parthasarathi *et al.* (1974) have classified the host plants of sandal into 3 categories. (i) good hosts - where the CEC of host roots tends to increase subsequent to parasitisation by sandal; (ii) medium quality hosts where CEC did not, show any marked variation subsequent to parasitisation and (iii) poor hosts where CEC showed a decrease subsequent to parasitisation. Kamala and Angadi (1992) observed that CEC of roots of sandal plants parasitising on different hosts is higher than CEC's of non-parasitising sandal seedlings and CEC's of host roots and sandal roots are almost the same.

Iyengar (1965) compiled a list of 320 known host plants of sandal. Ananthapadmanabha *et al.* (1988) also categorised the hosts of sandal into good, medium and poor depending on growth, quantity of biomass and number of haustoria produced by sandal when associated with different hosts. Taide (1991) developed a multi-trait selection index for the host species of sandal and recommended five sandal-host combinations for large scale sandal plantations. Both Taide (1991) and Ananthapadmanabha (1988) selected *Casuarina equisetifolia* as the best host for sandal.

Provision of suitable hosts is a must for ensuring successful artificial regeneration of sandal. Iyengar (1965) suggested that in sandal plantations, instead of one or more specified hosts, a mixed flora with a large variety of species known for their preference to sandal should take the role of the host. Srinivasan *et al.* (1992) also stressed provision of suitable hosts in the cultivation of sandal viz. a primary host usually *Cajanus cajan* in the seedling stage in polybags and secondary forest species like *Casuarina, Albizia, Cassia siamea* and *Acacia* as host plants either in the same pit or at a distance in quincunx with sandal.

2.7 Growth and Management

Sandal is considered as a slow growing species under forest conditions. Shetty (1977) reported that growth increment of sandal is 1 cm girth at breast height per annum (0.33 cm DBH) and after an initial spurt of growth, the rate of increment becomes steady and continue at the same rate upto and beyond 100 years. Venkatesan (1980) pointed out that growth rate could vary from 1 to 5 cm girth per year depending on quality of site.

Krishnamurthy *et al.* (1983) in a study of natural forest soils in Talaimalai range found out that, surface layer of the soil (0-30 cm) mainly contributes to the growth of sandal and there is a significant relation between available nitrogen in the 'A' horizon and the annual girth increment of sandal. Troup (1919) and Choudhary and Ghosh (1950) observed that age of sandal can not be correctly estimated by annual ring counting. The peculiar physiology of this parasitic species is thought to render it prone to false ring formation.

Heart wood formation in sandal commences around 5-7 years, but it is almost negligible. Optimum heart wood formation from commercial point of view occurs at an age of 30-50 years.

In sandal forests, dead and dying trees and trees above a minimum girth limit (usually 60 cm girth at breast height) are only removed (Chaturvedi and Date, 1981). According to Karnataka state forest rules, for a sandal tree to be categorised mature its heartwood should be present at a maximum depth of 2.5 cm from the surface. The relationship between DBH (X) and yield of scented heartwood (Y) per tree in different DBH classes of sandal in Belgaum, Karnataka is expressed by the relation Y = 0.001476 X ($0.X^{3.3564}$) (Rai and Sarma, 1986). According to the relationship a tree in the girth class 65-75 cm is expected to yield about 50 kg of heartwood.

Rangaswamy *et al.* (1990) reported that application of inorganic fertilizers in small doses to the seedlings of sandal have resulted in fertilizer toxicity and subsequent mortality. Angadi *et al.* (1995) found out that application of individual nutrient elements, Ca, K, Mg, Mn, Cu, Zn and Mo has increased growth of sandal seedlings and also increased uptake of N, P and K in seedling with and without host plants. However in sandal seedlings with host maximum beneficial effect was conferred by the elements K_1 and Zn, whereas in sandal without host Mo and K_2 was most effective

2.8 Genetics and tree improvement

The number of chromosomes in sandal root tip is 2n = 20 (Darlington and Wylie, 1955). However in the haustorium, increase in size as well as number of chromosomes even upon 40 was observed in many of the cells, which was attributed to endopolyploidy (Srimathi and Sreenivasaya, 1962). Srimathi and Kulkarni (1980) were of the view that heartwood formation is dependent on genetic factors of the tree and the phenotypic factors play only a secondary role. Nagaveni and Srimathi (1985) observed that three percentage of the plants had formed no haustoria even one year after transplanting. It is suggested that they are genetically distinct.

A tree improvement programme for sandal consisting of selection of plus trees, identification of seed stands in Kerala, Karnataka and Tamilnadu, establishment of clonal seed orchards, progeny trials and tissue culture is currently going on. In Kerala one seed stand of sandal was identified in Anchalpetty, Marayoor which was later converted to a seed production area (Srinivasan, *et al.*, 1992).

2.9 Utilization

The scented heartwood is the most valuable portion of the sandal tree. The heart wood is yellowish brown, strongly scented, moderately hard with an oily feel, even textured (straight, close grains and uniform fibres) and it is considered ideal for carvings and other fancy work (Troup, 1921; CSIR, 1972).

Heartwood of sandal tree yields a characteristic oil known as East Indian Sandal Wood Oil used extensively in perfumes and medicine. The price of heartwood is about Rs.275/kg and sandal oil is worth about Rs.4000/- per litre. Sandal oil is nearly colourless to golden yellow in appearance, a viscous oily liquid with a specific gravity of 0.962-0.985, refractive index 1.499 to 1.506, ester content 1.6 to 5.4 per cent and solubility in 70% aqueous ethanol 1:5 volumes (Parthasarathi and Rai, 1989). Sandal oil is having a unique position in the perfumery world because of a rare combination of unusual properties such as high boiling point for an essential oil conferring great fixative properties and the pale colour which enables blending without discolouration, with other perfumery raw materials.

Sandal oil content decreases from root to the tip of the tree (about 45% decrease) and from core to the periphery (about 20% decrease) of heartwood. The oil from mature trees contained more of santalols ($C_{15}H_{24}O$) and less of santalenes and santalyl acetates as compared to the oil from young trees (Shankaranarayana and Parthasarathi, 1984).

Portions of sandal tree other than heartwood is also used. Leaf is an excellent fodder, green manure and a rich source of aminoacid (Allo-hydroxy proline). Bark yields tannin and also used as chemosterilant against insect pests and bacteria. Seed meal is used as an animal feed (Kulkarni, 1994).

Review of the available literature reveals that, though considerable investigations have been carried out on the parasitism of sandal, a clearcut understanding of the process has not yet been obtained. Difference of opinion exists among scientists regarding which of the elements are absorbed by sandal directly from soil and which are absorbed from host. The possibilities of raising sandal in the farm lands and its parasitic behaviour on common agricultural crop species in a farm are also not investigated. Though sandal wood has a long history in India, its management practices, artificial regeneration techniques and yield improvement strategies even now remain far from perfected.

Materials and Methods

3. MATERIALS AND METHODS

Experiments were conducted at College of Forestry, Vellanikkara during 1995-96 to elucidate the parasitisation behaviour of sandal on common agricultural crops. The response of selected sandal-host combinations to application of manures and fertilizers were also studied. For studying the uptake and translocation of minerals and photosynthates between sandal and selected hosts, experiments were conducted using the radioisotopes ^{45}Ca, ^{35}S, ^{32}P and ^{14}C. Vellanikkara is located in the Thrissur district of Kerala, India at latitude 10° 32′ N and 76° 10′ E longitude at an altitude of 22.25 m from mean sea level. The location experiences a humid tropical climate with a mean annual rainfall of 2668.6 mm. The minimum temperature vary from 22.2° C (December) to 24.7° C (May) and the maximum temperature from 28.6° C (July) to 36.2° C (March). The weather data (Appendix I) for the experimental period is presented in Fig.1.

3.1 Experiment I

For elucidating the parasitisation behaviour of sandal on common agricultural crops from the homesteads of Kerala, sandal seedlings were grown in poly bags for a period of 10 months in association with selected agricultural crops. Sandal was allowed to parasitise on the following species and the growth of sandal as well as the hosts were observed for a period of 10 months.

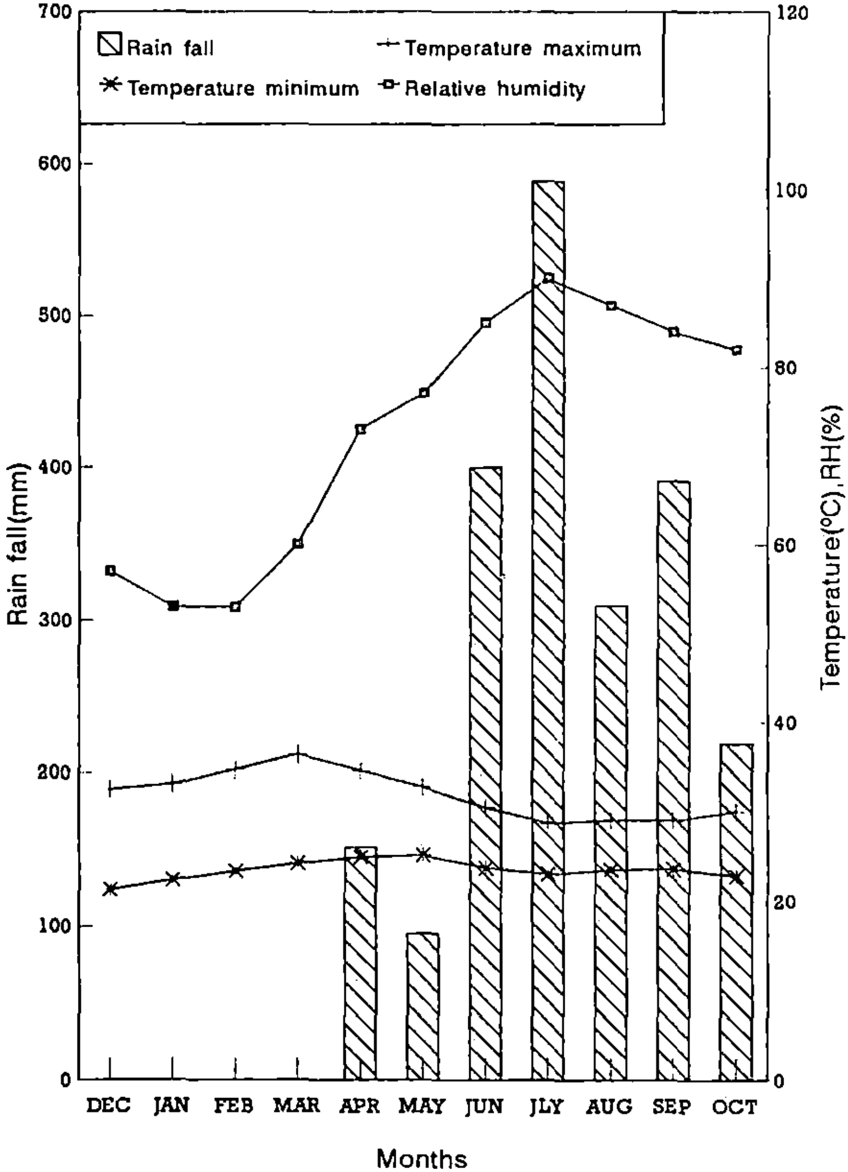


Fig.1 Weather parameters during the experimental period(Dec.1995 to Oct.1996)

1. Coconut (*Cocos nucifera* Linn.)

2. Black pepper (*Piper nigrum* Linn.)

3. Rubber (*Hevea braziliensis* (H.B.K.) M.A)

4. Cashew (*Anacardium occidentale* Linn.)

5. Casuarina (*Casuarina equisetifolia* J.R.& G. Frost.)

6. Mango (*Mangifera indica* Linn.)

7. Jack (*Artocarpus heterophyllus* Lamk.)

8. Banana (*Musa sp.*)

Controls - Sandal alone

- Host plants alone

Sandal seeds were purchased from seed sales division, Tamil Nadu Forest Department, Coimbatore. After a pretreatment of 24 hours soaking in water, they were broadcast sown into a standard nursery bed (12 m x 1.2 m x 0.3 m) in May 1995. Watering and weeding were regularly done and by July 1995 good germination was obtained. Good quality seedlings of all the other species listed above were purchased from the Kerala Agricultural University nursery.

3.1.1 Potting of sandal and hosts

For potting, black polythene bags of size 35 x 18 cm (gauge 250) were used. The bags were filled with 10 kg of 1:1:1 mixture of sand:soil:farmyard manure. In each bag one sandal seedling (5 months old) and one of the above mentioned agricultural crop (5 months old) were planted. Sandal plants alone and each of the agricultural crops alone were also maintained as controls. The design of the experiment was

Completely Randomised Design with 6 replications. The plants were grown for a period of 10 months. Monthly observations were recorded on height and collar diameter of both sandal and hosts. At the end of the experimental period destructive sampling was carried out on 3 replications and observations were recorded on shoot length, root length, shoot and root biomass, number of leaves and number of haustcrial connections between sandal and host combinations.

3.2 Experiment II

3.2.1 Response of sandal host combinations to manures and fertilizers

For studying the response of sandal-host combinations to manures and fertilizers, another experiment was conducted. A good host of sandal, *Casuarina equisetifolia* (Ananthapadmanabha, 1988; Taide, 1991) and a bad host of sandal, *Erythrina indica* (Venkata Rao, 1938) were selected and combinations of manures and fertilizers as specified below were applied to them.

Sandal-host combinations	Levels of manures and fertilizers
1. Sandal alone	1. Without farmyard manure (FYM) and fertilizer
2. Sandal + *Casuarina equisetifolia*	2. With fertilizer 50 kg/ha (0.22 g/pot) each of N,P & K
3. Sandal + *Casuarina equisetifolia* + *Erythrina indica*	3. With FYM 10 t/ha (45 g/pot)
4. Sandal + *Erythrina indica*	4. With FYM (10 t/ha) and Fertilizers (50 kg/ha each N, P & K)

The crop combinations mentioned above formed the treatments of the study. The experiment was laid in completely Randomised Design with three replications. The composition of the potting mixture was sand : soil (1:1). Raising of seedlings, potting, periodic observations and destructive sampling were carried out in the same manner as detailed in Experiment I (3.1.1).

3.2.2 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 both *Casuarina equisetifolia* and *Erythrina indica* 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.

3.3 Experiment III

For studying the uptake and translocation of ^{45}Ca between sandal and host, a recommended primary host of sandal, redgram (*Cajanus cajan*) (Sreenivasan *et al.*, 1992) was used. The uptake of the element from soil and its translocation between sandal and hosts were studied in two separate experiments as detailed below.

3.3.1 Soil labelling

In one experiment soil was labelled with ^{45}Ca and sandal-host combinations were grown in the labelled soil. For soil labelling an activity of 56 μCi in the form of $^{45}CaCl_2$ in 160 ml of water was thoroughly mixed with 1 kg of potting mixture (1:1 sand-soil) and filled into plastic pots (18 x 10 cm). Seedlings of sandal and host (two months old) were planted in the pots and grown for a period of 75 days in the green house. There were three treatments as follows:

1. Sandal + Redgram
2. Sandal alone
3. Redgram alone

The experiment was laid out in Completely Randomised Design (CRD) and replicated five times.

3.3.2 Plant labelling

For plant labelling, root system of plant was dipped into the radioactive solution of $^{45}CaCl_2$ (56 μCi in 20 ml of water) in a vial and placed in sunlight for a period of 24 hours for facilitating effective absorption of the activity. Before planting into the pots, the root system of the plants were thoroughly washed with water for avoiding soil contamination. The details of the sandal-host combinations are given below. The labelled plants are indicated by the parenthesis.

1. (Sandal) ^{45}Ca + Redgram
2. Sandal + (Redgram) ^{45}Ca

Two months old sandal and host seedlings in the combinations listed were planted in plastic pots (18 x 10 cm) filled with 1 kg of sand-soil mixture (1:1). In each pot one of the species was labelled and the other species was not labelled. The experiment was laid out in CRD and replicated five times.

After 75 days of growth these plants in both experiments (soil labelled and plant labelled) were cut at the soil level and dried in a hot air oven at a temperature of 65-70° C for 48 hours. Samples from this were subjected to radioassay as explained in 3.7.1.

3.4 Experiment IV

For studying the uptake and translocation of ^{35}S, the same experimental setup described in Experiment III (3.3) was used. Sandal-host combinations and the method of labelling, growing, sampling and radioassay were the same as explained for ^{45}Ca. The radioisotope, ^{35}S was applied at the rate of 47 μCi in the form of $H_2{}^{35}SO_4$ per pot in case of soil labelling and per plant in case of plant labelling.

3.5 Experiment V

The uptake and translocation of ^{32}P between sandal and a good host, *Casuarina equisetifolia* and a bad host, *Erythrina indica* were studied in two separate experiments by soil labelling and plant labelling with ^{32}P. Potting mixture, methods of potting, soil and plant labelling were exactly the same as in experiment III (3.3.1 and 3.3.2). The radioactivity used for labelling was at the rate of 300 μCi per pot (soil labelling) and per plant (plant labelling) in the form of $H_3{}^{32}PO_4$. The sandal-host combinations studied under soil labelling are given below:

1. Sandal + Casuarina
2. Sandal + Erythrina

3. Sandal alone

4. Casuarina alone

5. Erythrina alone

The experiment was laid out in CRD and replicated five times.

The sandal-host combinations used for plant labelling studies are given below: Labelled plants are indicated by parenthesis and for each plant 230 μCi in the form of $H_3{}^{32}PO_4$ was used for labelling.

1. (Sandal)^{32}P + Casuarina

2. Sandal + (Casuarina)^{32}P

3. (Sandal)^{32}P + Erythrina

4. Sandal + (Erythrina)^{32}P

The experiment was laid out in CRD and replicated five times.

Five months old seedlings of sandal and hosts (in the combinations mentioned above) were planted in plastic pots (18 x 10cm) after labelling and were grown for a period of 90 days. At the end of the experimental period the plants were cut at the soil level and dried in a hot air oven at a temperature of 65-70°C for 48 hours. The dried and powdered sample was used for radioassay as explained in section 3.7.2

3.6 Experiment VI

The translocation of ^{14}C between sandal and hosts were studied in this experiment.

Seeds of sandal, casuarina and erythrina were sown separately in circular plastic trays of (diameter 20 cm) filled with 10 kg (1:1) sand:soil mixture. These plants were labelled with ^{14}C when they were 90 days old.

3.6.1 Labelling of plants with ^{14}C

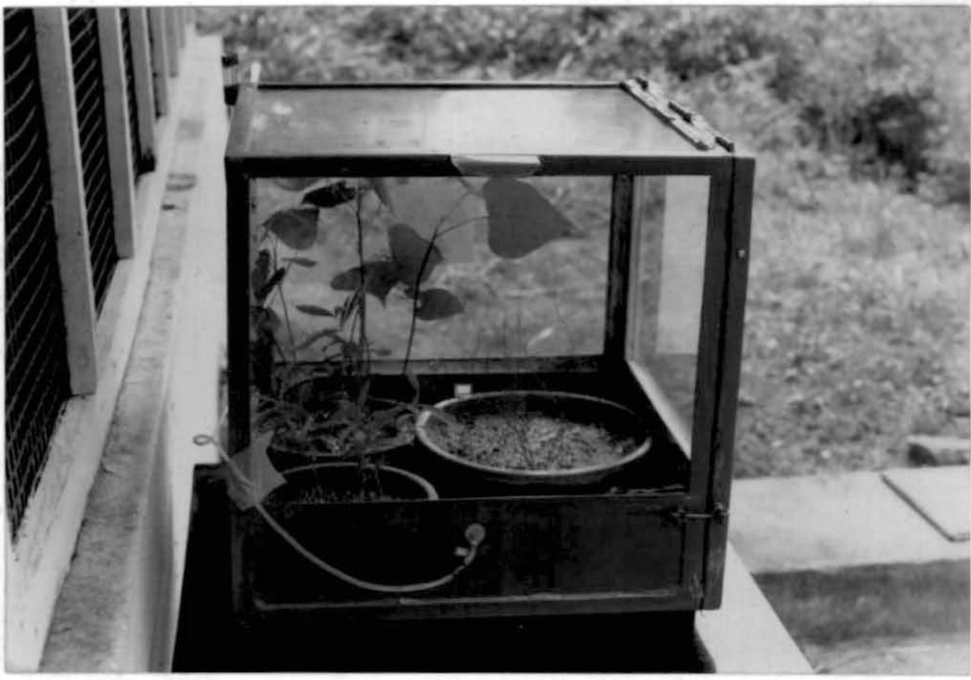
The plants to be labelled were put into a specially fabricated air tight glass chamber (45 x 45 x 45 cm) (Plate 1). In the chamber, 100μCi ^{14}C in the form of $NaH^{14}CO_3$ was placed in a petridish and a drip system for ensuring a controlled supply of dilute (0.75 N) H_2SO_4 to the petridish was installed. Acid was dripped into $NaH^{14}CO_3$ to liberate $^{14}CO_2$ in to the chamber. The plants were kept inside the chamber for a period of 3 hours in full sunlight for effective assimilation of ^{14}C. Then they were taken out and planted in polythene bags (27 x 18cm) filled with 5 kg sand-soil mixture (1:1).

Labelled seedlings of sandal were put in the same pots with unlabelled host/hosts. Similarly labelled host was planted in association with unlabelled sandal seedlings. The details of the sandal-host combinations are given below. The labelled plants are indicated by the parenthesis.

Sandal-host combinations

1. (Sandal)^{14}C + Casuarina
2. Sandal + (Casuarina)^{14}C
3. (Sandal)^{14}C + Erythrina

Plate 1 Glass chamber used for ^{14}C labelling with plants inside



4. Sandal + (Erythrina)^{14}C

5. (Sandal)^{14}C + Casuarina + Erythrina

6. Sandal + (Casuarina)^{14}C + Erythrina

7. Sandal + Casuarina + (Erythrina)^{14}C

The experiment was laid out in CRD and replicated three times.

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 as explained in section 3.7.3.

3.7 Radioassay of plant samples

The details of radioassay for ^{45}Ca, ^{35}S, ^{32}P and ^{14}C are described below:

3.7.1 Radioassay for ^{45}Ca and ^{35}S

One gram of the dried powdered sample was acid digested in a digestion mixture (Nitric acid : Perchloric acid 2:1). Digested samples were made upto 50 ml and one ml of this solution was transferred into a vial along with 5 ml of the scintillation liquid (Appendix II) and counting was done in a micro computer controlled liquid scintillation system (Model Wallac 1409 of Wallac Oy, Finland). The radio activity was expressed as Disintegrations per minute (DPM).

3.7.2 Radioassay for ^{32}P

One gram of the dried and powdered sample was acid digested in a 2:1 mixture of Nitric acid - Perchloric acid. The digests made upto 20 ml in a vial, were radioassayed by Cerenkov counting technique (Wahid, *et al.*, 1985) in a micro computer controlled liquid scintillation system (Model Wallac, 1409, Wallac Oy, Finland) and the activity was expressed in counts per minute (CPM).

3.7.3 Radioassay for ^{14}C

The dried, powdered plant samples of 0.2 g each was oxidised in a biological sample oxidizer (OX 500 of RJ Harvey Instrument Corporation, Hills dale, New Jersey) and the $^{14}CO_2$ liberated during combustion was collected in a specially formulated ^{14}C cocktail solution supplied by the RJ Harvey Instrument Corporation. The radioactivity was then determined in a micro computer controlled liquid scintillation system (Model Wallac 1409 of Wallac, Oy, Finland) and the activity was expressed in disintegrations per minute (DPM).

3.8 Autoradiography

One replication of all the plant labelled sandal and host combinations from experiments III and IV were removed from the pots with their roots intact and herbarium-pressed at room temperature for seven days. Dried plants were autoradiographed by placing them on X-ray films in dark for a period of 2 months and later developed using X-ray film developer solutions.

3.9 Statistical analyses

Data pertaining to the height and collar diameter of sandal in experiments I and II were analysed following the analysis of co-variance technique (ANACOVA) taking initial height and collar diameter as the covariate respectively and the rest by analysis of variance technique (ANOVA) (Snedecor and Cochran, 1967). The data on radioactivity counts were subjected to logarithmic transformation before doing the ANOVA.

Results and Discussion

RESULTS AND DISCUSSION

4.1 Experiment I

The parasitisation behaviour of sandal on eight common agricultural crops occurring in the homesteads of Kerala was studied in a pot culture during the period from December 1995 to October 1996. The results of the trial are presented and discussed below.

4.1.1 Height

The mean height of sandal seedlings grown in association with different hosts is presented in Table 1. The height of sandal varied significantly depending on the host associated with it, for most of the experimental period except during 150-240 days after transplanting. The maximum height growth of sandal was observed in association with the host, casuarina.

For the initial period, upto 120 days after planting, maximum height growth of sandal was observed in association with cashew followed by rubber and these associations showed significant height increase of sandal over sandal grown alone. Sandal in sandal-banana association showed a decrease in height which was however not significantly different from sandal alone.

Table 1 Height of sandal seedlings in association with different hosts

Treatments (Sandal+Host associations)	Height of sandal (cm)									
	30 DAP	60 DAP	90 DAP	120 DAP	150 DAP	180 DAP	210 DAP	240 DAP	270 DAP	300 DAP
1. Sandal alone	13.6	14.8	15.8	16.8	17.5	19.8	20.9	22.7	24.1	26.5
2. Sandal + coconut	12.2	13.7	14.6	16.3	17.5	18.2	18.8	20.3	21.0	21.6
3. Sandal + black pepper	12.9	14.3	15.9	16.9	18.4	20.2	21.4	23.1	24.1	25.4
4. Sandal + rubber	14.2	15.9	18.7	20.5	21.7	23.3	24.5	26.2	27.5	32.8
5. sandal + cashew	15.1	16.9	19.3	20.7	21.6	22.4	22.9	24.3	25.2	26.3
6. Sandal + casuarina	13.5	15.1	16.9	18.3	22.3	26.4	29.8	34.5	39.9	46.9
7. Sandal + mango	13.6	15.8	16.7	17.6	18.8	20.7	21.9	23.8	25.5	27.3
8. Sandal + jack	12.9	14.3	15.7	16.9	19.0	20.6	22.1	23.6	24.9	27.0
9. Sandal + banana	11.9	12.4	12.9	14.2	14.9	15.5	15.9	17.4	18.5	19.8
F test	**	**	**	*	NS	NS	NS	NS	*	**
LSD (0.05)	1.06	1.76	2.42	3.18	-	-	-	-	8.00	9.29
SEM (±)	0.13	0.61	0.78	1.09	1.51	1.97	2.15	2.62	2.75	3.20

DAP - Days after transplanting ** Significant at 1% level * Significant at 5% level NS - Not significant

After 120 days, the difference in height growth between the treatments gradually evened out and there was no significant difference upto 240 days after planting. The observations during the 270 days after planting and 300 days after planting showed a significant increase in height for sandal (46.9 cm) grown in association with casuarina over all other hosts. Sandal in association with rubber showed the second best performance in height growth (32.8 cm) which was significantly superior to sandal in banana and coconut associations and at par with sandal alone. On 300 days after planting, hosts associated with sandal in the decreasing order of height growth of sandal were casuarina, rubber, mango, jack, cashew, black pepper, coconut and banana. The sandal in sandal-casuarina association had a significant height increase over sandal alone and sandal in all other host associations were statistically at par with sandal alone.

Height is an important growth parameter of seedlings, since a faster height increase may help the seedlings to avoid suppression by the weeds. Host associations like casuarina caused a significant height increase than sandal grown alone whereas hosts like banana and coconut even reduced the height increment of sandal. This implies that, by providing good hosts like casuarina significant advantages can be gained in the growth of sandal. The results also indicate that agricultural crops tried in this experiment are not good hosts to sandal which indirectly implies that sandal may not influence adversely the growth of these agricultural crops by way of its parasitisation.

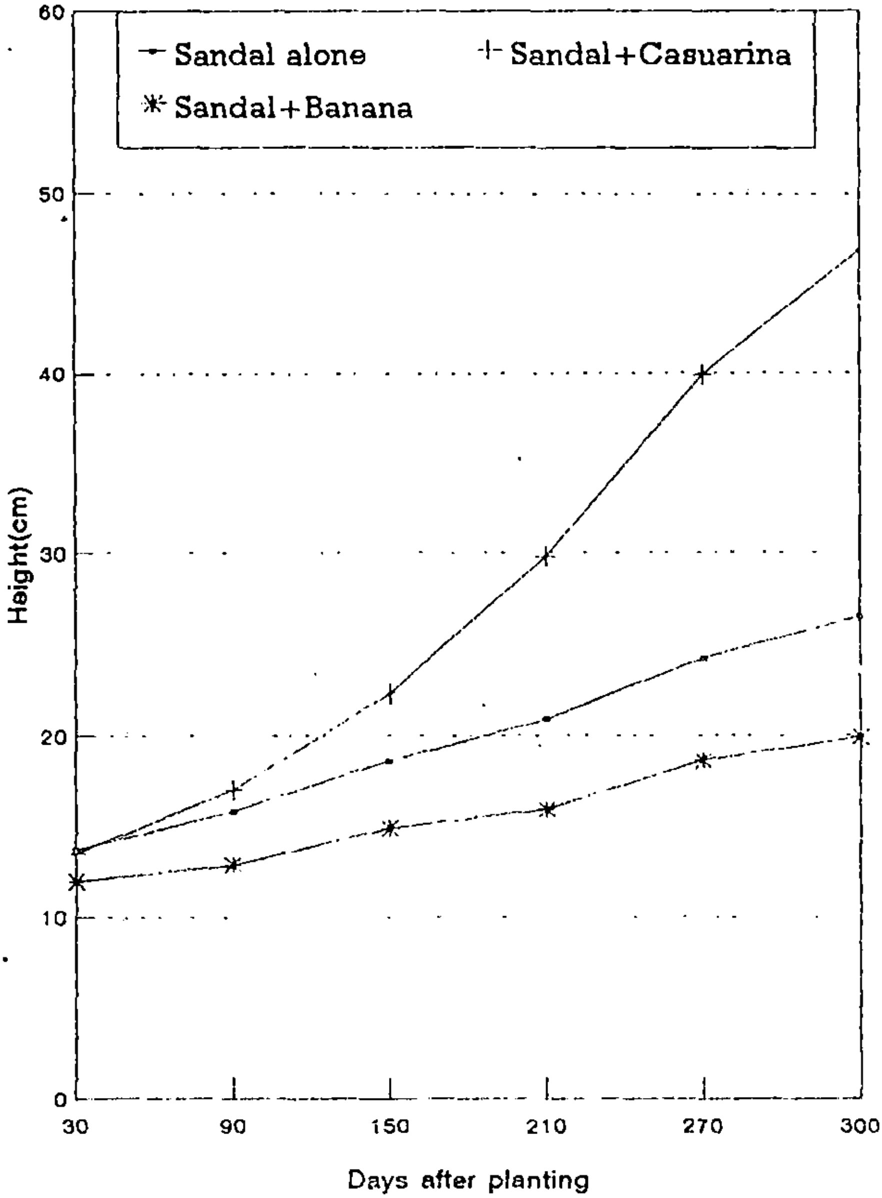


Fig.2 Height growth of sandal seedlings in association with different hosts

The reasons for the variation in height growth of sandal, depending on the type of hosts are not clearly understood from this study. Nevertheless the results adequately reflects the influence of hosts on sandal's height growth ie., some hosts exerted a favourable influence whereas others adversely affected sandal's growth (Fig.2). Venkata Rao (1938) and Ananthapadmanabha (1988) after pot culture studies with sandal-host associations, classified the hosts of sandal into good, medium and poor depending on their capability to help the parasite grow. The superiority of casuarina as a good host to sandal was also reported by Ananthapadmanabha (1988) and Taide (1991).

4.1.2 Collar diameter

The collar diameter of sandal seedlings in association with different hosts is presented in Table 2. The collar diameter of sandal varied significantly depending on the host associated with it, for most of the experimental period except 60-120 days after planting. The maximum collar diameter was observed in association with the host casuarina.

Collar diameter of sandal in sandal-casuarina association at 30 days after planting showed no significant increase as compared to sandal alone, while sandal in sandal + banana and sandal + coconut associations showed a significant decrease in diameter than control. Then the difference in collar diameter between the treatments was not significant upto 120 days after planting. During this period also sandal in sandal + casuarina association showed the maximum collar diameter.

Table 2 Collar diameter of sandal seedlings in association with different hosts

Treatments (Sandal+Host associations)	Collar diameter of sandal (mm)									
	30 DAP	60 DAP	90 DAP	120 DAP	150 DAP	180 DAP	210 DAP	240 DAP	270 DAP	300 DAP
1. Sandal alone	1.67	1.89	2.08	2.36	2.53	2.71	2.83	2.99	3.14	3.28
2. Sandal + coconut	1.46	1.75	1.86	2.00	2.11	2.22	2.37	2.54	2.67	2.86
3. Sandal + black pepper	1.53	1.65	1.85	1.98	2.07	2.18	2.30	2.48	2.65	2.83
4. Sandal + rubber	1.65	1.90	2.08	2.29	2.44	2.69	2.89	3.02	3.17	3.33
5. sandal + cashew	1.64	1.72	1.92	2.16	2.33	2.50	2.59	2.64	2.84	2.92
6. Sandal + casuarina	1.69	2.15	2.47	2.71	3.14	3.58	4.07	4.56	5.14	6.05
7. Sandal + mango	1.56	1.77	1.97	2.74	2.26	2.39	2.49	2.63	2.78	2.88
8. Sandal + jack	1.53	1.73	1.85	2.06	2.17	2.29	2.42	2.57	2.67	2.83
9. Sandal + banana	1.36	1.49	1.56	1.63	1.63	1.75	1.80	1.95	2.03	2.18
F test	*	NS	NS	NS	**	**	**	**	**	**
LSD (0.05)	0.17	-	-	-	0.57	0.70	0.83	0.93	0.97	1.19
SEM (±)	0.16	0.13	0.16	0.18	0.20	0.24	0.29	0.32	0.33	0.41

DAP - Days after transplanting ** Significant at 1% level * Significant at 5% level NS - Not significant

On 150 days after planting, sandal in sandal + casuarina association showed a superior collar diameter than all other hosts. The collar diameter of sandal when grown with all other hosts were lower than that of sandal alone. However significant reduction in collar diameter was observed only when banana was the host. The same trend continued for the period 180-270 days after planting. During this period sandal in sandal + rubber association showed a small increase in collar diameter, though not significant than sandal alone. By 300 days after planting sandal in sandal + casuarina association showed the highest collar diameter which was significantly superior to all other hosts. The collar diameter of sandal in all other sandal-host associations were on par with sandal alone at this stage.

Collar diameter of sandal seedlings varied considerably depending on the host. Sandal + casuarina association at 300 days after planting had a collar diameter (6.05 mm) which was almost double than that of sandal alone (3.28 mm). Hosts associated with sandal in the decreasing order of collar diameter of sandal at 300 days after planting were casuarina, rubber, sandal alone, cashew, mango, coconut, black pepper, jack and banana.

As in the case of height, collar diameter of sandal seedling is also influenced by the type of hosts. Certain hosts like casuarina tends to increase the overall growth of sandal seedling considerably whereas hosts like banana and coconut reduced its growth (Fig.3). This corroborates the view that, some of the hosts are promoting the

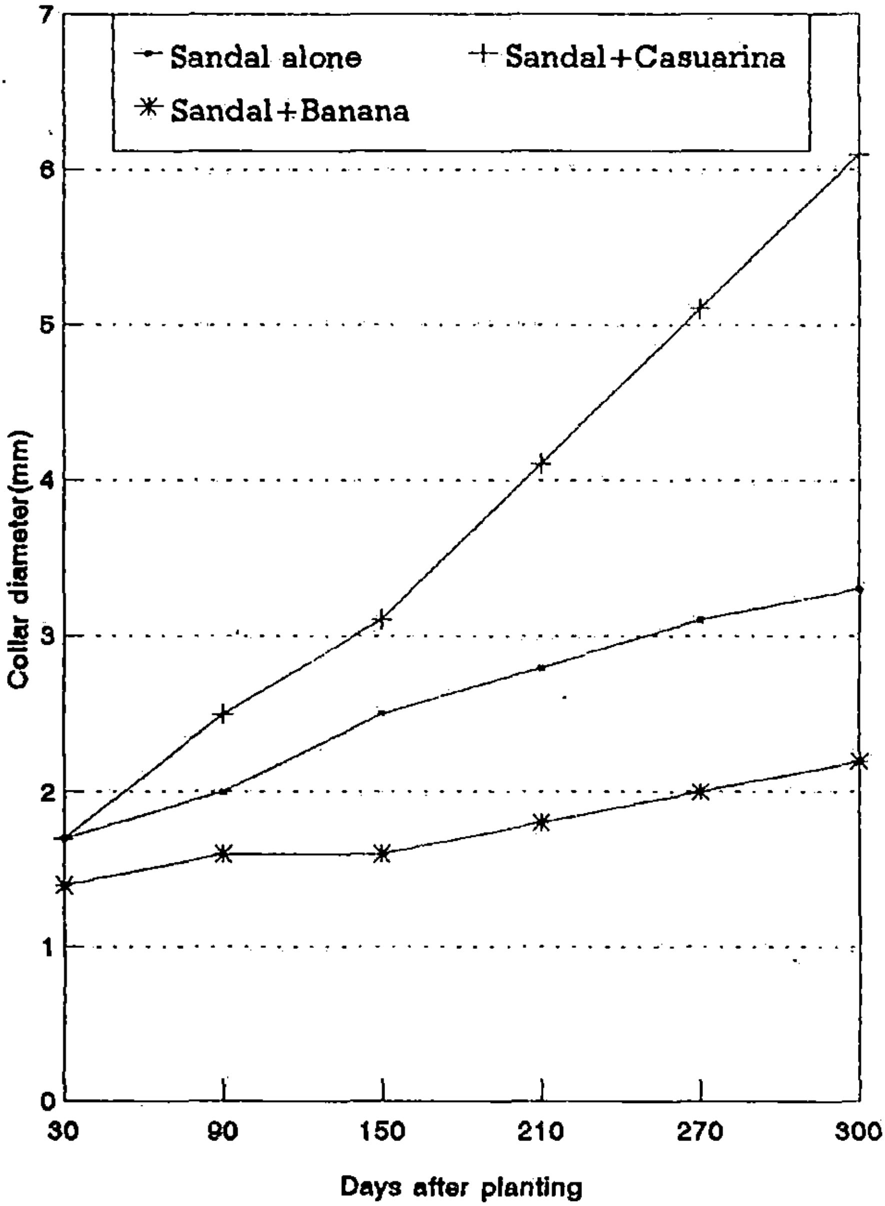


Fig.3 Collar diameter of sandal seedlings in association with different hosts

growth of sandal whereas others may be inhibiting the growth. Studies by Ananthapadmanabha (1988) and Taide (1991) also highlighted this influence of hosts on growth of sandal.

The results on collar diameter also indicates that, agricultural crops tried in this experiment are not preferred hosts of sandal and hence the possible adverse effects of sandal on growth of agricultural crops due to parasitisation will be negligible if sandal is planted in association with the agricultural crops.

4.1.3 Other growth parameters of sandal

The influence of different hosts on other growth attributes of sandal seedling at the end of the experimental period (300 days after planting) is presented in Table 3. All the other growth attributes of sandal seedling examined viz., root length, shoot, root as well as total dry matter, number of haustoria and number of leaves also varied significantly depending on the host associated with sandal.

Only the sandal in association with the host casuarina had a significant increase in total dry matter than the sandal grown alone, while sandal in association with mango, rubber, jack, cashew and black pepper were on par with sandal grown alone. This significant increase in dry weight of sandal in association with casuarina highlights the favourable influences brought about in growth of sandal by certain hosts. This result indicates that, by providing good hosts like casuarina, significant advantages can be gained in the growth of sandal.

Table 3 Growth attributes of sandal seedlings at 300 DAP in association with different hosts

Treatments (Sandal+Host associations)	Growth attributes of sandal seedlings					
	Root length (cm)	Shoot dry weight (g)	Root dry weight (g)	Total dry weight (g)	Number of haustoria	Number of leaves
1. Sandal alone	24.9	0.49	0.23	0.72	3.00	44.00
2. Sandal + coconut	17.8	0.17	0.14	0.31	1.70	36.00
3. Sandal + black pepper	21.1	0.32	0.18	0.50	3.70	46.70
4. Sandal + rubber	21.8	0.55	0.28	0.83	6.70	48.00
5. sandal + cashew	26.5	0.39	0.16	0.55	7.00	38.00
6. Sandal + casuarina	19.6	0.70	0.29	0.99	13.00	58.00
7. Sandal + mango	23.8	0.58	0.28	0.86	5.00	39.30
8. Sandal + jack	19.8	0.50	0.18	0.68	6.30	38.70
9. Sandal + banana	9.7	0.19	0.14	0.33	1.70	34.70
F test	*	**	**	**	**	**
LSD (0.05)	9.14	0.18	0.09	0.25	1.95	5.28
SEM (±)	1.25	0.04	0.01	0.05	0.66	1.78

DAP - Days after transplanting ** Significant at 1% level * Significant at 5% level

Number of leaves of sandal in association with casuarina showed definite superiority over all others. Sandal in association with hosts like banana, coconut and cashew had a significantly lower number of leaves than the sandal grown alone while the number of leaves of sandal with hosts like rubber, mango and jack and black pepper were at par with sandal grown alone.

Number of haustoria of sandal in sandal + casuarina association showed significant superiority over all others. Sandal grown with cashew, rubber, mango and jack as hosts showed significantly more number of haustoria than sandal alone while sandal with coconut, banana, black pepper and sandal-alone were on par.

Barber (1906) and Rama Rao (1910) stated that, sandal haustoria is having a selective power and it attacked good hosts extensively and bad hosts only very sparingly. Rama Rao (1910) and Rangaswami and Griffith (1939) had classified hosts of sandal into good, medium and poor depending on number of haustorial connections. But Iyengar (1965) stated that, haustoria formation is an inherent capacity of sandal and it can be seen even attached to wooden parts and pebbles in the field. Venkata Rao (1938) observed that good and bad hosts are often equally well attacked by haustoria. Results from this study indicates that, haustoria formation is an inherent capacity of sandal, since sandal grown alone also produced haustoria. However, a definite difference in number of haustoria depending on host was evident. Sandal in sandal + casuarina association had significantly more number of haustoria than all others and in almost all growth parameters this association was significantly superior.

Sandal in cashew, rubber, mango and jack associations also had more number of haustoria than sandal alone, but the growth parameters of sandal was not favourably influenced in a significant manner by these hosts. So formation of haustoria is not the sole criteria for deciding a good host even though a good host may induce production of more number of haustoria.

The physiological reasons for variation in growth of sandal, depending on the host is not clear. It is generally agreed that, sandal depends on hosts for its supply of minerals like nitrogen and phosphorus (Sreenivasa Rao, 1933; Iyengar, 1965 and Kunda *et al.*, 1974 a,b). Ananthapadmanabha (1988) observed that, sandal in association with good hosts like casuarina had not only luxuriant growth but also a higher level of mineral elements in the leaves. Eventhough there are a lot of contradictions about the parasitic behaviour of sandal, increased growth observed in sandal when grown with a good host, emphasises the need for detailed studies to understand the physiological implications of sandal-host association.

Among the agricultural crops which were planted as hosts to sandal, mango and rubber caused a slight increase in total dry matter content of sandal associated with them, which was however not significantly different from sandal alone. But Venkata Rao (1938) indicated mango as a bad host to sandal. Specific information about sandal's parasitisation behaviour on rubber is lacking in literature, but Venkata Rao (1938) and Taide (1991) observed that some Euphorbiacea members like gooseberry, castor are bad hosts of sandal. Though rubber is a member of the family, euphorbiaceae, the trends of the results showed that rubber is not a bad host of sandal. Further investigations for a longer period are necessary for ascertaining the implications of mango + sandal and rubber + sandal associations to both the crops so that the potential of raising sandal in association with these crops can be evaluated.

Sandal exhibited a significantly lower growth in association with banana and coconut indicating that these are bad hosts of sandal. These observations indicate that sandal if planted in the homesteads may not affect the growth and yield of agricultural crops like banana, coconut, mango, jack, cashew, black pepper and rubber grown in the homesteads of Kerala.

4.1.4 Effect of parasitisation by sandal on growth characteristics of hosts

A comparison of growth parameters of parasitised and unparasitised hosts is given in Table 4. The growth parameters of the hosts, were not significantly influenced by the parasitisation of sandal. Venkata Rao (1938) cited instances, where certain hosts in pot cultures, were killed due to their inability to withstand parasitisation by sandal. Ananthapadmanabha (1988) in a 2 year pot culture experiment also noticed that, the level of nitrogen, phosphorus, calcium, magnesium and potassium were decreased in the host plants, when the growth of sandal was more. However, in this study, no significant decrease in growth of hosts was observed. One probable reason is the short experimental period (10 months) during which, the dependence of sandal on hosts for nutrients might not have been considerable, so as to be manifested in the growth of hosts. Sandal-host associations may be grown for

Table 4 Growth attributes of hosts at 300 DAP as influenced by the parasitisation of sandal

Treatments	Growth attributes of host seedlings					
	Initial height (cm)	Final height (cm)	Initial collar diameter (mm)	Final collar diameter (mm)	Root length (cm)	Total dry weight (g)
1	2	3	4	5	6	7
Coconut (alone)	34.6	155.7	22.4	45.2	78.0	553.3
Coconut (parasitised)	34.3	159.3	23.4	40.5	78.7	535.1
F test	NS	NS	NS	NS	NS	NS
T test	NS	NS	NS	NS	NS	NS
Black pepper (alone)	22.8	161.4	4.8	6.3	71.6	15.2
Black pepper (parasitised)	21.9	158.5	4.8	6.1	71.1	15.4
F test	NS	NS	NS	NS	NS	NS
T test	NS	NS	NS	NS	NS	NS
Rubber (alone)	57.3	136.7	7.5	19.4	94.5	90.6
Rubber (parasitised)	44.5	130.0	6.2	18.7	65.3	89.5
F test	NS	NS	NS	NS	*	NS
T test	*	NS	NS	NS	NS	NS
Cashew (alone)	21.8	75.7	11.6	27.9	54.9	99.6
Cashew (parasitised)	20.0	70.6	10.8	25.9	52.6	87.6
F test	NS	NS	NS	NS	NS	NS
T test	NS	NS	NS	NS	NS	NS

Contd....2

Table 4 contd....

1	2	3	4	5	6	7
Casuarina (alone)	55.8	242.6	5.2	20.8	112.0	224.6
Casuarina (parasitised)	55.8	251.5	4.2	22.2	104.5	232.3
F test	NS	NS	NS	NS	NS	NS
T test	NS	NS	NS	NS	NS	NS
Mango (alone)	20.6	81.8	6.6	20.6	61.9	108.3
Mango (parasitised)	20.0	89.1	7.5	20.0	72.7	92.7
F test	NS	NS	NS	NS	NS	NS
T test	NS	NS	NS	NS	NS	NS
Jack (alone)	55.1	136.7	9.4	20.3	38.8	112.4
Jack (parasitised)	53.7	131.7	8.7	21.1	41.8	122.5
F test	NS	NS	NS	NS	NS	NS
T test	NS	NS	NS	NS	NS	NS
Banana (alone)	45.1	240.6	36.8	90.3	100.5	140.1
Banana (parasitised)	40.3	250.3	35.6	94.6	94.8	136.7
F test	NS	NS	NS	NS	NS	NS
T test	NS	NS	NS	NS	NS	NS

F test - For the hypothesis variance 1 = variance 2
T test - For the hypothesis mean 1 = mean 2

* Significant at 5% level
NS - Not significant

a considerably longer period, for ascertaining the long-term effects of parasitisation by sandal on hosts.

The results of the study indicates that, sandal may be grown as a component of homesteads of Kerala without detrimental effects on other crops in the homesteads and for ensuring sandal's maximum growth and development, a preferred host like casuarina may be incorporated into the cropping system. Formulation of such a cropping system and its evaluation in the farm lands will go a long way in raising sandal outside forest lands, to meet our future demands for sandal.

4.2 Experiment II

The response of selected sandal-host combinations to manures and fertilizers was studied in this experiment and the results are presented and discussed in this section.

4.2.1 Height of sandal

Height of sandal seedlings was significantly influenced only by hosts. The effect of fertilizer levels and interactions between the fertilizer and host levels were not significant (Table 5). Initially for a period of 90 days, sandal (alone) showed the maximum height whereas the lowest height was for the sandal in sandal + erythrina association and the other host combinations were at par with sandal alone. By 180 days after planting sandal in sandal + casuarina + erythrina association had the maximum height which was at par with sandal in sandal + casuarina and sandal alone

Table 5 Effect of different host combinations and fertilizer levels on height growth of sandal seedlings

Treatments (Sandal+Host associations)	Height of sandal (cm)									
	30 DAP	60 DAP	90 DAP	120 DAP	150 DAP	180 DAP	210 DAP	240 DAP	270 DAP	300 DAP
1. Sandal alone	13.7	15.1	16.6	17.9	19.4	20.6	21.7	23.0	23.8	25.3
2. Sandal + casuarina	13.1	14.4	16.4	18.5	21.2	23.2	25.2	27.9	30.5	33.4
3. Sandal + casuarina + erythrina	12.8	14.0	15.7	18.1	21.0	24.6	28.0	32.3	35.3	39.2
4. Sandal + erythrina	12.6	13.1	13.5	14.0	14.6	15.1	16.0	17.0	18.5	19.8
F test	**	**	*	NS	*	**	**	**	**	**
LSD (0.05)	0.57	1.08	2.10	-	4.40	5.4	6.58	8.03	9.36	10.79
SEM (±)	0.19	0.36	0.70	1.16	1.47	1.8	2.20	2.67	3.12	3.59

Contd........

Table 5 contd...

Treatments (Fertilizer levels)	Height of sandal (cm)									
	30 DAP	60 DAP	90 DAP	120 DAP	150 DAP	180 DAP	210 DAP	240 DAP	270 DAP	300 DAP
1. Without farm yard manure and fertilizer	13.5	14.8	16.6	18.7	21.2	23.4	25.7	28.5	31.6	34.8
2. Fertilizer 50 kg/ha each of N, P and K	12.9	13.9	15.2	16.3	18.0	19.5	20.8	22.9	24.4	26.3
3. Farm yard manure 10 t/ha	12.9	14.0	15.2	16.4	18.0	19.2	20.6	22.4	23.8	25.9
4. Farm yard manure and fertilizer 10 t/ha and 50 kg/ha	13.1	13.9	15.2	17.3	19.1	21.3	23.6	26.5	28.3	30.6
F test	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
LSD (0.05)	-	-	-	-	-	-	-	-	-	-
SEM (±)	0.19	0.36	0.70	1.16	1.47	1.10	2.19	2.67	3.12	3.60
Host combination x fertilizer interaction										
F test	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
SEM (±)	0.38	0.72	1.40	2.32	2.93	3.59	4.39	5.35	6.24	7.19

DAP - Days after transplanting NS - Not significant

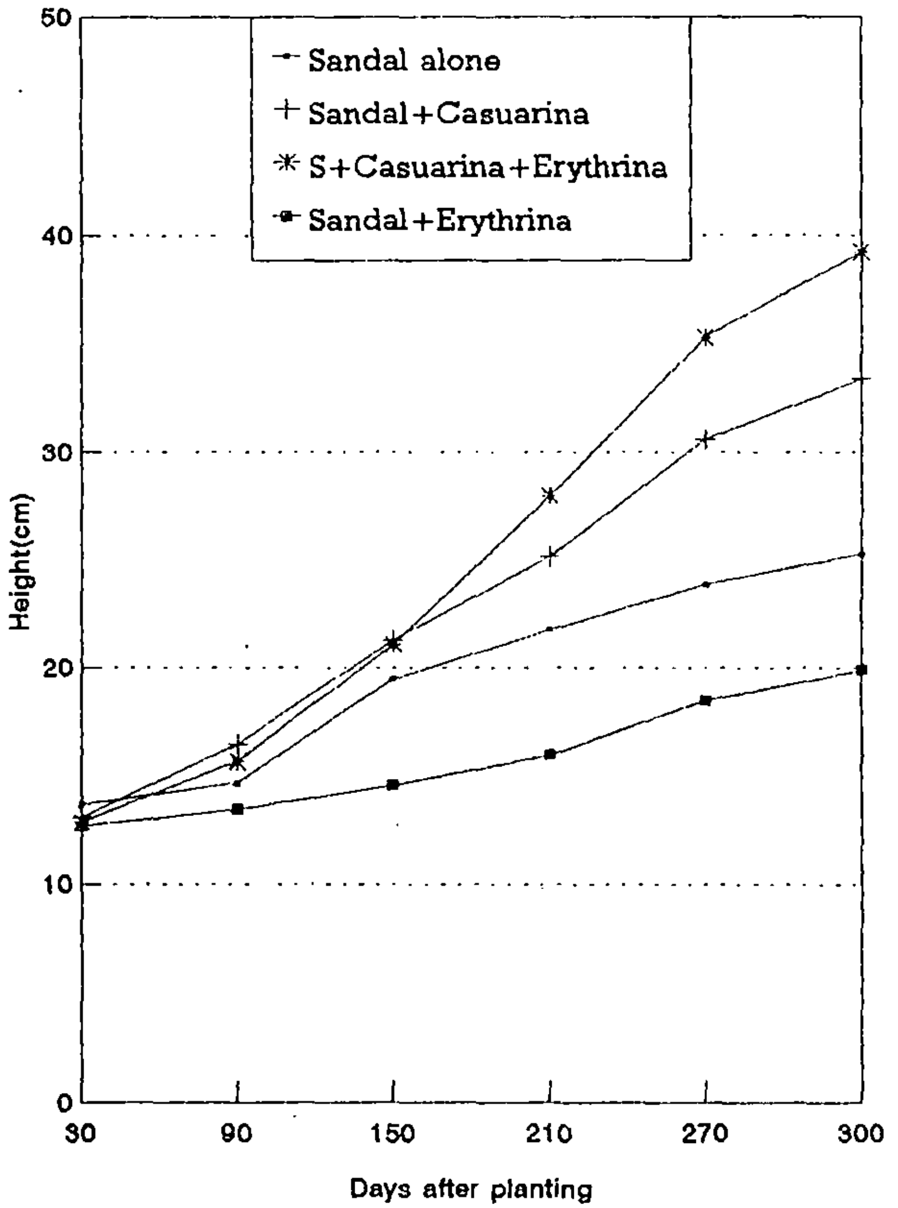


Fig.4 Height of sandal seedlings as influenced by different host levels

but significantly superior in height to the sandal grown with erythrina. The superiority of the sandal in sandal + casuarina+erythrina association continued till the end of the experimental period (Fig.4).

Erythrina is reported to be a poor host of sandal and in pot culture studies, continued association of sandal with erythrina eventually led to the killing of sandal seedlings (Venkata Rao, 1938). In this study, sandal in association with erythrina exhibited a reduced growth. However, when sandal was grown with the host complex of erythrina+casuarina, it exhibited a slight increase in growth than the sandal with the good host casuarina which was however not significant. This indicates possible complementary effects between hosts and sandal when grown with more than one host. There was no significant difference in height of sandal due to the fertilizer levels. The interactions between the fertilizer levels and the host levels were also not significant.

The results indicate that, the role of a host for sandal cannot be replaced by supplementing plant nutrients through mineral fertilizers or farmyard manure. Eventhough sandal is reported to depend on the host plants mainly for mineral nutrients like N and P (Iyengar, 1965 and Kunda *et al.*, 1974 a,b), there may be some other physiological and/or biochemical factors over and above the mineral nutrient supplementation, which govern the performance of sandal grown with a particular host.

4.2.2 Collar diameter

Similar to the response observed in height of sandal, collar diameter also was significantly influenced only by the hosts. The effect of fertilizers and interactions between hosts and fertilizers were not significant. The significant influence of hosts on collar diameter was manifested only towards a later stage (Table 6). As in the case of height, sandal in sandal + casuarina + erythrina association showed the maximum collar diameter. The collar diameter was lowest in sandal with erythrina as the host (Fig.5). Fertilizer levels did not cause any significant difference in collar diameter of sandal. These results also confirm the earlier conclusion that, the role of hosts for sandal can not be substituted by providing supplementary source of nutrients in the form of fertilizers/manures.

4.2.3 Other growth parameters of sandal

The effect of different host levels and fertilizer levels on other growth attributes of sandal at the end of the experimental period (300 days after planting) is given in Table 7.

Only the hosts showed significant influence on other growth parameters of sandal. The fertilizer levels and interactions between hosts and fertilizer levels were not significant. Sandal in sandal-casuarina+erythrina association showed significantly higher values in almost all the growth parameters and the sandal in sandal+casuarina association also exhibited a comparable performance. Sandal in sandal+erythrina association recorded lower values for all growth parameters except number of leaves and number of haustoria.

Table 6 Effect of different host combinations and fertilizer levels on collar diameter of sandal seedlings

Treatments (Sandal+Host associations)	Collar diameter (mm)									
	30 DAP	60 DAP	90 DAP	120 DAP	150 DAP	180 DAP	210 DAP	240 DAP	270 DAP	300 DAP
1. Sandal alone	1.59	1.7	1.90	2.06	2.18	2.28	2.39	2.53	2.70	2.90
2. Sandal + casuarina	1.52	1.64	1.78	1.98	2.17	2.34	2.51	2.73	3.01	3.28
3. Sandal + casuarina + erythrina	1.55	1.73	1.90	2.13	2.44	2.70	3.01	3.27	3.61	4.06
4. Sandal + erythrina	1.55	1.72	1.84	1.99	2.18	2.32	2.44	2.55	2.70	2.88
F test	NS	NS	NS	NS	NS	NS	NS	NS	NS	*
LSD (0.05)	-	-	-	-	-	-	-	-	-	0.96
SEM (±)	0.02	0.03	0.05	0.07	0.13	0.16	0.20	0.26	0.26	0.32

Contd........

Table 6 contd....

Treatments (Fertilizer levels)	Collar diameter (mm)									
	30 DAP	60 DAP	90 DAP	120 DAP	150 DAP	180 DAP	210 DAP	240 DAP	270 DAP	300 DAP
1. Without farm yard manure and fertilizer	1.57	1.75	1.93	2.17	2.51	2.74	3.00	3.25	3.60	4.03
2. Fertilizer 50 kg/ha each of N, P and K	1.57	1.69	1.83	2.00	2.20	2.36	2.51	2.66	2.86	3.05
3. Farm yard manur 10 t/ha	1.53	1.69	1.84	2.00	2.14	2.29	2.45	2.60	2.78	2.94
4. Farm yard manure and fertilizer 10 t/ha and 50 kg/ha	1.54	1.69	1.82	1.97	2.10	2.25	2.40	2.57	2.80	3.08
F test	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
LSD (0.05)	-	-	-	-	-	-	-	-	-	-
SEM (±)	0.02	0.03	0.05	0.07	0.13	0.16	0.20	0.26	0.26	0.32
Host combination x fertilizer interaction										
F test	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
SEM (±)	0.04	0.07	0.09	0.15	0.27	0.32	0.40	0.51	0.51	0.63

DAP - Days after transplanting
NS - Not significant
* Significant at 5% level
** Significant at 1% level

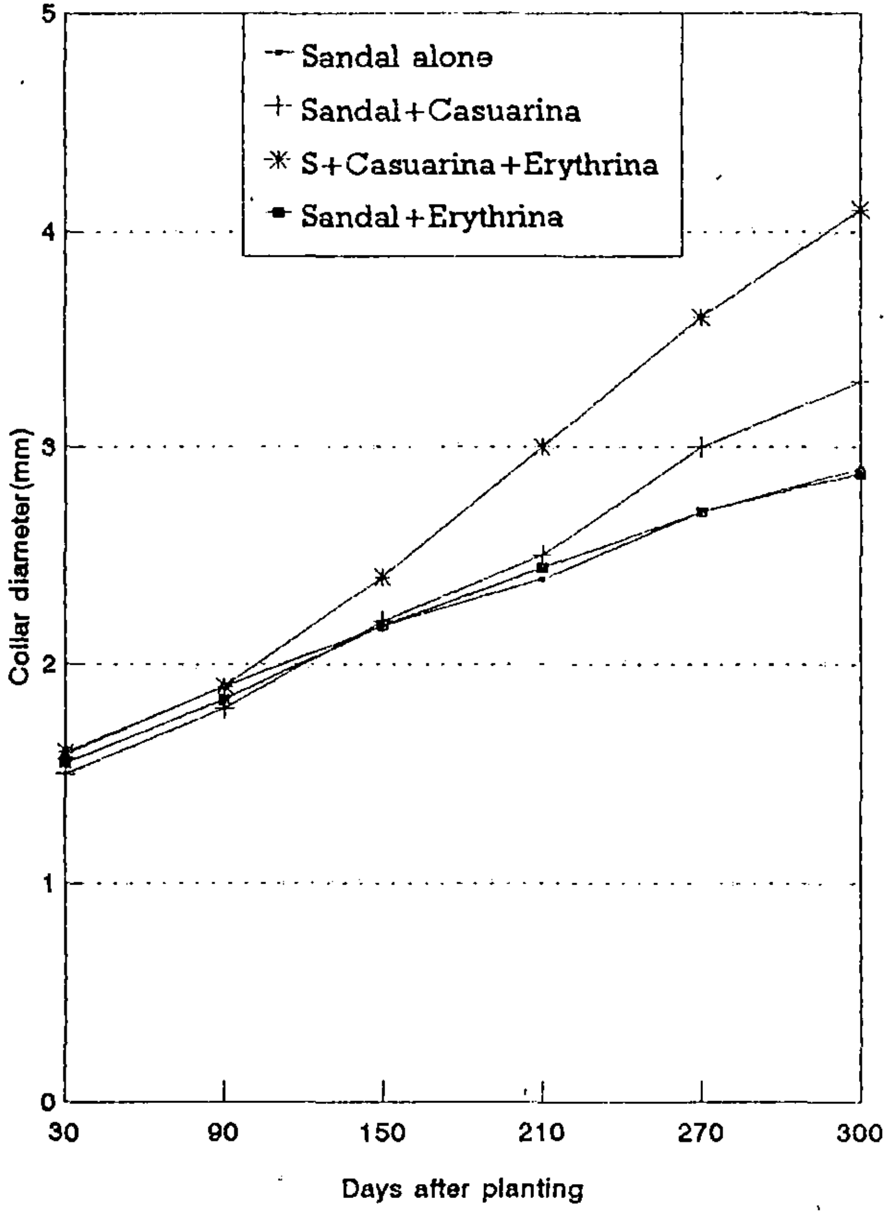


Fig.5 Collar diameter of sandal seedlings as influenced by different host levels

Table 7 Effect of different host combinations and fertilizer levels on various growth attributes of sandal seedlings at 300 DAP

Treatments (Sandal+host associations)	Root length (cm)	Shoot dry weight (g)	Root dry weight (g)	Total dry weight (g)	Number of leaves	Number of haustoria
Sandal alone	18.55	3.29	1.74	5.03	33.4	3.2
Sandal + casuarina	21.66	10.11	4.82	14.93	46.6	7.6
Sandal + casuarina + erythrina	24.98	18.91	8.82	27.73	51.1	8.4
Sandal + erythrina	14.18	3.04	1.37	4.41	34.0	5.5
F test	**	NS	NS	NS	**	**
LSD (0.05)	6.81	-	-	-	8.8	1.1
SEM(±)	2.36	0.40	0.19	0.58	3.05	0.41
Fertilizer levels without farmyard manure and fertilizer	24.28	17.54	8.57	26.11	46.5	6.5
Fertilizer 50 kg/ha (N,P&K each)	18.72	4.51	1.90	6.41	41.8	6.5
Farmyard manure 10 tonns/ha	17.96	4.32	1.85	6.17	38.9	6.4
With farmyard manure and fertilizer 10 tonns/ha and 50 kg/ha	20.43	8.98	4.43	13.41	38.0	5.3
F test	NS	NS	NS	NS	NS	NS
LSD (0.05)	-	-	-	-	-	-
SEM (±)	2.36	0.40	0.19	0.58	3.05	0.41
Host combination x fertilizer interaction						
F test	NS	NS	NS	NS	NS	NS
SEM (±)	4.92	0.73	0.37	1.17	6.12	0.82

DAP - Days after transplanting ** Significant at 1% level NS - Not significant

Among the different host levels studied, the performance of sandal was found to be superior when the double hosts viz., casuarina + erythrina were provided for sandal. This was closely followed by the single host situation ie., sandal+casuarina. Casuarina was indicated as a good host for sandal by workers like Ananthapadmanabha (1988) and Taide (1991), whereas Venkata Rao (1938) indicated erythrina as a bad host for sandal. The growth of sandal in association with erythrina was significantly lower than that with a good host like casuarina and it confirmed its status as a bad host. However, sandal in association with two hosts, one a good host (casuarina) and the other a bad host (erythrina) showed a slightly better growth than sandal in association with a good host only. This indicates that a good host may mitigate the negative effects of a bad host or certain combinations of hosts may be having a complementary effect on growth of sandal. Venkata Rao (1938) observed that, in association with bad hosts, the growth of sandal is reduced, but whenever a good host is provided along with it, normal growth is restored even though sandal may still be feeding on the bad host and he cited this as the reason for some bad hosts in pot culture experiments appearing as good hosts in field studies. Nevertheless here the complementary influence of the double host situation ie. good host + bad host is not clearly understood.

Iyengar (1965) observed that, in the field no single species has been found to be constantly associated with sandal ie. its hosts are heterogenous in character. He also suggested that, a single host may not be supplying all the host dependent nutrients for sandal in the field. A particular host may be best in the supply of certain elements, while other elements can be optimally supplied by some other hosts. So he suggested that, a mixed flora with a large variety of species known for their preference to sandal as the essence of its silviculture. Radiotracer experiments conducted (Table 13 and 14) showed that casuarina was better in the supply of phosphorus to sandal whereas erythrina was better in the supply of carbon compounds. So in this experiment, when both the hosts were provided together, it results in an increased growth of sandal even though one of them was a bad host. So the idea of a mixed flora, with a variety of good hosts as the essence of sandal silviculture, should be given due consideration and the complementary/competitive effects of multiple host combinations need be studied in greater detail.

Supplementing mineral nutrients to sandal in the presence or absence of hosts, through fertilizers or farmyard manure had not caused any significant difference in the growth parameters of sandal. Generally the unfertilized control (without farmyard manure and fertilizers) recorded a relative higher value, though not significant. Rangaswamy *et al.* (1990) observed that, inorganic fertilizer application in small doses to the seedlings of sandal have caused toxicity and subsequent mortality whereas Angadi *et al.* (1995) found that, application of individual nutrient elements both micro and macro nutrients, boosted the growth of sandal seedlings. The above two reports are contradictory. No mortality was observed, consequent to fertilization in this study. Mineral supplementation had not significantly influenced the growth of sandal. The hosts associated with sandal is the principal factor deciding the induced growth of sandal.

4.2.4 Anatomical features

Microphotographs of sandal haustorium, haustorium in association with casuarina root and the haustorium on erythrina root are given in plates 2, 3 and 4 respectively.

In the sandal haustorium, the vascular cylinder appears as an inverted flask with both xylem and phloem elements in it. In association with both the hosts, sandal haustoria established intimate vascular connections between host roots and the sandal roots with xylem as well as phloem connections. By 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.

Barber (1906), Ramaiah *et al.*(1962) and Taide (1991) observed direct vascular connections between host and sandal roots through haustoria. Taide (1991) opined that, the vascular connections between the host and sandal becomes so intimate that, the host root and parasitic root become almost a single physiological unit catering to the nutritional requirements of sandal.

Sandal haustoria have 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 species like acacia, ailanthus and emblica with poor growth of sandal associated with them. In this study sandal's

Plate 2 Transverse section of sandal haustorium (x35)

Plate 3 Cross section of sandal haustorium on casuarina root (x35)

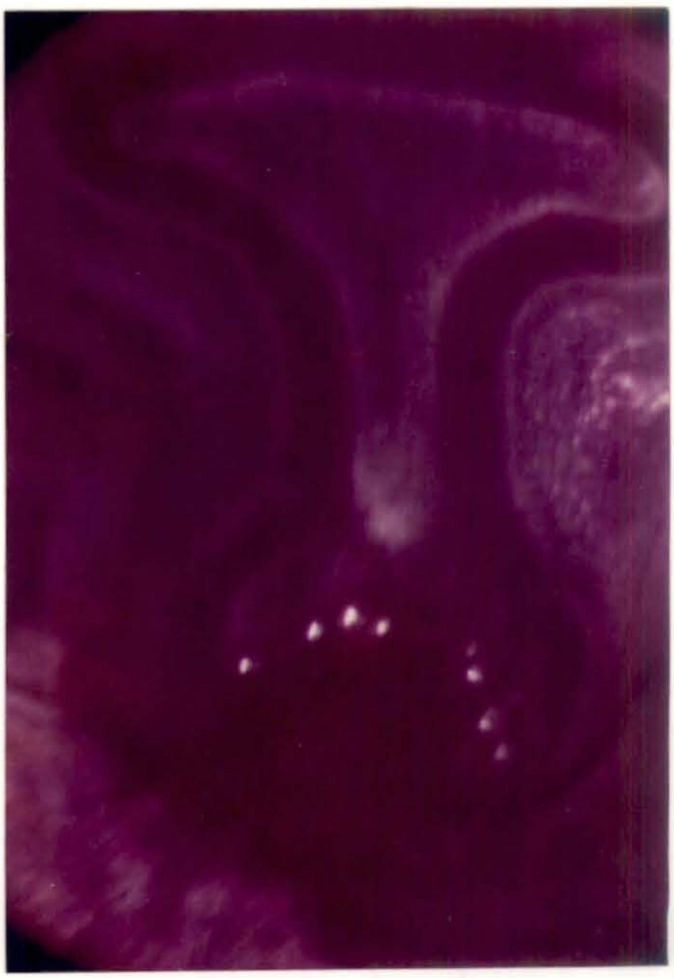


Plate 4 Cross section of sandal haustorium on erythrina root (x70)

growth in association with erythrina was poor, but the well developed haustorial connections which ensures only a path for transfer of materials between sandal and erythrina highlights the role of sandal-host interactions other than haustorial development alone in deciding the overall growth of sandal.

4.3 Experiment III

The results of the study on the uptake and translocation of ^{45}Ca by sandal + redgram (host) association are presented below:

Sandal without any host plant absorbed significantly higher quantity of ^{45}Ca from soil as compared to the redgram (alone), indicating the variation in the calcium uptake of sandal and the host (Table 8). There was no significant difference in the uptake of ^{45}Ca by the sandal when grown with or without the host, redgram. So it is deduced that sandal is taking up calcium from soil and its dependence on host for calcium is negligible.

Kunda *et al.* (1974 a and b) from radiotracer studies involving sandal and a host (*Dolichos lablab*) and Iyengar (1965) after soil-plant analyses of spiked and healthy sandal inferred that calcium is taken up directly from the soil by the sandal plants.

The uptake of calcium was significantly more in redgram grown as a host for sandal than the redgram alone (Table 8). The results of the plant

Table 8 Uptake of ^{45}Ca from soil by sandal and the host in sandal + redgram association

Sl. No.	Treatments (Sandal + host associations)	Radioassayed plant of the association	^{45}Ca counts (log dpm)
1	Sandal alone		4.923 (84117.9)*
2	Redgram alone		4.468 (29961.08)
3	Sandal + redgram	Sandal	4.948 (88910.56)
4	Sandal + redgram	Redgram	4.682 (50139.70)
	F test		**
	CD (0.05)		0.14
	SEM (±)		0.04

* Values in parenthesis indicates actual counts
** Significant at 1% level

Table 9 Uptake of ^{35}S from soil by sandal and the host in sandal + redgram association

Treatments (Sandal + host associations)	Radioassayed plant of the association	^{35}S counts (log dpm)
1. Sandal alone		4.408 (26304.79)*
2. Redgram alone		4.311 (21502.60)
3. Sandal + redgram	Sandal	4.498 (31596.62)
4. Sandal + redgram	Redgram	4.355 (22868.70)
F test		NS
SEM (±)		0.04

* Values in parenthesis indicates actual counts
NS Non significant

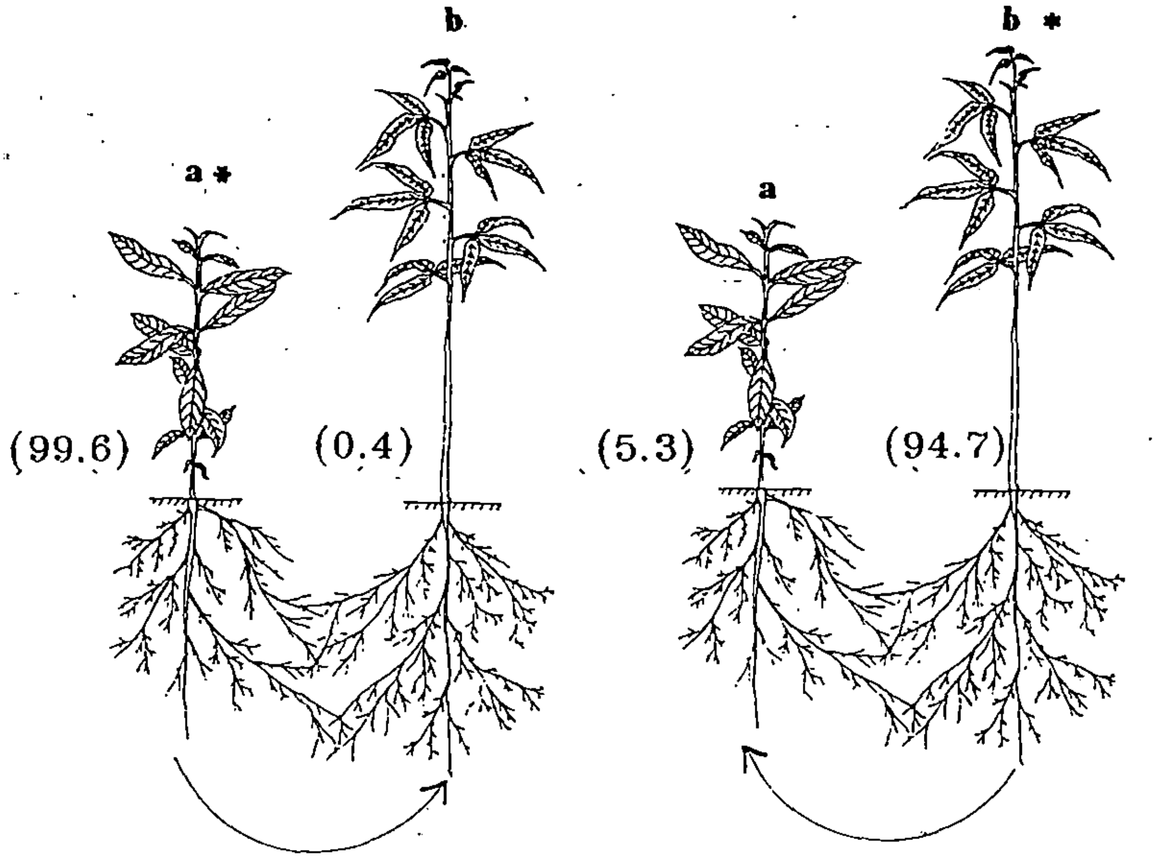
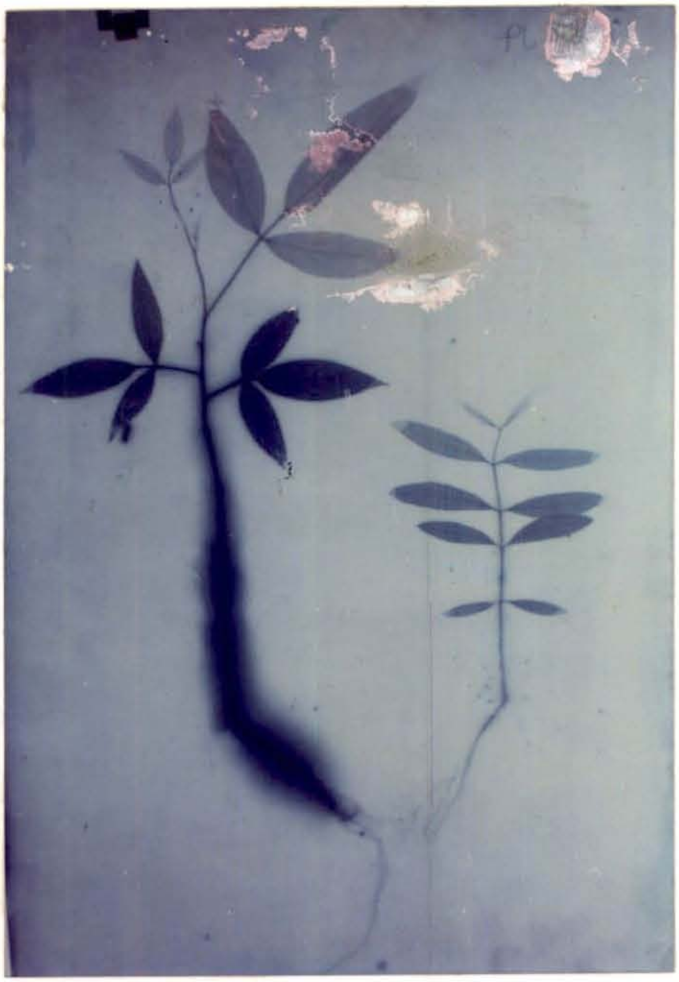


Fig. 6 Translocation of ^{45}Ca between sandal and host in (a)sandal-(b)redgram association

* Labelled plant.
Activity in each plant as percentage is given in parenthesis.

Plate 5 Autoradiograph of the (a) sandal - (b) redgram association in which redgram is labelled with ^{45}Ca

Plate 6 Autoradiograph of the (a) sandal - (b) redgram association in which sandal is labelled with ^{45}Ca.



labelling experiment (Fig.6) indicated that, translocation of ^{45}Ca from sandal to redgram was negligible or absent. So the increase is not due to reverse translocation of calcium from sandal to red gram. Parthasarathi, *et al.* (1974) observed that, in good hosts, the cation exchange capacity of host roots tends to increase subsequent to parasitisation by sandal. The increased uptake of ^{45}Ca by the parasitised redgram may be due to the increased cation exchange capacity of its roots. So in some hosts, sandal though a partial parasite, may induce favourable response.

When sandal plants were labelled with ^{45}Ca in a sandal+redgram association, 99.6 per cent of the total radioactivity detected in the association was observed in sandal itself and that translocated to redgram was only 0.4 per cent. On the otherhand when redgram was labelled in the sandal-redgram association about 5 per cent of the ^{45}Ca, was translocated from redgram to sandal (Fig.6). Nevertheless redgram retained 95 per cent of the ^{45}Ca. This difference in translocation was very much corroborated by the autoradiographs. When redgram was labelled activity translocated (5%) to sandal created a clear image of sandal also in addition to the labelled redgram in the auto radiograph (Plate 5). On the other hand when sandal was labelled, the slight translocation (0.4%) to the redgram created only a scarcely visible image of the redgram so that only the labelled sandal is seen on the autoradiograph (Plate 6).

The results of the soil labelling study and the plant labelling study are complementary and it is evident that, sandal can take up calcium directly from soil and it does not depend considerably on a host plant for obtaining its calcium supply.

4.4 Experiment IV

The results of the study on the uptake and translocation of ^{35}S by sandal + redgram (host) association are presented here.

The uptake of ^{35}S by sandal and redgram were nearly the same, when they were grown independently, whereas sandal took up more calcium from soil than redgram (Table 8). The uptake of ^{35}S from soil did not vary significantly when sandal was grown alone or with the host, redgram (Table 9).

So it follows that, sandal is taking up sulphur from soil or it dependence on host for sulphur is negligible. Redgram showed no significant difference in the uptake of sulphur whether or not parasitised by sandal (Table 9), whereas in the case of calcium, the uptake was significantly more in case of parasitised redgram (Table 8). As discussed earlier, the increased uptake of calcium may be due to the increased cation exchange capacity of the host roots subsequent to parasitisation (Parthasarathi *et al.*, 1974), however sulphur being an anion its uptake may not be enhanced by the increased cation exchange capacity of the host roots.

When the sandal and the host were alternately labelled, the translocation of ^{35}S was more from redgram to sandal (4.3%) than the other way (1.3%) Fig.7). The pattern of translocation is evident on the autoradiographs also. When redgram was labelled, both labelled plant and sandal was visible on the autoradiographs due to the translocated radio activity from host to sandal (Plate 7). On the other hand, when

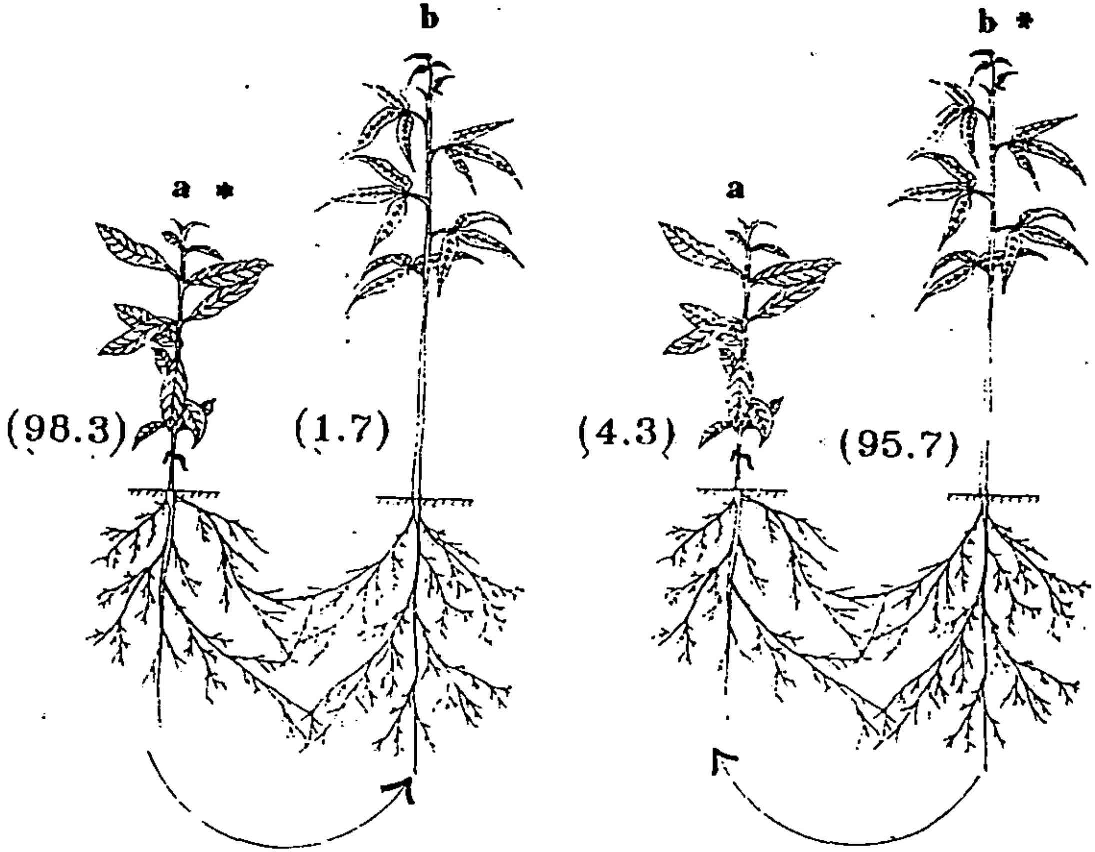


Fig. 7 Translocation of ^{35}S between sandal and host in (a)sandal-(b)redgram association

* -Labelled plant.
Activity in each plant as percentage is given in parenthesis.

Plate 7 Autoradiograph of the (a) sandal - (b) redgram association in which redgram is labelled with ^{35}S.

Plate 8 Autoradiograph of the (a) sandal - (b) redgram association in which sandal is labelled with ^{35}S.

sandal was labelled, the activity translocated to the redgram (1.3%) was so negligible that the image sandal only is visible on the autoradiograph (Plate 8).

The translocation from sandal to host was more (1.3%) in case of sulphur than calcium (0.44%). Nayar (1974) and Ananthapadmanabha (1988) opined that, haustorial connections in certain instances may permit movement of substances in both the ways or may serve as two way traffic. Here also the translocation of ^{35}S from host to sandal and sandal to host give indication of the haustoria acting as a two way pathway for translocation of sulphur, though the reverse translocation from sandal to host was only marginal.

The results of the study indicate that, sandal can take up sulphur from soil and it does not depend considerably on a host plant for obtaining its sulphur supply.

4.5 Experiment V

The results of the study on uptake and translocation of ^{32}P by different sandal-host associations are presented below:

When the uptake of ^{32}P by the three species grown independently were considered, casuarina showed the maximum uptake followed by erythrina and sandal respectively (Table 10). There was no significant difference between erythrina and sandal in the uptake of ^{32}P, whereas, casuarina showed a significantly higher uptake than both of them. This may be due to the inherent difference in phosphorus uptake between these species.

Table 10 . Uptake of ^{32}P from soil by sandal and the host in two different sandal-host associations

Sl. No.	Treatments (Sandal + host associations)	Radioassayed plant of the association	^{32}P counts (log cpm)
1	Sandal alone		3.727 (5698.62)*
2	Casuarina alone		4.497 (34249.67)
3	Erythrina alone		3.766 (8623.15)
4	Sandal+erythrina	Sandal	3.694 (5208.02)
5	Sandal+erythrina	Erythrina	4.036 (13447.23)
6	Sandal+casuarina	Sandal	3.338 (2425.56)
7	Sandal+casuarina	Casuarina	4.511 (43440.51)
	F test		**
	CD (0.05)		0.47
	SEM (±)		0.16

** Significant at 1% level

* Values in parenthesis indicates actual counts

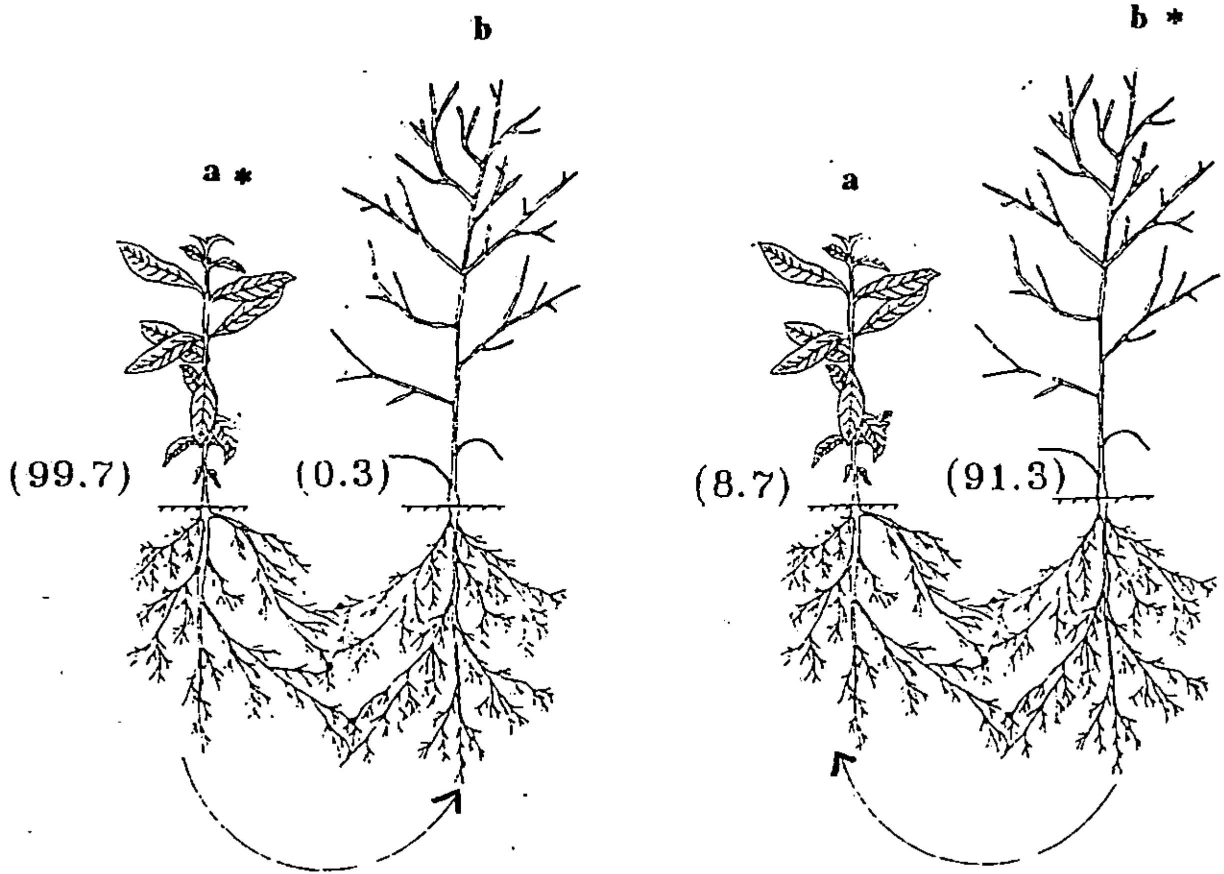


Fig. 8 Translocation of ^{32}P between sandal and host in (a)sandal -(b)casuarina association

* Labelled plant.
Activity in each plant as percentage is given in parenthesis.

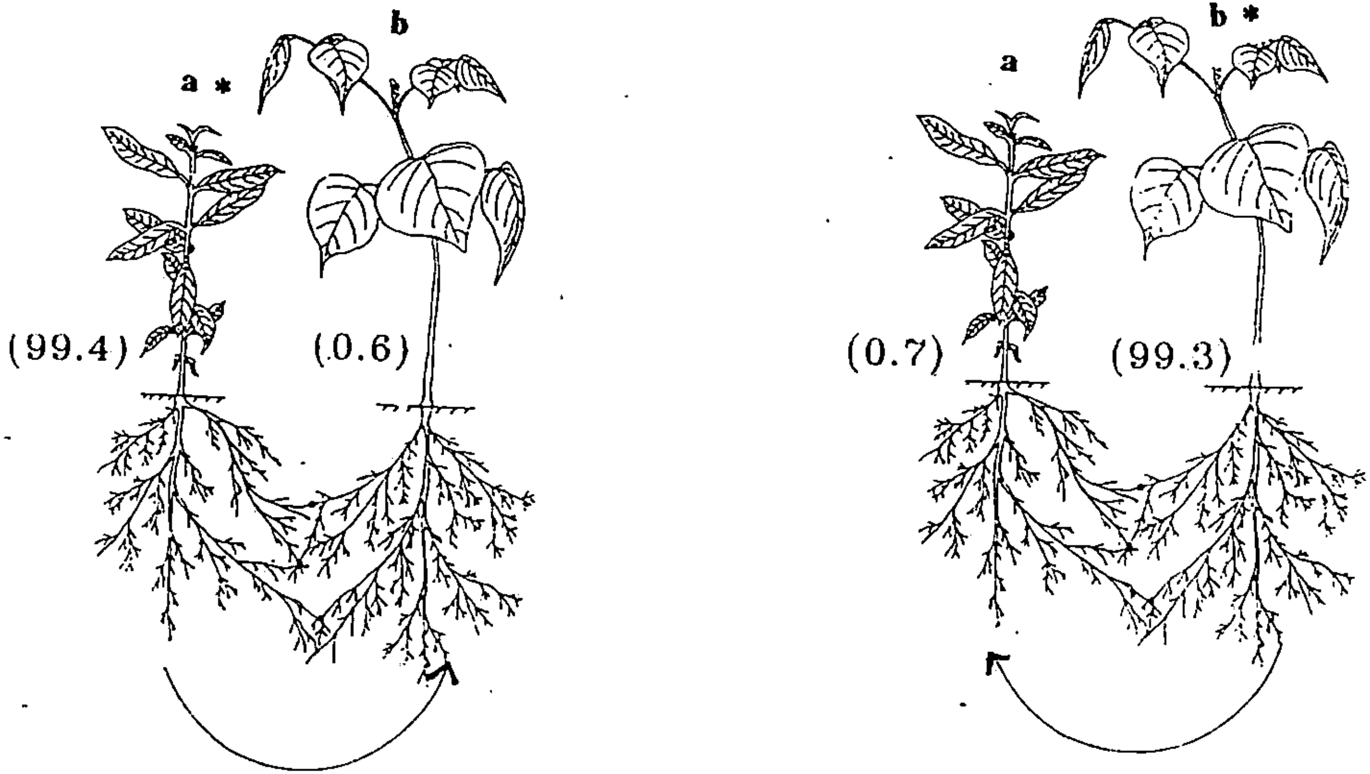


Fig. 9 Translocation of ^{32}P between sandal and host in (a)sandal -(b)erythrina association

* Labelled plant
Activity in each plant as percentage is given in parenthesis.

There was no significant difference in the uptake of phosphorus by sandal, when grown alone or when grown with hosts, erythrina or casuarina. However, a slight decrease in uptake of phosphorus was observed, when hosts were present and the extent of decrease was more when casuarina was the host. As the uptake of phosphorus by casuarina was higher compared to the other two species, the lower phosphorus uptake observed in sandal when grown with casuarina may be due to temporary competition. Erythrina and casuarina showed no significant increase in the uptake of ^{32}P when grown alone or as a host for sandal.

When sandal and the hosts were alternately labelled with ^{32}P, translocation from sandal to hosts was negligible (Fig. 8 and 9). Translocation from hosts to sandal was 0.70% in case of erythrina (Fig.9) and 8.7% in case of casuarina (Fig.8) ie., translocation of ^{32}P from casuarina to sandal was considerably higher than that from erythrina. Venkata Rao (1938) indicated erythrina as a bad host for sandal and Ananthapadmanabha (1988) and Taide (1991) indicated *Casuarina equisetifolia* as a good host. At least for the supply of phosphorus to sandal, casuarina is a superior host than erythrina, as is evident from the plant labelling study.

The results of the soil labelling and plant labelling experiments indicated that, the supply of phosphorus to sandal vary with the host. If soil supplies are limiting, a good host translocates more phosphorus to sandal. The soil labelling experiments points to the independent absorption of phosphorus by sandal even if a host is present. Many of the earlier workers indicated sandal's dependence on hosts for phosphorus (Iyengar, 1965; Kunda, *et al.* 1974 a,b). The present study indicates that, sandal may derive its phosphorus requirement independently from soil. If hosts are present, they may contribute a small fraction of the phosphorus requirement of sandal. If the soil source is not limiting, sandal may not have to depend on the host for phosphorus.

4.6 Experiment VI

The results of the study on translocation of ^{14}C by two different sandal host associations are presented below.

Transfer of ^{14}C from sandal to casuarina and erythrina was negligible in single host and dual host situations whereas the transfer of ^{14}C from host to sandal varied with the host. Casuarina did not transfer much ^{14}C to sandal (Fig.10) whereas erythrina did transfer about 5.5% of the ^{14}C fixed by it (Fig.11).

When the two host species, viz., casuarina and erythrina were provided simultaneously and casuarina was labelled, the translocation from casuarina to sandal was negligible (Fig.12-A). In the dual host situation, when erythrina was labelled the ^{14}C in erythrina was translocated to sandal. About 7% of ^{14}C from erythrina was translocated to sandal and surprisingly about 1.6% of ^{14}C from erythrina was translocated to casuarina also (Fig.12-B). The transfer from erythrina to casuarina may be mediated by sandal through the haustorial connections existing between sandal and both the hosts.

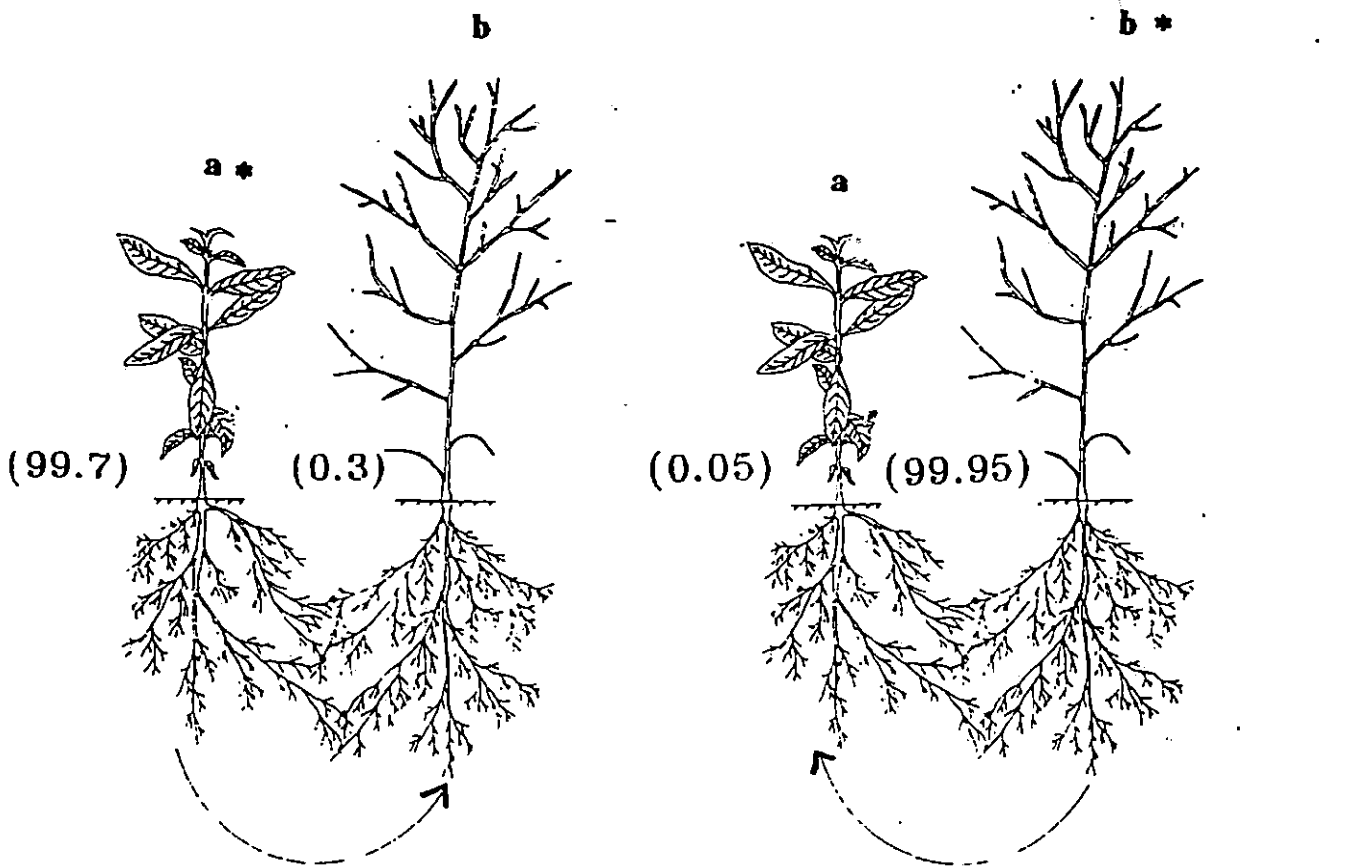


Fig.10 Translocation of ^{14}C between sandal and host in (a)sandal -(b)casuarina association

* Labelled plant.
Activity in each plant as percentage is given in parenthesis.

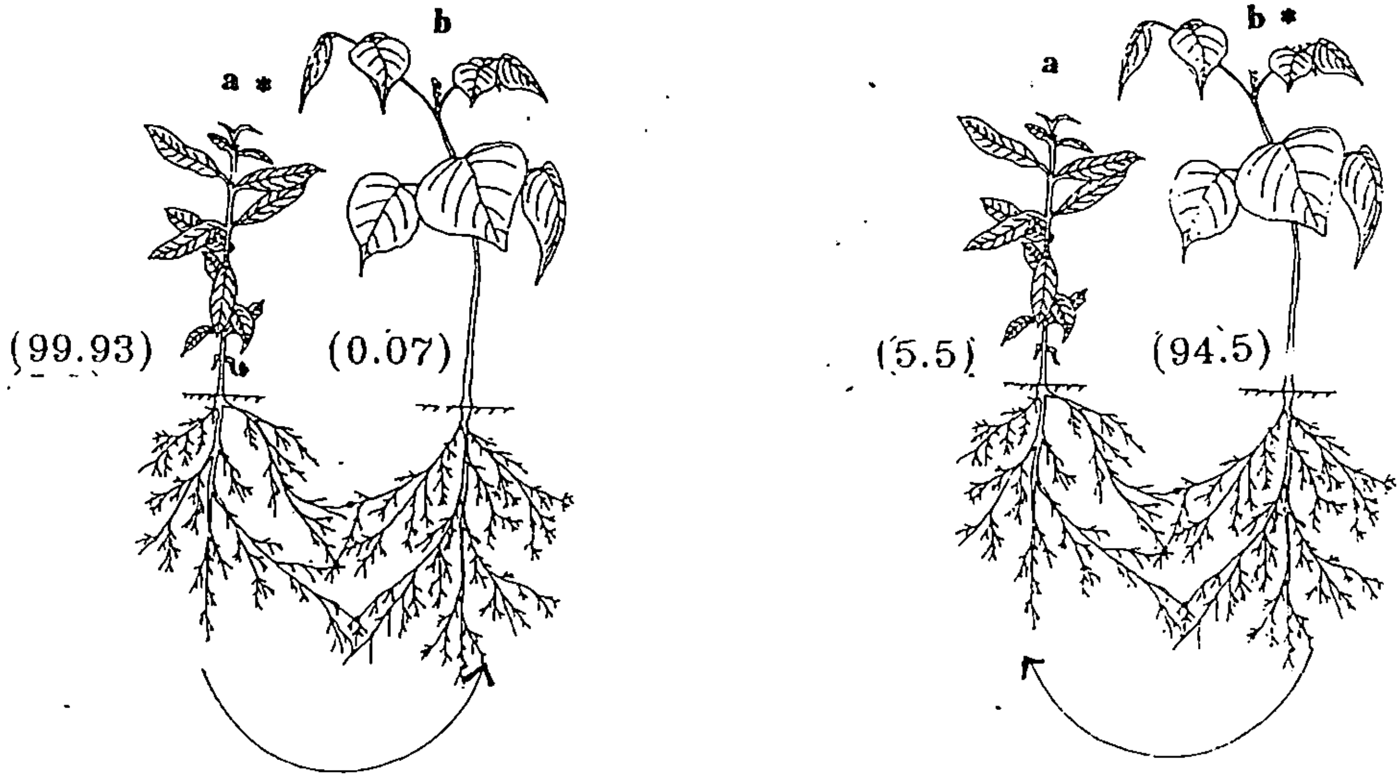


Fig.11 Translocation of ^{14}C between sandal and host in (a)sandal -(b)erythrina association

* Labelled plant
Activity in each plant as percentage is given in parenthesis.

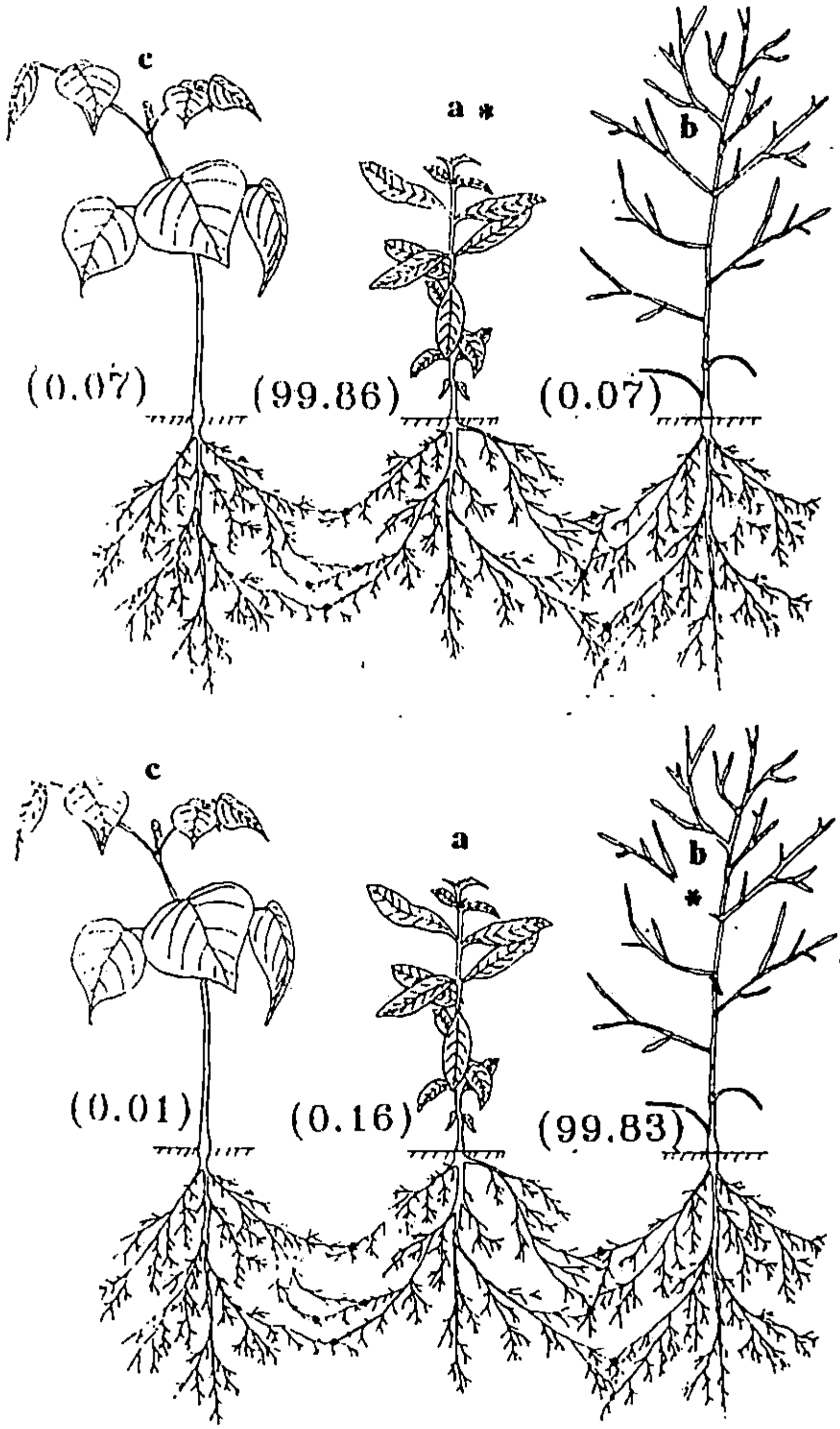


Fig.12-A Translocation of ^{14}C between sandal and hosts in (a)sandal-(b)casuarina-(c)erythrina association * Labelled plant.
Activity in each plant as percentage is given in parenthesis.

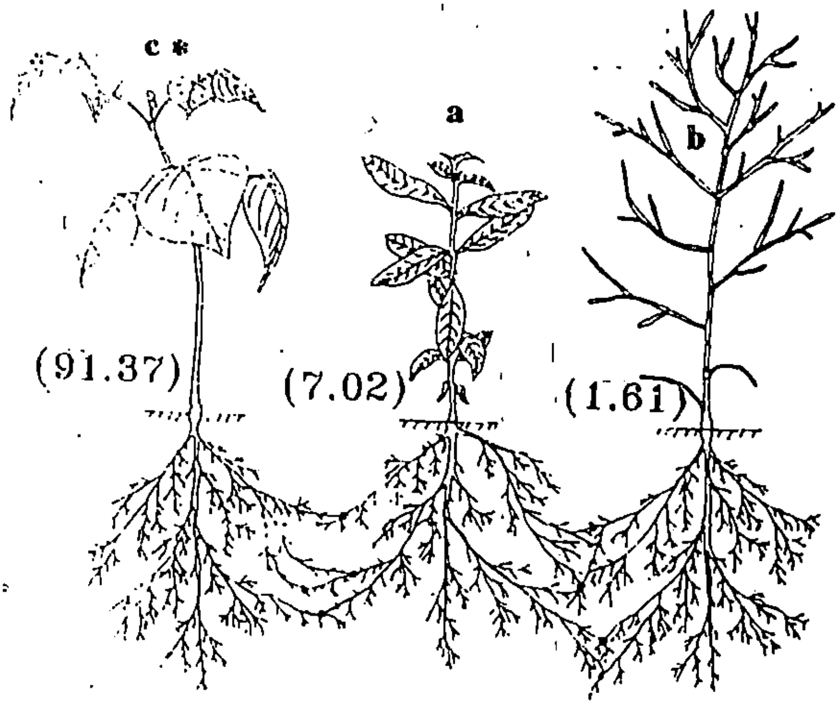


Fig.12-B Translocation of ^{14}C between sandal and hosts in (a)sandal-(b)casuarina-(c)erythrina association.

* Labelled plant.

Activity in each plant as percentage is given in parenthesis.

The results of the experiment indicates that, translocation of carbon compounds from sandal to hosts was negligible whereas the extent of transfer from hosts to sandal varied depending on the host species. Kunda *et al.* (1974 a,b) indicated transfer of organic substances between sandal and hosts.

Translocation of ^{14}C to sandal was more from erythrina than from casuarina in both the single host and dual host situations (Fig. 11 and 12-B) whereas ^{32}P translocation was more from casuarina (Fig. 8). So with respect to ^{14}C translocation to sandal, erythrina was better but in the case of ^{32}P translocation, casuarina was better. In the ^{14}C experiment both the hosts were of the same age but growth of erythrina was much faster than that of casuarina indicating the possibility of surplus carbon being fixed, part of which may be translocated to sandal. The results of the experiment points to the possibility of the same host differing in its effectiveness, in supplying different growth inputs to sandal. In the supply of phosphorus to sandal, casuarina may be superior but in supply of carbon compounds, erythrina may be the superior host. This may be the reason for the better growth of sandal observed in experiment II. When sandal was associated with both hosts ie, casuarina and erythrina rather than either of them.

Iyengar (1965) was of the opinion that, hosts of the sandal are heterogenous in character and he suggested the possibility that, a particular host may be best in the supply of certain elements, while some other elements can be optimally supplied by some other hosts. The results of this study confirmed the possibility. Casuarina was better in the supply of phosphorus to sandal, whereas erythrina which was regarded as a bad host had shown superiority in the supply of carbon compounds to sandal. So it suggests that, for ensuring the maximum growth and development of sandal in field, it should be provided with a variety of good hosts instead of depending on a single host. It also calls for a review of the classification of the hosts like erythrina as bad host, because in combination with other good hosts the so called `bad' hosts may show complementary effect and improve growth of sandal.

Results of radiotracer studies also highlighted the semiparasitic nature of sandal. Though elements like Ca, S and P were directly absorbed from the soil, a fraction of these elements may be derived by the sandal through the host. Translocation of carbon compounds from hosts to sandal was also observed. The superiority of some of the hosts in supporting growth of sandal may be due to not only translocation of essential minerals from host to sandal but also due to the translocation of some of the carbon compounds which may include growth promoting substances. The form in which nutrients are supplied to sandal by the host and the exact mechanism of transfer is yet to be worked out.

Summary and Conclusions

SUMMARY AND CONCLUSIONS

Experiments were conducted at College of Forestry, Vellanikkara during 1995-96 to elucidate the various aspects of parasitisation behaviour of sandal (*Santalum album* Linn.). The principal objectives were to study the parasitisation behaviour of sandal on selected agricultural crops occurring in the homesteads of Kerala and to know the effect of application of manures and fertilizers to selected sandal-host associations. The uptake and translocation of nutrients and photosynthates by sandal-host associations were also examined using radioisotopes. The study was conducted in pot culture and separate experiments involving a number of hosts like coconut, cashew, banana, black pepper, jack, mango, rubber, casuarina, erythrina and redgram were conducted as part of the study. The salient findings of the study are presented below.

1. Growth parameters of the sandal seedling, like height, collar diameter, total dry matter, number of leaves, and number of haustoria varied significantly depending on the host associated with sandal. For all the parameters maximum growth was observed in association with the host - *Casuarina equisetifolia.*

2. By providing good hosts like casuarina, significant advantages can be gained in the growth of sandal.

3. Variation in growth of sandal, depending on the host emphasizes the need for detailed studies to understand the physiological implications of sandal-host associations.

4. Agricultural crops tried in this experiment, viz., cashew, coconut, banana, black pepper, mango, jack, rubber are not preferred hosts of sandal and it indirectly implies that, sandal may not adversely affect the growth of these agricultural crops by way of its parasitisation.

5. No significant decrease was observed in the growth of any of the hosts consequent to the parasitisation by the sandal. During the short experimental period, the dependence of sandal on hosts for nutrients might not have been considerable, so as to be manifested in the growth of hosts. Long term studies are needed for ascertaining the exact effects due to the parasitisation of sandal on the hosts.

6. Sandal plants, grown without any hosts also produced haustoria, so haustoria formation is an inherent capacity of sandal. Number of haustoria produced varied depending on the host species associated with sandal and a good host may induce production of more number of haustoria. But formation of haustoria is not the sole criteria for deciding a good host.

7. Growth parameters of sandal seedlings like height, collar diameter, number of leaves and number of haustoria were significantly influenced by the host levels only. Fertilizer levels and interaction between hosts and fertilizer levels had not caused by significant difference.

8. Host is the principal factor governing the growth of sandal and the role of a host for sandal cannot be replaced by supplementing nutrients through mineral fertilizers or farmyard manure. There may be some other physiological or biochemical factors over and above the mineral nutrient supplementation, which govern the performance of sandal grown with a particular host.

9. Of the host levels tried, sandal in sandal + casuarina + erythrina association had the maximum growth and sandal in sandal + casuarina association had a comparable growth, whereas the lowest growth was for the sandal in sandal + erythrina association

10. Combination of a good host and a bad host together like casuarina + erythrina had a more favourable influence on sandal's growth than a good host, casuarina alone. The possible complementary/ competitive effects of multiple host combinations on sandal's growth need be studied in more detail.

11. Sandal plants can take up calcium directly from soil and its dependence on host for calcium is negligible.

12. Redgram parasitised by sandal had a higher uptake of calcium than the redgram grown alone, which may be caused by the increased cation exchange capacity of roots of the parasitised plant.

13. Sandal can take up sulphur directly from soil and its dependence on hosts for sulphur is negligible. Haustoria acted as a two directional path way in the translocation of sulphur ie. from sandal to host and host to sandal.

14. Sandal can take up phosphorous directly from soil and host may also provide a small traction of the phosphorous requirement of sandal. If the soil source is not limiting, sandal may not have to depend on the hosts for phosphorous.

15. Hosts differed in their ability to supply phosphorous to sandal. Casuarina as a host was superior in supplying phosphorous to sandal than erythrina.

16. Translocation of carbon compounds between sandal and hosts is there and the extent of transfer varied depending on the host. Erythrina was the better host in the supply of carbon compounds to sandal.

17. The same host differed in its ability to supply different nutrients to sandal. Casuarina was superior in the supply of phosphorous to sandal, but in the supply of carbon compounds erythrina was better than casuarina. So instead of providing a single host to sandal, a variety of hosts may be ideal in ensuring a balanced supply of growth inputs and a more wholesome growth of sandal.

18. Direct vascular connections between sandal roots and host roots are established through the sandal haustoria. Xylem as well as phloem connections are present which may facilitate translocation of water and other substances between sandal and hosts.

The findings of the study led to the following conclusions.

Sandal may be grown as a component in the homesteads of Kerala without detrimental effects on other crop components of the homestead system and for ensuring sandal's maximum growth and development, a preferred host like casuarina can be incorporated into the cropping system. Formulation of such a cropping system and its evaluation in the homesteads will go a long way in raising sandal outside forest lands for meeting our future demands of sandal.

Host is the principal factor governing sandal's growth and the role of hosts can not be substituted by nutrient supplementation through other forms like fertilization or manuring. In view of the synergistic effect of certain host combinations on growth of sandal, physiological as well as other investigations on complementary/competitive effects of multiple hosts on growth of sandal need be examined in greater detail.

Radiotracer studies highlighted the semiparasitic nature of sandal. Though elements like calcium, sulphur and phosphorous can be directly taken up by sandal from soil, a fraction of these are also obtained by transfer from hosts. Transfer of carbon compounds from hosts to sandal also occur. The exact form of supply of these nutrients and mode of transfer is yet to be worked out. The favourable effect of multiple hosts on sandals growth, coupled with the findings that a particular host may be best in the supply of a certain element while some other hosts may supply other elements better stresses the point that, a more wholesome growth of sandal maybe achieved by providing a variety of good host species instead of a single host.

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Appendices

APPENDIX I

Weather parameters for the experimental period

Month	Rainfall (mm)	Temperature (°C)		Relative humidity (%)
		Maximum	Minimum	
1995				
Dec	0.0	32.5	21.3	57
1996				
Jan	0.0	33.1	22.4	53
Feb	0.0	34.7	23.4	53
Mar	0.0	36.4	24.3	60
Apr	152.0	34.6	25.0	73
May	95.4	32.0	25.2	77
Jun	400.3	30.5	23.8	85
Jul	588.7	28.8	23.1	90
Aug	310.0	29.1	23.6	87
Sep	391.6	29.1	23.7	84
Oct	219.3	30.1	22.9	82

APPENDIX II

Composition of the scintillation liquid used in the radioassay of ^{45}Ca and ^{35}S

Sl. No.	Chemical	Quantity/litre of the scintillation liquid
1.	Naphthalene	60 g
2.	ppo	4 g
3.	popop	0.2 g
4.	Methanol	100 ml
5.	Ethylene glycol	20 ml
6.	Dioxane	880 ml

PARASITIC INTERFERENCE OF SANDAL (*SANTALUM ALBUM* LINN.) ON COMMON AGRICULTURAL CROPS FROM THE HOMESTEADS

By

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ABSTRACT OF A THESIS

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Experiments were conducted at College of Forestry, Kerala Agricultural University, Vellanikkara, Thrissur during 1995-96 to elucidate the various aspects of parasitisation behaviour of sandal (*Santalum album* Linn.). Parasitisation behaviour of sandal on selected agricultural crops occurring in the homesteads of Kerala, response of selected sandal-host combinations to manures and fertilizers and uptake and translocation of nutrients and photosynthates by sandal-host associations were the principal aspects investigated. Pot culture experiments involving a number of hosts like coconut, cashew, banana, black pepper, jack, mango, rubber, casuarina, erythrina and redgram were conducted as part of the study.

The results indicated that, growth parameters of the sandal seedling ike total dry weight and number of haustoria varied significantly depending on the host associated with sandal. Maximum growth of sandal was observed in association with the host - *Casuarina equisetifolia*. No significant decrease was observed in the growth of any of the hosts consequent to the parasitisation by sandal. Host is the principal factor governing the growth of sandal and fertilizer levels tried in this experiment had not caused any significant influence on the growth of sandal seedlings. In view of the favourable influences by the host complex of a good and bad host together ie., casuarina + erythrina, on sandal's growth, the possible competitive/complementary effects of multiple host combinations on sandal's growth, need be investigated in greater detail.

Sandal plants can take up elements like calcium, sulphur and phosphorus directly from soil and a small fraction of these are also obtained from host. Carbon compounds also are translocated between sandal and hosts. The same host differed in its ability to supply different elements to sandal ie., in the supply of phosphorus to sandal, casuarina was better while carbon compounds were optimally supplied by erythrina. So instead of providing a single host to sandal, a variety of good hosts should be provided in the field for ensuring a more optimal growth of sandal. Anatomical studies showed that, sandal roots can establish direct vascular connections with host roots through haustoria.