ROOT COMPETITION BETWEEN COCONUT PALMS AND INTERPLANTED MULTIPURPOSE TREES UNDER VARYING NUTRIENT MANAGEMENT REGIMES

By

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THESIS

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DECLARATION

I hereby declare that this thesis entitled **"Root competition between coconut palms and interplanted multipurpose trees under varying nutrient management regimes"** 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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CERTIFICATE

Certified that this thesis, entitled "**Root competition between coconut palms and interplanted multipurpose trees under varying nutrient management regimes**" is a record of research work done independently by **Sri. H.B. Sanjeev Gowda** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to him.

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Finally, I bow my head before the ALMIGHTY.

H.B.Sanjeev Gowda

Dedicated

to my

Loving Parents

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Introduction

INTRODUCTION

Coconut palm [*Cocos nucifera* L. (Palmae)] is an important plantation crop in the tropics. Area under coconut is estimated to be about 12 million hectares in the world. Nearly three-fourth of the worlds coconut production is from India, Indonesia and Philippines; Sri Lanka with about 5.22 per cent of the production occupies the fourth position in this respect (APCC, 1999). In India, coconut is grown over an area of about 1.91 million hectares with an annual production of 14,925 million nuts. The state of Kerala represents an important coconut growing region, with an area of over ten lakh hectares and a total annual production of 6672 million nuts (GOK, 2000).

Coconut plantation in Kerala are usually established at a recommended spacing of 7.6 to 9 m (KAU, 1996). This wide spacing intended to meet the resource requirements of the trees at maturity. It, however, results in incomplete utilization of the site resources. As regards to light capture, the palms normally do not intercept much of the incoming solar radiation (7 to 86 per cent light infiltration; according to Abraham, 1993). Coincidentally, the limited lateral spread (20 to 30 per cent of land area) of the coconut roots (Anilkumar and Wahid, 1988) contributes to sub-optimal utilisation of the below ground resources. As a result, a wide spectrum of annual, biennial and perennial crops are often grown as intercrops in the coconut plantations (Thomas and Nair, 1996).

Although there is little tradition of interplanting multipurpose trees in coconut plantation with a view to develop low input sustainable production systems, of late, several multipurpose trees are systematically inter-planted in the coconut plantations (Nair, 1983; Kumar, 1999). These multipurpose trees are intended to produce green manure, fodder and timber or serve as support trees for trailing pepper vines. Nevertheless, they are likely to compete with main crop for site resources. Previous reports suggested that in mixed species systems, roots of several species intermingle and often this overlap can be extensive (Clements *et al.*, 1929). Also, the concentration of feeder roots in the surface horizons of the soil profile (Sankar *et al.*, 1988; Ruhigwa *et al.*, 1992; Jamaludheen *et al.*, 1997; Thomas *et al.*, 1998) aggravates the problem of root competition.

However, the magnitude of root competition in mixed species system is thought to be a function of the soil fertility regimes (Wilson and Tilman, 1993). Two contrasting hypothesis exists in this regard (Wilson and Tilman, 1993). First is that, competition may be most intense in productive habitats, because such habitats support high growth rates and large amount of biomass that results in pre-emption of space and light. So both above and below ground competition may increase with soil fertility (Campbell *et al.*, 1991; Pysek and Leps, 1991). Second is that in habitats with low soil resource availability, soils may have low standing crop and root competition in such habitats may be intense (Newman, 1983). Nevertheless, information pertaining to the competitive interactions along a fertility gradient in the managed land use systems of the tropics is scarce. Hence an experiment was conducted to evaluate the magnitude of root competition in a mixed cropping situation involving coconut and multipurpose trees along a soil fertility gradient. In addition, information on spatial distribution of the multipurpose tree root system, which decides its ability to acquire water and nutrients preferentially over other associated crops is seldom available in the literature. Therefore a study was undertaken with the following objectives.

1. To evaluate the influence of interplanted multipurpose trees on coconut productivity.
2. To assess the performance of selected multipurpose trees interplanted in coconut plantation.
3. To determine the nature of below ground interactions between coconut palms and associated multipurpose trees along a soil fertility gradient and to characterise the root distribution pattern of three multipurpose trees.

Review of Literature

2. REVIEW OF LITERATURE

Agroforestry is internationally accepted today as a land-use system that involves socially and ecologically acceptable integration of trees with agricultural crops and/or animals, simultaneously or sequentially, so as to get increased productivity of plant and animal components in a sustainable manner, especially under conditions of low levels of technological inputs and marginal lands (Nair, 1989). Agroforestry has attracted considerable attention because of its potential to maintain or increase productivity in areas where high energy input and large scale agriculture is impractical (Kidd and Pimental, 1992). Based on the nature of components agroforestry is subdivided into agrisilviculture (crops, pasture/ animals/and/trees); silvopastoral (pasture/animals and trees) and agrosilvopastoral (crops, pasture/animals and trees) (Nair, 1985). Information on agrisilvicultural systems is reviewed here with the principal focus on the tree-based production systems in Kerala.

2.1 Agroforestry systems in Kerala

Although integrated tree-crop production system abound in Kerala, the coconut (*Cocos nucifera* L.) based agroforestry systems, by far, represents the single most important agroforestry system. The palms normally do not intercept much of the solar radiation (Abraham, 1993). In addition, the limited lateral spread of roots (Anilkumar and Wahid, 1988) may lead to sub-optimal utilisation of below ground resources. Consequently, intercropping a wide spectrum of annual, biennal and perennial crops are feasible in coconut plantations. Many field crops are grown in the interspaces of coconut; it often includes rainfed tuber crops like cassava and yams (Nair and Sreedharan, 1986; Ramanujam *et al.*, 1984; Varghese *et al.*, 1979), ginger and turmeric (Bai and Nair, 1982; Nair and Varghese, 1976). Several fodder grasses are also planted in the coconut gardens: eg. guinea grass, para, rhodes, napier, lemon grasses and blue panic grass (Dagar and Kumar, 1992; Samraj, 1977; Pant, 1980; George, 1993; Sharma *et al.*, 1980).

Traditionally multipurpose trees are included in coconut gardens either as scattered trees, or on farm boundaries for green manure and fodder purposes and/or as support for trailing pepper vines. *Erythrina indica, Panjanelia rheedi* and *Leucaena leucocephala* are prominent in this respect (Ghosh *et al.*, 1989; Liyanage *et al.*, 1990). Lately, however with a view to develop low input sustainable production systems numerous multipurpose trees are systematically interplanted in coconut plantations (Nair, 1983; Kumar *et al.*, 1999). Many nitrogen fixing species like *Calliandra calothyrsus, Acacia aurculiformis* and *Gliricidia sepium* are intercropped in the coconut gardens (Arachchi and Liyanage, 1998). Increase in coconut production owing to the incorporation of loppings from Leucaena has been reported by Liyanage *et al.* (1993). Several reports also indicate the role of intercropping in ameliorating the intensity of root (wilt) disease (Menon and Nayar, 1978; Amma *et al.*, 1983; Nair *et al.*, 1975).

2.2 Plant interactions in multispecies combinations

Nair (1978) reported that plant community interactions in intensive crop combinations with perennials are of greater magnitude than that of sole crop systems. Plant interactions have been referred to as 'interference effects' (Harper, 1961) or 'neighbouring effects' (Trenbath and Harper, 1973). Interaction between components of the multispecies crop combinations may result in sharing of the growth factors. Manifestations of such complementary interaction involve favourable microclimatic conditions, increased activity of beneficial rhizosphere microorganisms and better efficiency in the use of native and applied nutrients. Other interaction effects include annidation, allelopathy, plant parasites, economic complementarity etc.

But normally in a plant community, interference between plants lower the absorption or interception rates of growth factors relative to those in isolated plants. Such interactions between neighbouring plants with respect to growth factors are often described as competition. Competition may be for factors absorbed through both leaves (light and Co_2) and roots (water and nutrients). A knowledge of plant community interactions in crop combinations are indispensable in the design of agroforestry systems.

2.3 Root level interactions

According to Trenbath (1974) the advantages in some mixed crop situations is due to difference in the rooting patterns, which occur due to the mutual avoidance of different root systems. In contrast, Clements *et al.* (1929) observed that in mixed farming systems roots of several species frequently intermingle and often this overlap of the roots can be extensive. In intercropping systems, roots of two or more species share the same space and compete for moisture and nutrients. The concentration of feeder roots in the surface horizon of the soil profile (Sankar *et al.*, 1988; Ruhigwa *et al.*, 1992; Jamaludheen *et al.*, 1997; Thomas *et al.*, 1998), however, increase the probability of root competition. Other characters which contribute to success in competition for soil factors include early and fast penetration of roots through soil (McCown and Williams, 1968), high root density (Andrews and Newman, 1970), high productivity of actively growing roots (Slayter, 1967; Barley, 1970) and a high uptake potential for the nutrients (Bowen, 1973). Several workers have evaluated the competitive/ complementary interactions between tree and herbaceous crop components in an agroforestry. They are described in the ensuring section.

In crop combinations involving coconuts, where the canopies of components occupy different vertical layers, the coconut palm is generally not subjected to competition for factors absorbed by roots (Nair, 1978). Associated crops grown with coconuts could, however, be subjected to short supply of one or more other factors like water, nutrients and oxygen (Nair, 1978). Snaydon *et al.* (1989) have reported that root competition between coconut palms on the yield of two grass species and two legume species is more important than shoot competition in determining understorey productivity. Kumar *et al.* (1999) reported that the magnitude of root competition that the coconut palms may suffer from interplanted four-year-old MPTs is negligible initially, but it may be substantial as the MPT age increases.

George *et al.* (1996) studied the root competition in polyculture systems involving combination of four tree species viz., *Leucaena leucocephala, Casurina equesitifolia, Acacia aurculiformis* and *Ailanthus triphysa*, and four grasses. They found that all grass exerted a complementary effect on ^{32}P absorption by casuariana. Of the other tree species acacia and leucaena adversely affected ^{32}P uptake by grass species. Lott *et al.* (2000) concluded that there was always competition for available resources in *Grivellia*-maize production system irrespective of crop species or tree size. Divakara *et al.* (2001) found that the root competition between bamboo hedgerows and vateria and teak was lower in the topsoil, as bamboo and associated trees roots were in greater abundance in subsoil; From an experiment on intercropping involving ginger and *Ailanthus triphysa,* Thomas *et al.* (1998) observed that it is probably better to fertilise the herbaceous component of the mixed species system adequately, as it will also benefit the tree components.

Root studies have revealed a lack of spatial complementarity between the tree and crop components in water use, as a large percentage of fine roots of many species were in the top 0.5 m soil layer where crop roots were also concentrated (Rao *et al.*, 1993). The scope of managing below ground competition is, therefore, limited to manipulating the rooting intensities through species and/or cultivar selection for known soil nutrient deficiencies (Gillespie, 1989; Rao *et al.*, 1998) and by regulating spacing (Gillespie, 1989).

Further more the geometry of planting also decides the proportion of space exploited by the component species in intercropping systems. Studies on competitive or complementary interaction in nutrient uptake among the plants in mixed species system involving widely spaced crops are, however, scanty (Ashokan *et al.*, 1988).

2.4 Root competition along a fertility gradient

Species composition, diversity and growth form of plants communities change in a general and in a predictable manner along productivity gradients (Whittaker, 1975; Mooney, 1977; Grime, 1979; Austin, 1986; Tilman, 1988). There has been increasing interest in factors causing such patterns. Predictable patterns arise because factors such as plant competition, physical stress and herbivory vary in a predictable manner in either their intensity or quality along productivity gradients (Grime, 1973, 1979; Oksanen *et al.*, 1981; Coley, 1987; Tilman, 1988).

Two contrasting hypothesis exist on the relationship between resource availability and competition intensity in plant communities. First, competition may be most intense in productive habitats because such habitats support high growth rates and large amount of biomass that results in pre-emption of space and light. In this view, both above and below ground competition increase with soil fertility (Grime, 1973, 1979; Huston, 1979; Callaghan, 1988; Southwood, 1988; Keddy, 1989; Bertness, 1991; Campbell *et al.*, 1991; Pysek and Leps, 1991). In contrast, Newman (1973, 1983), Grubb (1985) and Tilman (1988) suggest that unproductive habitats should be characterized by intense competition for soil resources. Tilman's (1987, 1988) theory of resource competition predicts that there may be no quantitative change in the intensity of competition along a productivity gradients, but that there may be an important qualitative change, with plants mainly competing for soil resources in unproductive habitats and mainly competing for light in more productive areas. Wilson and Tilman (1991), tested this variation in the intensity of below ground and above ground competition along an experimental gradient of nitrogen availability involving three grass species and found that competition shifted from being mainly below ground in least productive sites to both above and below ground in fertilized plots. Similarly, Wilson and Tilman (1993), evaluated changes in community structure associated with variable fertility and disturbance on a native perennial grass and found that below ground competition was most intensive in plots with lowest nitrogen availability and decreased significantly with increased nitrogen availability.

Tilman and Wedin (1991) grew five grass species for three years on an experimental nitrogen gradient and reported that differential nutrient reduction, not tolerance, may be the main mechanism of species survival in infertile habits. From the above studies it is clear that competition may be important at all points along a productivity gradient, but its quality may vary (Grubb, 1985; Tilman, 1988). Literature are however, scanty regarding the root interactions in the mixed cropping system at different nutrient regimes.

2.5 Root distribution pattern of multipurpose trees

Multipurpose trees refers to all woody perennials that are deliberately grown so as to make more than one significant contribution to the production and/or service functions. In addition to wood, the MPTs may also yield fruits, flowers, bark, roots, gums, honey, medicines etc., which may be eaten and/or utilised for other purposes (Singh, 1989). Although a wide spectrum of MPTs are/regularly encountered in agroforestry, little is known about their root distribution pattern, which determines the magnitude of their competition with associated crops.

Root systems studies are of prime importance in plant nutrition as roots represents the primary organs responsible for absorption of nutrients and extraction of soil moisture; besides they provide anchorage. However, the role of tree root system is ambiguous, in some situations they may depress crop yields by root competition for water and nutrients (Ong *et al.*, 1991; Rao *et al.*, 1991; Schroth *et al.*, 1994; Singh *et al.*, 1989) and possibly allelopathic effects (Inostrosa and Fourrinier, 1982; Suresh and Rai, 1987). Information on spatial distribution of the MPT root system, which decides its ability to acquire water and nutrients preferentially over other associated crops is seldom available. Studies on these aspects are reviewed here under.

A study of fine root distribution of five tree species [*Cassia siamea* Lam., *Eucalyptus camaldulensis* Dehnh., *E. tereticornis* Sm., *Leucaena leucocephala* (Lam.) de Wit. and *Prosopsis chilensis* (Mol.) Sturtz] by Jonsson *et al.* (1988) indicated that the vertical root distribution was similar to that of maize (*Zea mays* L.). They concluded that these trees would likely to compete with maize and other crops for nutrients and water. Dhyani *et al.* (1990) evaluated the rooting behaviour and distribution of fine roots of five multipurpose tree species and found that bulk of roots were found near the soil surface. The roots of some tropical tree species such as *Adansonia digitate, Bombax costatum, Eucalyptus camaldulensis* and *Senna siamea* may extend several tens of meters from the trunk (Kessler and Breman, 1991; Stone and Kalisz, 1991; Schroth *et al.*, 1995). Such an extensive root system is particularly useful where soils are infertile and often dry, especially when nutrient distribution is irregular (Stone and Kalisz, 1991) as in many savanna areas.

Erythrina (*Erythrina indica*) is a popular support tree in Kerala for trailing black pepper vines. The root activity pattern of this tree was studied in conjunction with that of black pepper vines (Sankar, 1985). Feeder roots of erythrina were found to grow laterally over a distance of 90 cm. The tree is a surface feeder with as much as 90 per cent of its active roots confining to the uppermost 20 cm soil layer. Similarly gliricidia (*Gliricidia sepium*), a leguminous green manure plant was studied by Vasu *et al.* (1994). About 30-35 per cent of the active roots of this plant were distributed with 50 cm radius from the plant. The vertical distribution of active roots was more or less uniform (23-28%) up to 120 cm soil depth. Jamaludheen *et al.* (1997), found that wild jack (*Artocarpus hirsutus*) a prominent multipurpose tree in agroforestry systems exhibited the highest concentration of physiologically active roots at 75 cm from the base at a depth of 30 cm.

Fine root tumover in a sole crop and an alley cropping system involving *Sorghum bicolor* and *Acacia saligna* in semiarid Northern Kenya was carried out by Lehmann and Zech (1998). They found that tree system showed a very static root development with little fluctuation between seasons, whereas root biomass were very dynamic in the crop and tree + crop systems. Total root biomass of Eucalyptus hybrid decreased continuously with increasing soil depth at all radial distances (Mohsin *et al.*, 2000).

The lack of concerted efforts in studying the root systems of trees and other perennial plants is partly due to the complexity of structure of these systems and attendant difficulties involved in working with massive plants. Besides, paucity of suitable methods to study root system without disturbing its natural environment is the other reason (Wahid, 2001).

2.6 Root excavation studies

Root excavation studies probably give a clear picture of the entire root system of a plant as it exists naturally. It gives the interrelationships between competing root systems of other plants (Coker, 1939; Koleshikov, 1971). The main disadvantage of excavation is laborious, time consuming and also incapable of characterising the functional roots. Hence logarithmic spiral trenching has been used to characterise the root distribution (Huguet, 1973). The spiral nature of trench enables a large proportion of the root system to be examined with minimal damage to the trees (Tomlinson *et al.*, 1998). A similar procedure was employed by Divakara *et al.* (2001) to study the root distribution pattern of boundary planted Bamboos in hedgerow systems in Kerala.

2.7 Using radioisotopes in root activity studies

Among the isotopic techniques two methodologies are generally followed. One is plant injection technique (Racz *et al.*, 1964) which was subsequently improved and modified by Rennie and Halstead (1965), this is used in study of rooting pattern of small plants. Another method is soil injection technique for studying root activity pattern of tree crops. ^{32}P is the most commonly and widely used isotope because of its short half-life (14.3 days). It is also mobile and become uniformly distributed in root system of plant in short time and is relatively inexpensive (Bohm, 1979). A limitation of the tracer techniques is that it cannot be used in stony, crevices and cracks and also data obtained is not easy to relate with those from another (Page and Gerwitz, 1974). Regardless of the above constraints it is used as it gives information on uptake of nutrients from different soil layers and provides root information without separating from soil.

According to Wahid (2001), considerable variability exists among tree species and other perennials in root activity patterns. These differences can be taken advantage for deciding the crop combinations in mixed species systems for effective exploitation of resources in the various strata of the soil profile. A brief account of root activity patterns of perennial plant species is reviewed here.

Balakrishnamurthy (1977) in Sri Lanka reported that surface soil to a depth of 10 cm accounted for substantial root activity. In contrast to this Anilkumar and Wahid (1988) found that in Kerala, the uppermost 25 cm soil layer was practically devoid of roots, due to practice of annual fertilizer application in a soil basin of 20-25 cm depth.

Studies conducted with cocoa in Ghana had shown considerable root activity in the surface 7.5 cm soil layer with maximum activity often at 2.5 cm depth (IAEA, 1975). Wahid *et al.* (1989a, b) studied the root activity pattern of cashew and cocoa using ^{32}P. In cocoa 85 per cent of the feeder rots were found within the area of radius 150 cm around the tree. In case of cashew they found that the tree is a surface feeder with 80 per cent of roots are confined to top 15 cm soil layer and 72 per cent of root activity was found within the radial distance of 2 m from the tree. Grafted mango trees exhibited highest root activity in the surface 30 cm soil layer (Bojappa and Singh, 1974). About 77 per cent of the active roots were found in the upper 60 cm soil layer.

Kumar *et al.* (1999) carried out an experiment, in which they applied ^{32}P at several points in the root zone covering the entire effective forage space of coconut and studied the root level interactions between coconut palm and interplanted multipurpose trees (MPTs) namely *Vateria indica, Ailanthus triphysa* and *Grevillea robusta.* The results revealed that interplanted MPTs substantially altered absorption of ^{32}P by coconut. Both Ailanthus and Vateria exerted a modest depressing effect, while Grevillea enhanced ^{32}P uptake by coconut. Hence the selection of tree species with low root competitiveness and/or trees with complementary root interaction is thus of strategic importance in agroforestry and other tree based polyculture system.

The potential of trees and other perennials for improving the productivity and sustainability of land use systems is now well recognized (Huxley, 1982). Their actual potential for sustainability of the system depends however, on the interaction of great many variables which are not well understood. Root system development and utilization of below ground resources in natural plant communities as well as in man made multispecies cropping systems have not received due attention. A knowledge of rooting patterns and root activity is an essential pre-requisite for determining optimum spacing between plants, for arriving at the ideal planting geometry, for choosing the most suitable crop combination for a given land use system, for efficient utilization of below-ground resources through stratified exploitation of vertical soil space and also for developing efficient methods of fertilizer application.

Materials and Methods

3. MATERIALS AND METHODS

3.1 Location

The study was conducted at the Instructional Farm, College of Horticulture, Kerala Agricultural University, Vellanikkara, Thrissur, Kerala (10° 32' N latitude and 76° 10' E longitude and at an elevation of 22.5 m above sea level). An experiment on coconut-multipurpose tree intercropping was initiated at this site in June 1992 and the present study corresponds to the period from May 2000 to August 2001, of this long term experiment.

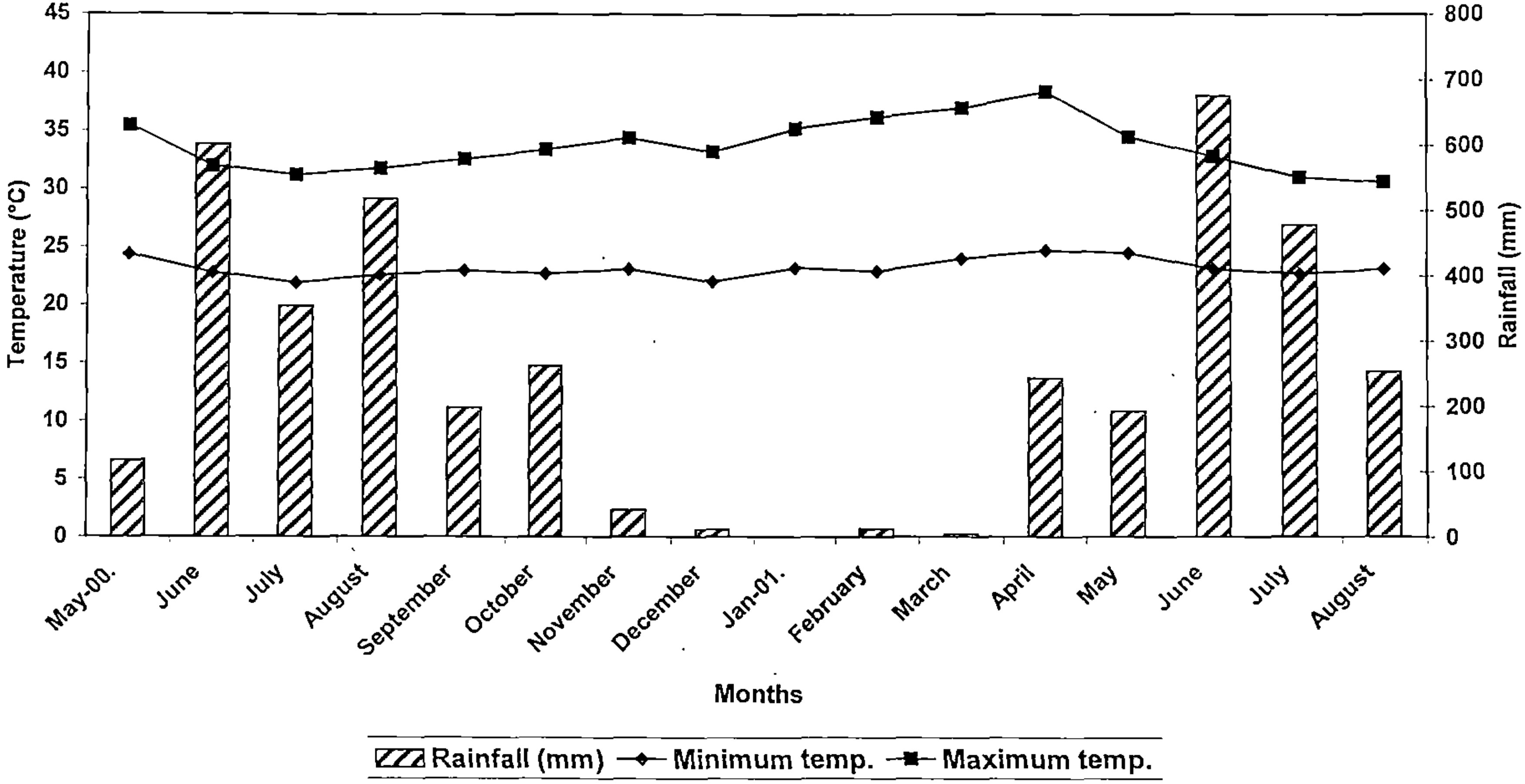
3.1.1 Climate

Vellanikkara experiences a warm humid climate with a mean annual rainfall of 2821 mm (mean corresponding to the ten year period from 1991-2001 August), most of which is received during the south-west monsoon (June to August). During the study period the mean maximum temperature ranges from 30.6°C (August 2001) to 38.4°C (April 2001) and mean minimum temperature ranges from 21.9°C (July 2000) to 24.7°C (April 2001). The total rainfall received during the study period (May 2000 to August 2001) was 3964.2 mm (Fig.1).

3.1.2 Soil

The soil at the experimental site is a Typic Plinthustult, Vellanikkara series midland laterite, ustic moisture regime and isohyperthermic temperature regime. Texturally it is sandy clay loam, with a bulk density of 1.34 g cm^3 (Latha, 1994) and pH 5.3-5.5.

Fig. 1. Weather parameters at Vellanikkara for the experimental period
(May 2000 to August 2001)



3.2 Field experiment

The field experiment (randomised complete block, design replicated thrice) involving three multipurpose trees (MPTs) grown as components of a coconut based production system was initiated at the Instructional Farm, Vellanikkara during 1992 in an existing 14 year old coconut plantation. The coconut plantation was established at this site in 1978 by planting one year-old hybrid coconut seedlings (Laccadive ordinary x Gangabondam) at a spacing of 7.5 m x 7.5 m). As part of the experimentation, 21 coconuts plots, each consisting of nine coconut palms per plot, with a size of 20 x 20 m were selected in 1992 (Fig. 2). Treatments included combinations of coconut with any one of the following three fast growing MPTS grown under two planting geometries.

MPTs

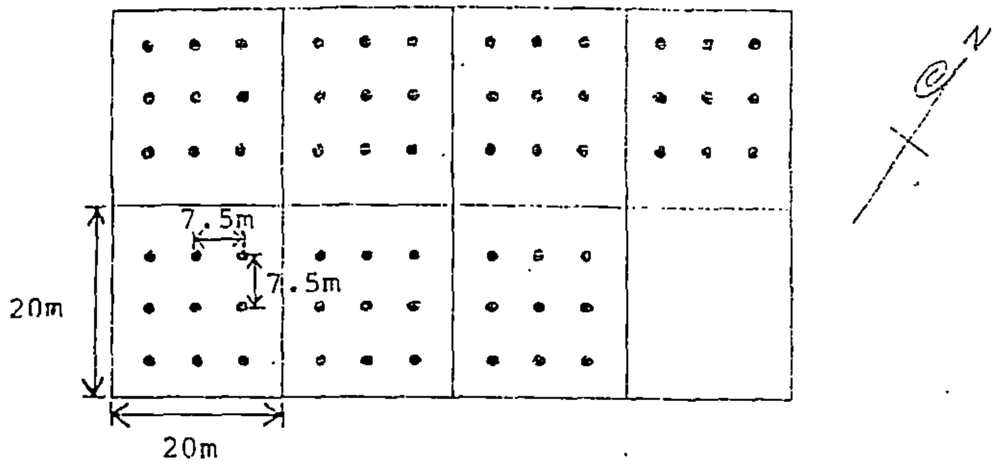
1. *Vateria indica* L. (Malbar white pine) (Family : Dipterocarpaceae)
2. *Ailanthus triphysa* (Densst.) Alston. (Matti) (Family : Simarubiaceae)
3. *Grevillea robusts* A. Cunn. (Silver oak) (Family : Proteaceae)
4. Control (monospecific coconut stand)

Planting geometry

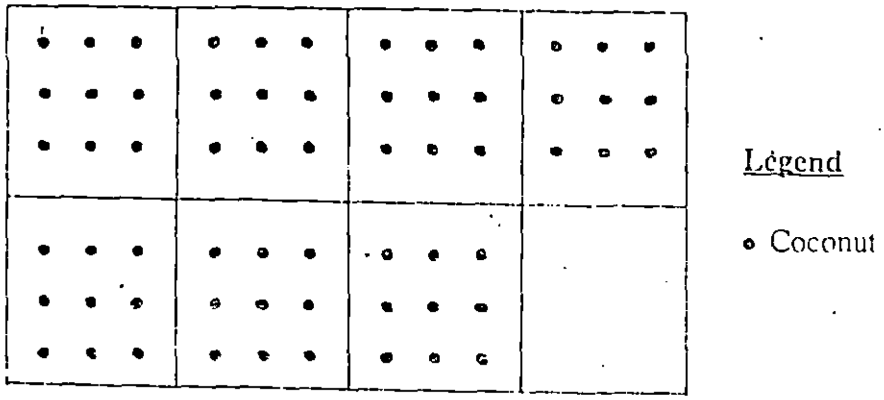
1. Single row (a row of multipurpose tree in the middle of two adjacent rows of coconut in both directions) (Fig. 3a).
2. Double row (two rows of multipurpose trees were planted in the middle of two adjacent rows of coconut palms), by adopting an east-west orientation (Fig. 3b).

Fig.2 Layout plan of the experimental plots

Replication 1



Replication 2



Replication 3

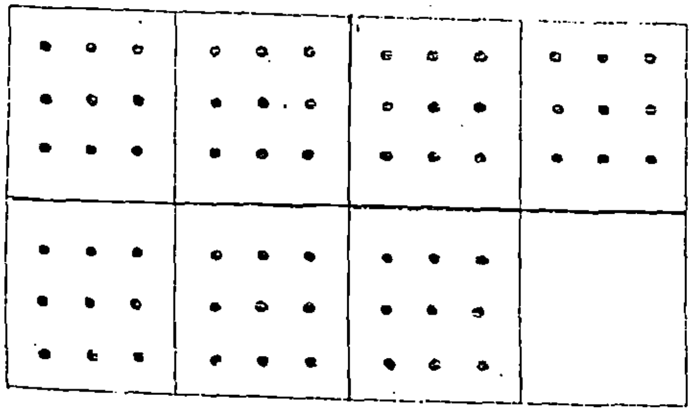


Fig. 3a. Diagram showing single hedge planting geometry of multipurpose trees

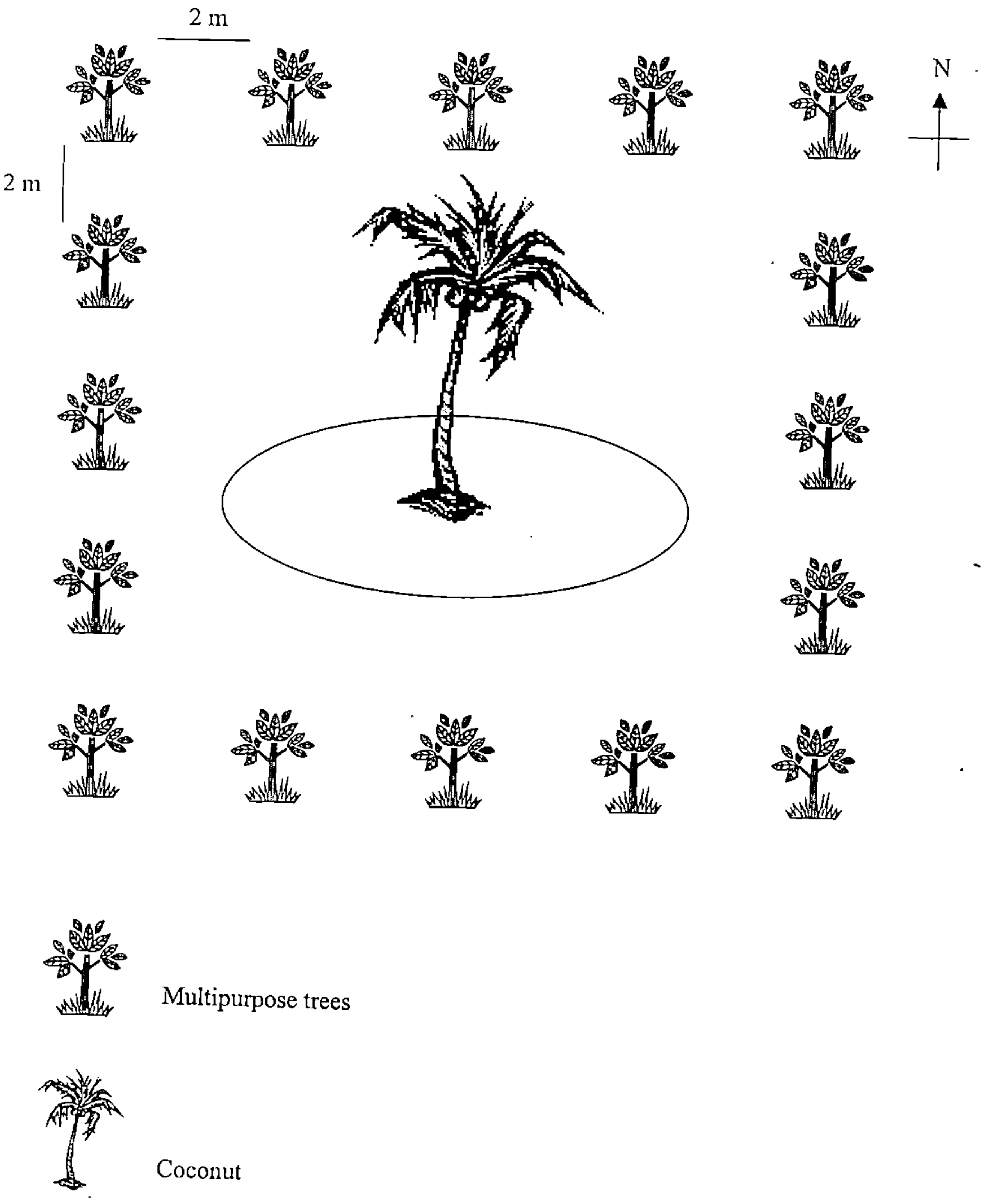
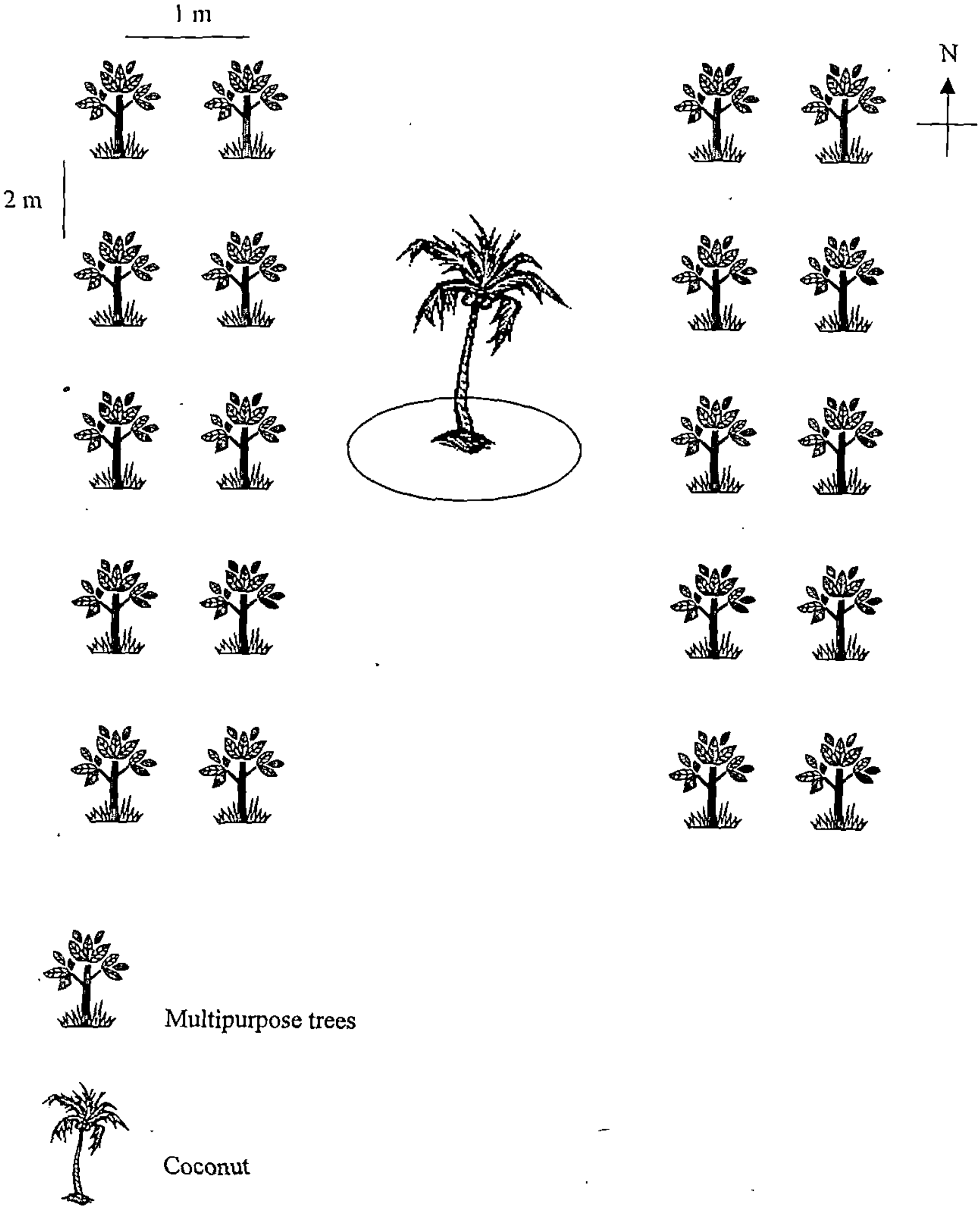


Fig. 3b. Diagram showing double hedge planting geometry of multipurpose trees



Tree population density was kept constant with 72 trees per plot (1800 trees ha^{-1}), in both treatments. Between tree spacing was 2 m in both geometrics and row spacing in double row planting system between the paired row was 1 m. Containerised seedlings of *Ailanthus triphysa* and *Grevillea robusta* (four to five months old) were planted in June 1992 in the interspaces of coconut. *Vateria indica* wildlings collected from the Vazhachal forest area and maintained in polybags for about four to five months in the nursery were planted in June 1992. The plantation was managed as per the packages of practices recommendation (KAU, 1996).

3.3 Evaluation of root competition using ^{32}P soil injection method along a soil fertility gradient

To evaluate the competitive relationships between coconut palms and the interplanted MPTs along a soil fertility gradient as envisaged for the present study, the coconut palms in different blocks of the trial were fertilized as follows. (June 2000) : good management (Block-I) : Palms were fertilised with 0.5, 0.32 and 1.2 kg of N, P_2O_5 and K_2O per palm, besides 25 kg of organic manure and 1 kg of lime; average management (Block-II): Palms were fertilised with 0.34, 0.17 and 0.68 kg, N, P_2O_5 and K_2O per palm, besides 15 kg organic manure and 0.5 kg lime and unfertilized control (Block-III) : no fertilizer.

The nature and extent of root competition between coconut palms and the neighbouring multipurpose trees was studied by soil injection of ^{32}P into the root zone of the coconut palms and evaluating the absorption of the radiotracer by not only the treated palm as well as the intercropped MPT.

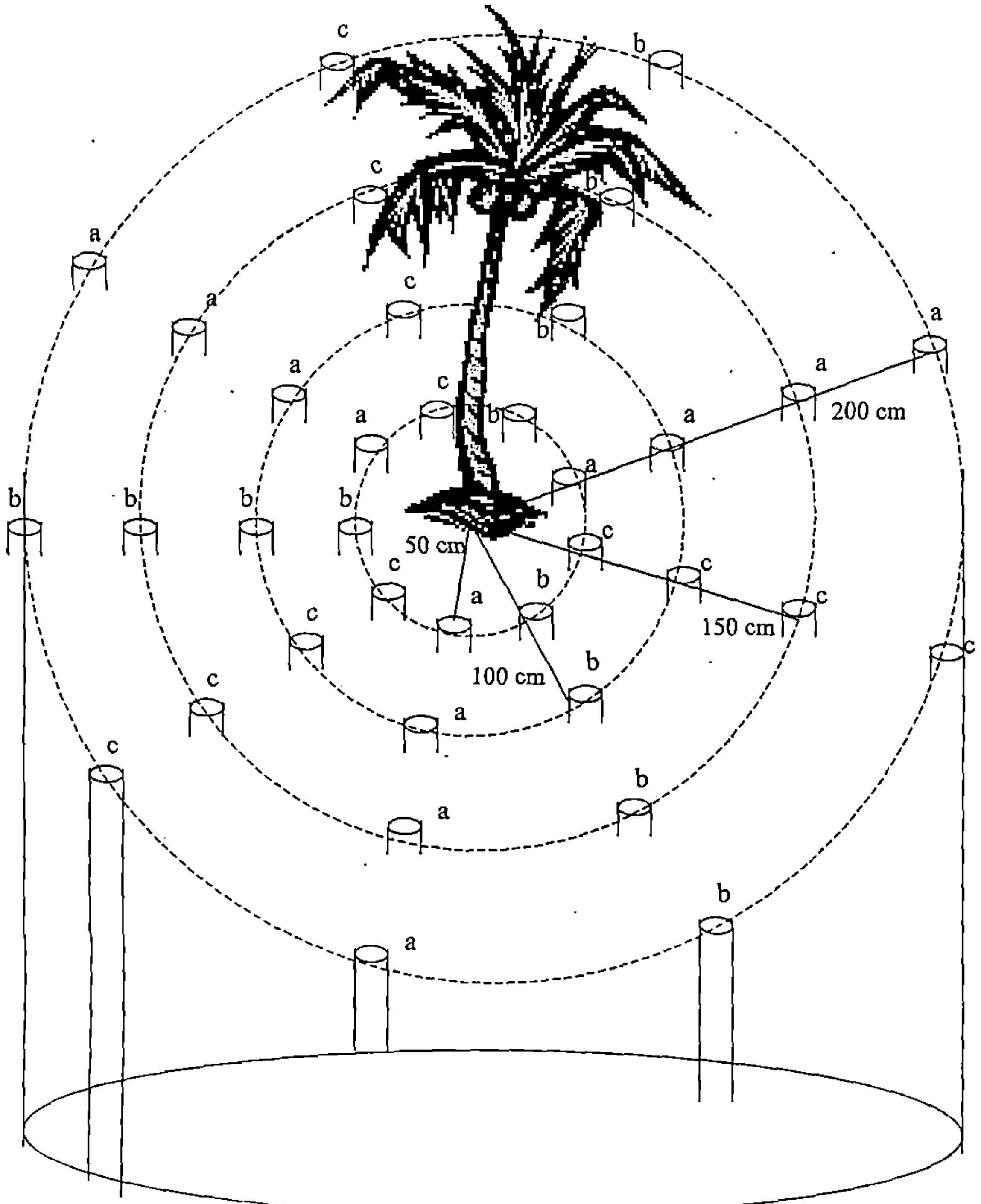
The central palm in each plot was selected for ^{32}P application. To ensure effective absorption of ^{32}P by the palms, the radioactivity was applied at 36 holes per palm basin corresponding to combinations of four lateral distances (50, 100, 150 and 200 cm) and three depths (30, 60 and 90 cm) (L200/D90, based on Anilkumar and Wahid, 1988).

Thirty six equidistant holes were drilled concentric circles around each palm (Fig.4), using a soil auger of 2.5 cm diameter. PVC acess tubes were inserted into the holes with 10-15 cm of the tube protuding above the soil surface. The open end of the tube was closed with polythene covers and secured with a rubber band to prevent entry of rain water into tubes. ^{32}P solution at the rate of 3 mCi per tree at a carrier level of 1000 ppm P was applied into each access tubes on October 30, 2000 using a dispenser designed for the purpose (Wahid *et al.*, 1985). The total radioactivity applied to each palm was 111 MBq. After dispensing the residual activity remaining inside access tube was washed down with a jet of 15 ml water. Carrier in the ^{32}P solution was included to minimise the soil fixation of the applied radio label (IAEA, 1975).

3.4 Leaf sampling and radioassay

Leaves from the treated coconut palms and neighbouring multipurpose trees were sampled for radioassay at 15 and 30 days after application of ^{32}P. For coconut, the sixth fully opened leaf was selected and three leaflets from either side of midrib from the middle portion were sampled (IAEA, 1975). For multipurpose trees, the most recently matured leaves were selected. In case of single row

Fig. 4. Layout plan for isotope application in coconut basin showing holes for injection of ^{32}p



Depth of holes
a 30 cm
b 60 cm
c 90 cm


50

planting tree were numbered from S_1 to S_{16} (Fi. 5) and in double row planting all the ten trees on right side in east-west direction were numbered from S_1 to S_{10} and same was repeated for the left side of the plot (Fig. 6).

The leaf samples were dried at 70°C and radioassayed by Cerenkov counting technique (Wahid *et al.*, 1985). The method consisted of wet digestion of one gram of dried leaf sample using diacid mixture (HNO_3 : $HClO_4$, 2 : 1). The digest was transferred to a counting vial and made up the volume to 20 ml with distilled water and counted in a Liquid Scintillation Counter (Wallac model 1409, Pharmacia, Finland) for first sampling and (Wallac model 1400, Pharmacia, Finland) for second sampling. The count rates were expressed as cpm (counts per minute). Prior to statistical analysis the cpm values were corrected for background as well as for decay and subjected to $\log_{10}(x+1)$ transformation and analysed.

3.5 Observations

a) Coconut

To evaluate the yield response in terms of MPT intercropping, nut yield of all the palms in each plot was recorded from 1991-2000. Mean nut yield of palm from 1995-2000 were analysed to see the effect of multipurpose trees and planting geometry on the yield of palm.

b) Allometric observation on multipurpose tree species

To assess the growth response of tree species, tree height and basal stem girth of all the trees except the border trees were measured at four monthly intervals from May 2000 to August 2001. Earlier data of tree height and diameter

at breast height was also recorded and a graph was plotted combining all the data. Height was measured using a graduated pole and girth with a measuring tape.

3.6 Phytochemical analysis

Duplicate samples of coconut leaves and multipurpose tree foliage (most recently matured leaf) were collected on two occasions (14-11-2000 and 29-11-2000) and analysed for nitrogen, phosphorus and potassium contents.

The samples were initially oven dried at 70°C, ground to pass through a 2 mm sieve and stored. Total nitrogen was estimated following micro-kjeldahl method. Phosphorus and potassium contents were estimated after digesting the samples in a triacid mixture (HNO_3, H_2SO_4 and $HClO_4$ in the ratio 10:1:3). Phosphorus was determined by the Vanado-molybdo phosphoric yellow colour method using Milton Roy Spectronic 1001 plus (Milton Roy, Rochester, New York), and potassium by flame photometry (Jackson, 1958) using Elico Flame Photometer (Model CI-22D).

3.6.1 Soil chemical analyses

Soil samples were collected from all the central coconut basins from 21 experimental plots on 19 of September 2000. Samples were collected from the surface layer (10-15 cm) at three random points in each plot and mixed thoroughly to obtain a composite sample. Three samples were collected from each experimental plot. The samples were air dried and passed through a 2 mm sieve and stored in polythene containers. Duplicate samples were analysed for pH, organic carbon, nitrogen, phosphorus and potassium as follows.

Soil pH was determined using an aqueous suspension of soil (soil and water in 1:2 ratio) using an Elico pH meter (Model Li 613), organic carbon was estimated by Walkey and Black method (Walkey and Black, 1934) and total nitrogen by micro-kjeldahl method. Available phosphorus was extracted using Bray-I extractant (Bray and Kurtz, 1945) and the P content estimated colorimetrically using chloro-molybdic acid blue colour method with stannous chloride as reducing agent (Wattnabe and Olsen, 1965) using a Milton Roy Spectronic 1001 plus. Available potassium was determined by flame photometry using 1N neutral normal ammonium acetate solution, as the extractant (Jackson, 1958). All nutrient concentrations were expressed on an oven dry basis.

3.7 Characterizing root distribution using Logarithmic spiral trench method

For characterizing the root distribution pattern using modified Logarithmic spiral trench method, trees along the plot border were selected as the trees inside may have overlapping root systems. For this, all border trees were enumerated and based on diameter at breast height they were divided into three size classes. The class limits for *Vateria indica* and *Grevillea robusta* were 1-6 cm dbh (small), 6-12 cm dbh (medium) and >12 cm dbh (large) and that of *Ailanthus triphysa* were 1-9 cm dbh (small), 9-18 cm dbh (medium) and >18 cm dbh (large). Three mean trees (i.e., close to the arithmetic mean dbh) from each diameter class were selected (total of 27 trees representing three species and three size classes). Crown radii of the selected trees were measured by projecting the crown edges to the ground. The distance between two crown edges were summed up and mean crown radius (r) calculated. Crown radii ranged from 1.16 to 2.48 cm for Vateria, 1.12-2.16 m for Grevillea and 0.75 to 2.83 m for Ailanthus.

Root systems of each selected tree was partially excavated using the logarithmic spiral trenching (Huguet, 1973). The spiral nature of the trench enables a large proportion of the root system to be examined with minimal damage to trees (Tomlinson *et al.*, 1998). The dimension of each trench was determined using following formulae (modification of Tomilnson *et al.*, 1998) (Fig. 7).

$$X = 0.75\ (d) \qquad (1)$$

$$Y = [\ln(r/d)]/\pi/2 \qquad (2)$$

$$Z = xe^{y\theta} \qquad (3)$$

Where,

d = stem diameter in m

r = the average of the crown radius at four cardinal points in m

x = the distance of starting point of the spiral from the tree trunk in m

y = natural logarithm of the ratio of crown radius to diameter of stem divided by $\pi/2$ and

z = the distance of any point on the spiral from the tree base in m.

Inside trajectory of each trench (A) was obtained by computing 'x' from a north facing point on the tree base, the origin (O), with spiral bending clockwise in the opposite direction, thus sampling a 135° sector of the root system. θ was assigned 0°, 22.5° ($\pi/8$), 45° ($\pi/4$), 67.5° ($3\pi/8$), 90° ($\pi/2$), 112.5° ($5\pi/8$) and 135° ($3\pi/4$) to obtain the seven co-ordinates of the inside trench, OA, OB, OC, OD, OE,


← 50 cm →
60
SCHOLAR

OF and OG. Exterior side of trench was obtained by stretching the co-ordinates for the internal side by 40 cm to give OA', OB', OC', OD', OE', OF' and OG'. Contours of both internal and external spirals were marked on the ground using plastic rope. The trench was then dug to a depth of 60 cm and to a breadth of 40 cm taking care that the sides remain intact. Severed tree roots living on internal and external trench walls were counted by placing a 50 cm x 60 cm grid (subdivided into 10 x 10 cm units). The grid was placed along the spiral trench at 0.5 m interval upto the end where no roots were seen. Roots were classified into <2.5 mm, 2.5-5 mm and >5 mm diameter. Radial distance of each quadrat from the stem was measured. It ranged from 29 to 163 cm in Vateria, 24.5 to 228 cm in Grevillea and 33.2 to 469.3 cm in case of Ailanthus. Root counts were converted into rooting intensity (number of root m^{-2}, Bohm, 1979). Trenching work was done from 21 to 24th April 2001.

3.7.1 Root excavation studies

One tree was selected from each species for studying the root architectural pattern in May 2001. Here the largest dbh tree was selected (18 cm dbh in case of Grevillea, 19 cm dbh in case of Vateria and 27 cm dbh in case of Ailanthus) as they had a well developed boles and crowns. One side of the soil was completely excavated to a distance of 1 meter and to a depth of 1 meter. After excavation, morphological observations on the root spread and branching pattern were recorded and a size to scale sketch made to depict the root spread.


VATERIA
←1m→
- 50 -


AILANTHUS
←1m→
0.8m


GEVILLEA
50cm

3.8 Statistical analysis

The data pertaining to coconut, soil and biometric observations of MPTs were analysed using a programme developed in BASIC. Duncans Multiple Range Test was used to test the differences among treatment means.

Regression equations (Microsoft Excel 97) linking distance (independent variable) and multipurpose tree parameters like N, P, K and ^{32}P uptake as dependent variable were fitted following regression analysis.

Root intensity data (number m^{-2}) were analysed for differences between tree sizes and lateral distances using ANOVA with repeated measures (MANOVA; Moser *et al.*, 1990), employing the statistical package SSPS/PC + (Advanced statistics version 2.0). In case of *Ailanthus triphysa* it was done up to 60 cm depth, but in *Grevillea robusta* and *Vateria indica* it was done upto 50 cm depth because as there were no roots found beyond 50 cm depth. Regression equations (Microsoft Excel 1997) linking distance (independent variable) and multipurpose trees rooting intensity as dependent variable were fitted. Hierarchial cluster analysis was performed, as the multivariate tests for size, distance and depth by distance effects were significant. Clustering was done using average linkage between groups (Everitt, 1974). The distance measured used was Squared Euclidean distance.

Results

4. RESULTS

4.1 Coconut productivity and nutrient concentration in the coconut foliage

Species or planting geometry of the interplanted multipurpose trees (MPTs) did not seem to influence the quinquennial nut yield (1995-2000) of 22-year-old palms, till the MPTs were 8-years-old (Table 1, Figs. 8, 9 and Appendix II). As expected, the block effects on nut yield were significant; high fertility blocks recorded greater nut yield. However, the differences were not significant during 2000-2001. Concentrations of N, P and K in the coconut leaves as a function of the MPT treatments were also not significant during the two sampling periods (Table 2 and Appendix II). Block effects and interaction effects again were also not significant except for phosphorus content of leaves.

4.2 Soil chemical properties

Soil organic carbon and available P levels as a function of MPT species showed marked variations (Table 3 and Appendix III), abeit the difference in nitrogen, potassium and pH were not significant. *Ailanthus* plots recorded the highest soil organic carbon content, followed by that of *Grevillea* and *Vateria* plots. *Grevillea* plots recorded the highest available phosphorus levels, although it was statistically at par with that of *Vateria*. Block effects were significant except for organic carbon. As normal, the more fertile block showed greater NPK contents. Planting geometry and interaction effects were not significant.

Table 1. Quinquennial nut yield and nut yield for 2000-2001 of 22 years old coconut palms as affected by three multipurpose tree species (eight years after planting) and their planting geometry

Treatments	Coconut Yield	
	Quinquennial nut yield per palm from (1995-2000)[1]	Nut yield per palm from (2000-2001)[2]
Species		
1. *Vateria indica*	259.67	44.67
2. *Ailanthus triphysa*	264.17	36.33
3. *Grevillea robusta*	257.50	53.50
F test	NS	NS
SEm (±)	22.24	5.10
Planting geometry		
1. Single row	258.11	44.56
2. Double row	262.78	45.11
F test	NS	NS
SEm (±)	18.16	4.16
Species vs. planting geometry		
F test	NS	NS
SEm (±)	31.45	7.21
Control (coconut monoculture)	261	57
Control vs. rest		
F test	NS	NS
SEm (±)	31.45	7.21
Block effects		
1. High fertility	322.3	50.71
2. Medium fertility	213.1	43.71
3. Low fertility	246.1	45.28
F test	<0.01	NS
SEm (±)	20.59	4.72
CD	63.45	-

1 - January 1995 to December 2000
2 - September 2000 to August 2001
NS - Not significant

Fig. 8. Quinquennial nut yield of 22 years old coconut palm as affected by multipurpose trees (eight years old) and planting geometry

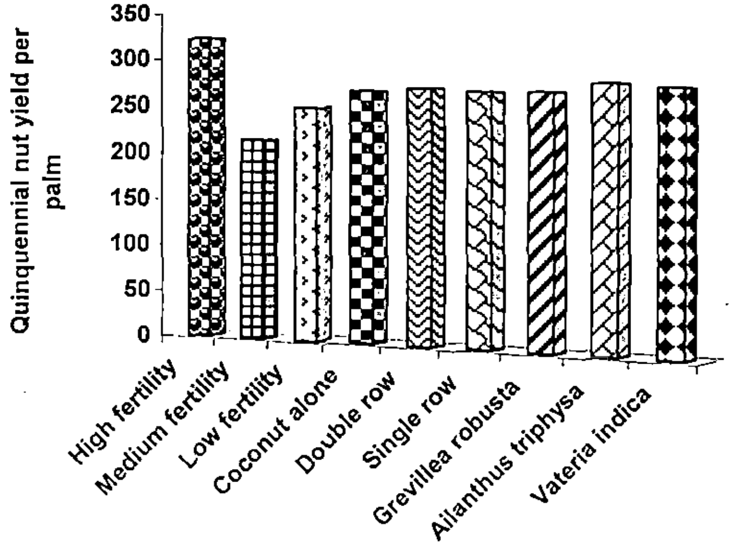


Fig. 9. Nut yield for the period (September 2000 to August 2001) of 22 years old coconut palm as affected by multipurpose trees (eight years old) and planting geometry

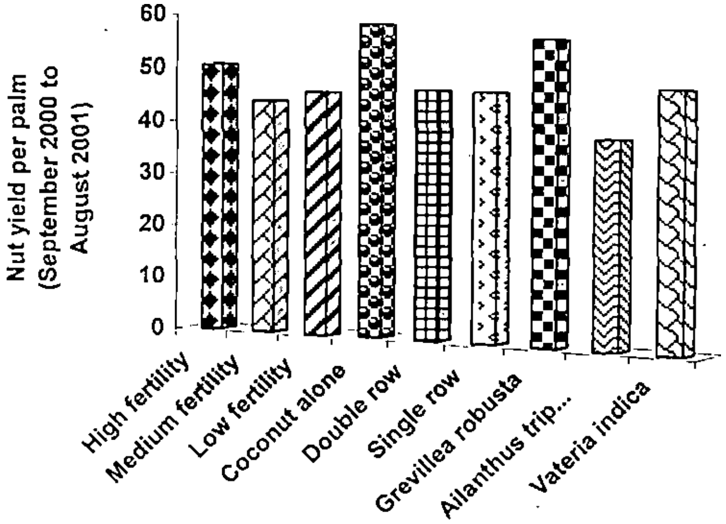


Table 2. Foliar nutrient concentration of 22 years old coconut palm as affected by multipurpose tree species (eight years old) and planting geometry

Treatments	Coconut					
	14th November			29th November		
	N (%)	P (%)	K (%)	N (%)	P (%)	K (%)
Species						
1. *Vateria indica*	1.82	0.12	1.32	1.74	0.12	1.85
2. *Ailanthus triphysa*	1.79	0.13	1.45	1.75	0.11	1.74
3. *Grevillea robusta*	1.77	0.14	1.22	1.68	0.13	1.85
F test	NS	NS	NS	NS	NS	NS
SEm (±)	0.119	0.0104	0.110	0.102	0.0056	0.071
Planting geometry						
1. Single row	1.87	0.13	1.32	1.73	0.11	1.82
2. Double row	1.71	0.13	1.34	1.71	0.12	1.81
F test	NS	NS	NS	NS	NS	NS
SEm (±)	0.097	0.0086	0.090	0.084	0.0046	0.058
Species vs. planting geometry						
F test	NS	NS	NS	NS	NS	NS
SEm (±)	0.168	0.015	0.155	0.145	0.0079	0.10
Control (coconut monoculture)	1.8	0.13	1.09	2.03	0.10	1.56
Control vs. rest						
F test	NS	NS	NS	NS	NS	NS
SEm (±)	0.168	0.015	0.155	0.145	0.0079	0.10
Block effects						
1.High fertility	1.92	0.11	1.34	1.84	0.101	1.81
2.Medium fertility	1.78	0.133	1.30	1.65	0.129	1.82
3.Low fertility	1.71	0.147	1.25	1.81	0.117	1.70
F test	NS	<0.05	NS	NS	<0.01	NS
SEm (±)	0.11	0.0097	0.102	0.095	0.0053	0.066
CD (0.05)	-	0.029	-	-	0.016	-

NS – Not significant

Table 3. Soil chemical properties in 22 years old coconut plantation as influenced by multipurpose trees (eight years old) and planting geometry

Treatments	Soil				
	OC (%)	Total N (%)	Available P (ppm)	Available K (ppm)	pH
Species					
1. *Vateria indica*	1.70	0.18	29.98	209.80	5.16
2. *Ailanthus triphysa*	1.91	0.18	21.30	197.08	5.26
3. *Grevillea robusta*	1.89	0.18	31.21	211.94	5.28
F test	<0.01	NS	<0.05	NS	NS
SEm (±)	0.046	0.003	2.81	8.66	0.044
CD (0.05)	0.142	-	8.66	-	-
Planting geometry					
1. Single row	1.85	0.18	26.06	211.04	5.24
2. Double row	1.82	0.18	28.94	201.51	5.23
F test	NS	NS	NS	NS	NS
SEm (±)	0.038	0.0025	2.30	7.07	0.036
Species vs. planting geometry					
F test	NS	NS	NS	NS	NS
SEm (±)	0.065	0.0044	3.98	12.24	0.063
Control (coconut monoculture)	1.83	0.17	25.55	202.65	5.23
F test	NS	NS	NS	NS	NS
Control vs. rest					
F test	NS	NS	NS	NS	NS
SEm (±)	0.065	0.0044	3.98	12.24	0.063
Block effects					
1.High fertility	1.79	0.200	44.10	224.4	5.50
2.Medium fertility	1.87	0.185	25.80	187.1	5.20
3.Low fertility	1.83	0.160	11.70	205.8	5.00
F test	NS	<0.01	<0.01	<0.01	<0.01
SEm (±)	0.042	0.0026	2.60	8.018	0.041
CD (0.05)	-	0.008	8.02	24.71	0.127

NS – Not significant

4.3 Growth characteristics of multipurpose trees

Eight-year-old multipurpose trees in the interspaces of coconut palms exhibited marked variations in their growth rates (Table 4, Fig.10 and Appendix IV). Species effects on height growth was significant except at 30, 36, 41 and 46 months and it followed the order ailanthus > vateria > grevillea. However, vateria showed faster height growth rates initially. Mean annual increment in height growth (Table 5) also was highest for vateria till 17 months after planting, thereafter it was grevillea (from 17 to 36 months), and ailanthus (from 41 months onwards). Differences in tree height on account of planting geometry were not significant.

Regarding radial growth, *Ailanthus triphysa* consistently showed faster radial growth (Table 6, Fig.11 and Appendix V). In August 2001, (111 months after MPT planting) it was 129 per cent greater than *Vateria indica* which recorded the second highest radial growth rates. Mean annual increment in diameter at breast height also followed a trend similar to that of total height (Table 7). Effects of planting geometry and species x planting geometry interactions were not significant.

4.4 Root interactions

4.4.1 ^{32}P recovery by coconut palms

In general ^{32}P uptake by coconut palms decreased from 15th to 30th days after application (Table 8 and Appendix VI). There was, however no statistically significant variations among monospecific coconut and MPT intercropped plots.

Table 4. Height (m) of eight years old multipurpose trees interplanted in coconut gardens at periodic intervals (September '92 to August '01)

Treatments	Spt. '92	Mar '93	Oct '93	Apl. '94	Nov. '94	May. '95	Oct. '95	Mar. '96	Jul. '96	Mar. '97	Sept. '97	Mar. '98	May. '00	Oct. '00	Mar. '01	Aug. '01
Age (months)	4	10	17	23	30	36	41	46	50	58	63	70	96	101	106	111
Species																
1.*Vateria indica*	0.93	1.33	1.78	1.93	2.42	2.73	3.06	3.35	3.64	4.29	4.535	5.19	7.607	7.847	8.290	8.587
2.*Ailanthus triphysa*	0.28	0.48	1.16	1.46	2.33	3.05	3.81	4.32	4.92	5.51	6.082	6.57	8.227	8.530	9.035	9.468
3.*Grevillea robusta*	0.35	0.66	1.48	1.99	2.68	3.13	3.49	3.78	4.06	4.71	4.878	5.33	6.280	6.438	6.993	7.338
F test	<0.01	<0.01	<0.01	<0.05	NS	NS	NS	NS	<0.05	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
SEm (±)	0.023	0.051	0.079	0.110	0.15	0.18	0.225	0.253	0.269	0.307	0.301	0.317	0.342	0.354	0.3907	0.3851
CD (0.05)	0.072	0.16	0.25	0.35	-				0.847	0.96	0.948	1.001	1.077	1.16	1.231	1.214
Planting geometry																
1.Single row	0.521	0.834	1.44	1.72	2.37	2.82	3.29	3.7	4.05	4.72	5.05	5.55	7.310	7.537	7.992	8.329
2.Double row	0.521	0.821	1.52	1.86	2.59	3.13	3.62	3.93	4.36	4.95	5.28	5.85	7.432	7.673	8.221	8.600
F test	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
SEm (±)	0.019	0.041	0.065	0.09	0.122	0.148	0.183	0.21	0.22	0.25	0.25	0.26	0.279	0.289	0.319	0.314
Species vs. planting geometry																
F test	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
SEm (±)	0.03	0.07	0.11	0.16	0.21	0.25	0.32	0.36	0.38	0.43	0.43	0.45	0.483	0.500	0.553	0.544

NS - Not significant

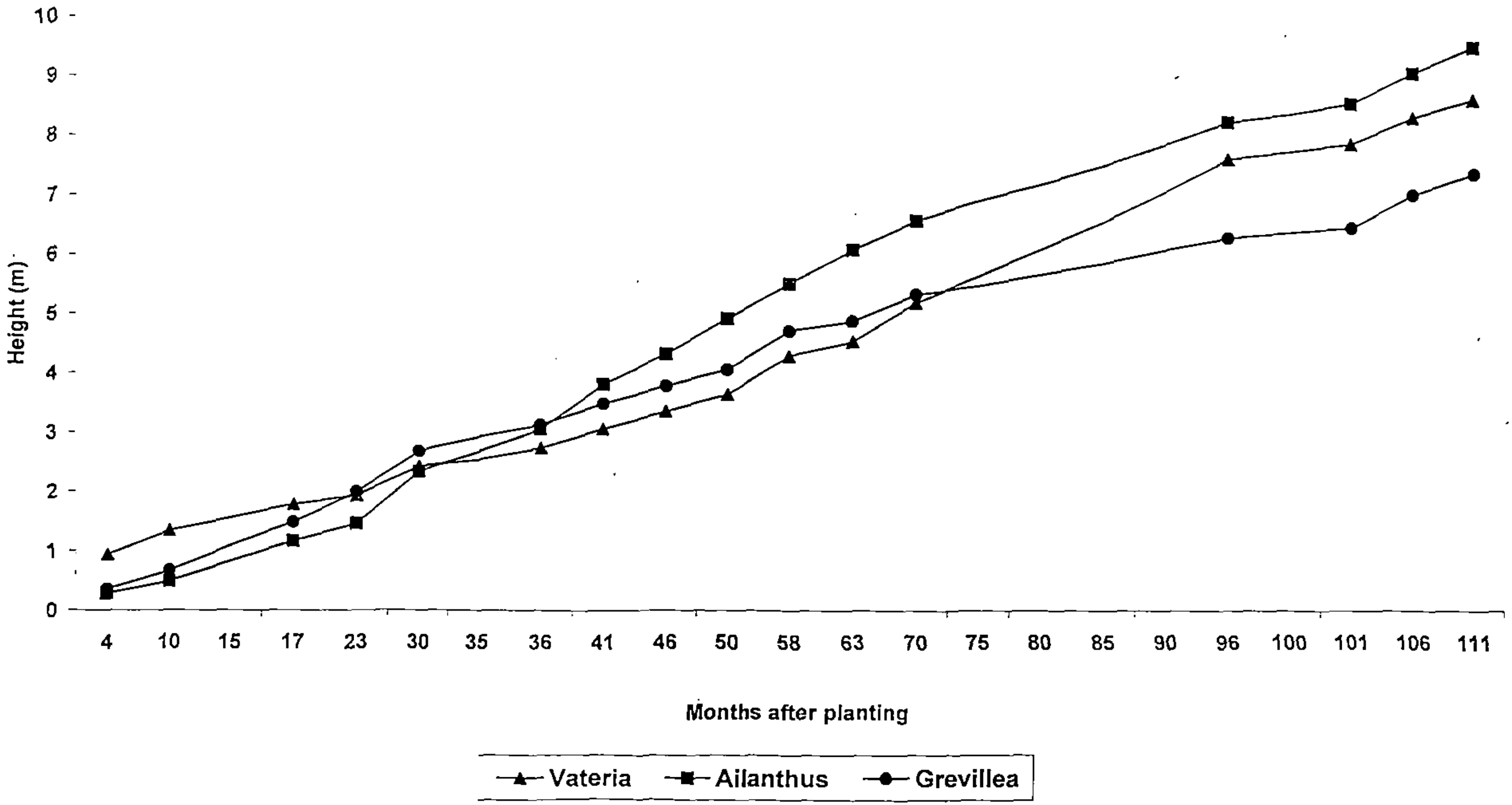


Fig. 10. Height of eight years old multipurpose trees (September ' 92 to August ' 01)

Table 5. Mean annual increment in height growth ($m\ yr^{-1}$) of eight years old multipurpose trees interplanted in coconut gardens at periodic intervals (September '92 to August '01)

Treatments	Spt. '92	Mar '93	Oct '93	Apl. 94	Nov. '94	May. '95	Oct. '95	Mar. '96	Jul. '96	Mar. '97	Sept. '97	Mar. '98	May. '00	Oct. '00	Mar. '01	Aug. '01
Age (months)	4	10	17	23	30	36	41	46	50	58	63	70	96	101	106	111
Species																
1.*Vateria indica*	2.79	1.596	1.256	1.006	0.968	0.91	0.89	0.87	0.87	0.88	0.86	0.88	0.95	0.75	0.94	0.93
2.*Ailanthus triphysa*	0.84	0.576	0.818	0.760	0.932	1.01	1.15	1.12	1.18	1.14	1.16	1.13	1.028	1.01	1.02	1.022
3.*Grevillea robusta*	1.05	0.79	1.04	1.038	1.070	1.04	1.02	0.98	0.97	0.97	0.93	0.91	0.785	0.76	0.79	0.79
F test	<0.01	<0.01	<0.01	<0.05	NS	NS	NS	NS	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
SEm (±)	0.069	0.061	0.055	0.057	0.060	0.06	0.065	0.066	0.064	0.063	0.057	0.054	0.042	0.04	0.04	0.04
CD (0.05)	0.22	0.192	0.176	0.180	-				0.20	0.19	0.18	0.17	0.134	0.137	0.139	0.13
Planting geometry																
1.Single row	1.56	1.00	1.016	0.88	0.95	0.94	0.96	0.96	0.972	0.976	0.96	0.95	0.91	0.895	0.90	0.89
2.Double row	1.56	0.985	1.073	0.97	1.036	1.04	1.05	1.025	1.046	1.024	1.005	1.002	0.93	0.911	0.93	0.93
F test	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
SEm (±)	0.054	0.049	0.045	0.047	0.049	0.049	0.05	0.054	0.052	0.051	0.047	0.045	0.034	0.034	0.036	0.033
Species vs. planting geometry																
F test	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
SEm (±)	0.09	0.084	0.078	0.083	0.084	0.083	0.093	0.094	0.091	0.088	0.081	0.077	0.06	0.059	0.062	0.058

NS - Not significant

Table 6. Diameter at breast height (cm) of eight years old multipurpose trees interplanted in coconut gardens at periodic intervals (July ’96 to August ’01)

Treatments	Jul. ’96	Mar. ’97	Sept. ’97	Mar. ’98	May. ‘00	Oct. ‘00	Mar. ‘01	Aug. ‘01
Age (months)	50	58	63	70	96	101	106	111
Species								
1.*Vateria indica*	3.53	5.070	5.32	6.72	8.397	9.087	9.635	10.34
2.*Ailanthus triphysa*	6.68	8.705	8.94	10.13	11.558	12.06	12.64	13.44
3.*Grevillea robusta*	3.25	4.977	5.195	6.077	6.660	7.06	8.04	8.66
F test	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
SEm (±)	0.363	0.3856	0.4403	0.4931	0.598	0.612	0.598	0.598
CD (0.05)	1.14	1.215	1.387	1.554	1.884	1.93	1.89	1.89
Planting geometry								
1.Single row	4.47	6.24	6.48	7.632	8.89	9.47	10.09	10.70
2.Double row	4.51	6.25	6.49	7.651	8.85	9.33	10.11	10.92
F test	NS	NS	NS	NS	NS	NS	NS	NS
SEm (±)	0.296	0.31	0.35	0.40	0.488	0.50	0.49	0.49
Species vs. planting geometry								
F test	NS	NS	NS	NS	NS	NS	NS	NS
SEm (±)	0.513	0.55	0.62	0.69	0.845	0.866	0.85	0.85

NS - Not significant

Fig. 11. Diameter at breast height of eight years old multipurpose trees (March ' 96 to August '01)

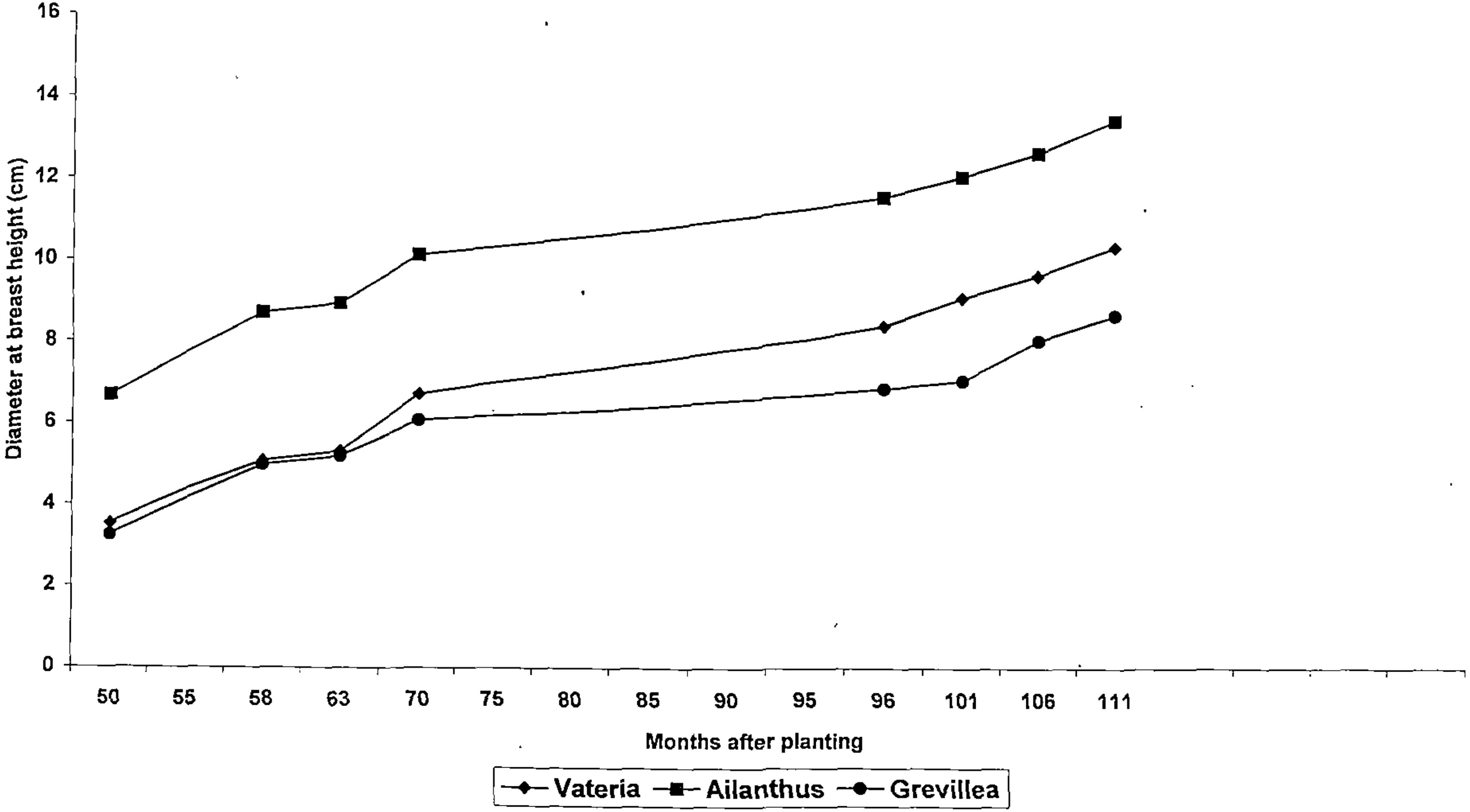


Table 7. Mean annual increment in diameter at breast height (cm yr^{-1}) of eight years old multipurpose trees interplanted in coconut gardens at periodic intervals (July ’96 to August ’01)

Treatments	Jul. ’96	Mar. ’97	Sept. ’97	Mar. ’98	May. ‘00	Oct. ‘00	Mar. ‘01	Aug. ‘01
Age (months)	50	58	63	70	96	101	106	111
Species								
1.*Vateria indica*	0.842	1.04	1.01	1.152	1.04	1.079	1.09	1.17
2.*Ailanthus triphysa*	1.603	1.80	1.70	1.74	1.44	1.43	1.43	1.45
3.*Grevillea robusta*	0.78	1.02	0.98	1.04	0.83	0.83	0.91	0.94
F test	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
SEm (±)	0.087	0.079	0.083	0.08	0.075	0.07	0.067	0.064
CD (0.05)	0.27	0.25	0.26	0.266	0.23	0.229	0.21	0.20
Planting geometry								
1.Single row	1.072	1.29	1.234	1.30	1.11	1.125	1.14	1.56
2.Double row	1.08	1.29	1.236	1.31	1.10	1.10	1.14	1.18
F test	NS	NS	NS	NS	NS	NS	NS	NS
SEm (±)	0.07	0.064	0.066	0.06	0.061	0.05	0.055	0.05
Species vs. planting geometry								
F test	NS	NS	NS	NS	NS	NS	NS	NS
SEm (±)	0.123	0.113	0.118	0.118	0.105	0.102	0.096	0.091

NS - Not significant

Table 8. ^{32}P uptake (cpm) by 22 years old coconut palms as affected by multipurpose trees (eight years old) and planting geometry [log $_{10}$ (x + 1) transformed values]

Treatments	Coconut	
	15 days after application	30 days after application
Species		
1. *Vateria indica*	2.3 (565.47)	2.26 (285.59)
2. *Ailanthus triphysa*	2.22 (412.25)	2.09 (176.59)
3. *Grevillea robusta*	2.16 (187.22)	2.13 (168.74)
F test	NS	NS
SEm (±)	0.22	0.15
Planting geometry		
1.Single row	2.35 (513.87)	2.27 (277.97)
2.Double row	2.10 (262.76)	2.05 (142.64)
F test	NS	NS
SEm (±)	0.18	0.12
Species vs. planting geometry		
F test	NS	NS
SEm (±)	0.31	0.22
Control (coconut monoculture)	2.09 (125.25)	2.39 (291.03)
Control vs. rest		
F test	NS	NS
SEm (±)	0.31	0.22
Block effects		
1. High fertility	2.88 (761.86)	2.52 (333.20)
2. Medium fertility	2.14 (139.07)	2.34 (220.02)
3. Low fertility	2.17 (151.26)	2.05 (112.28)
F test	NS	NS
SEm (±)	0.204	0.141

NS – Not significant
Figures in parentheses indicate retransformed values

Significantly, block effects, planting geometry and species x planting geometry interactions were also not significant.

4.4.2 ^{32}P recovery by neighbouring multipurpose trees

^{32}P uptake by *Vateria indica* and *Ailanthus triphysa* declined linearly with increasing distance from the treated palms both at 15 and 30 days after application (Figs. 12 and 13, Tables 9 and 10 and Appendix VII and VIII). For *Grevillea robusta*, however, there was an opposite trend, which is intriguing. That is, upto 6.5 lateral distance from the treated palms, there was an increase in ^{32}P recovery of the neighbouring grevillea trees (Table 11, Fig.14 and Appendix IX); it declined thereafter.

4.5 Foliar nutrient concentrations of multipurpose trees

Nutrient concentration of eight-year-old multipurpose trees were not significantly influenced by distance from the coconut palms. Fitted equations gave low R^2 values for all the three species. Foliar nitrogen concentration varied from 1.47 to 1.52 per cent, phosphorus content from 0.10 to 0.11 per cent and potassium from 0.41 to 0.68 per cent in *Vateria indica* (Fig.15, Table 9 and Appendix VII). While the nitrogen concentration of *Ailanthus triphysa* fell in the range of 1.85 to 1.93 per cent, phosphorus varied from 0.09 to 0.11 per cent and potassium from 0.81 to 0.96 per cent (Fig.16, Table 10 and Appendix VIII). For *Grevillea robusta* nitrogen concentration varied from 1.56 per cent to 2 per cent, phosphorus from 0.09 per cent to 0.13 per cent and potassium from 1.03 per cent to 1.13 per cent (Fig.17, Table 11 and Appendix IX).

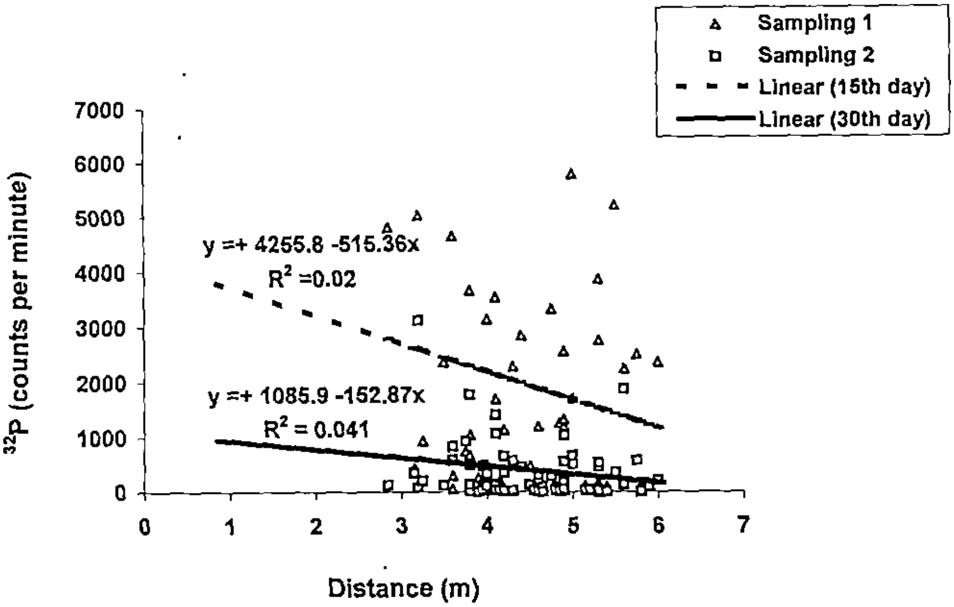


Fig. 12. ^{32}P uptake of eight years old *Vateria indica* at various distances from the treated coconut palm

Table 9. Nutrient content and ^{32}P uptake of eight years old *Vateria indica* as influenced by distance from the treated coconut palms

Parameters	Sampling	Equation Y= a + bx	R^2	SE	n	p
Nitrogen	1st	1.5168 + 0.0403x	0.007	0.226	78	0.892
	2nd	1.4756 + 0.0222x	0.005	0.350	78	0.732
Phosphorus	1st	0.114 + 0.0004x	0.0079	0.030	79	0.767
	2nd	0.1077 - 0.0037x	0.014	0.024	79	0.287
Potassium	1st	0.4117 + 0.0713x	0.024	0.352	79	0.169
	2nd	0.6866 + 0.0151x	0.002	0.238	79	0.664
^{32}P	1st	4255.9 - 515.36x	0.02	1600.402	65	0.524
	2nd	1085.9 - 152.87x	0.041	528.96	65	0.105

SE	Standard error
R^2	Coefficient of determination
n	number of observations
p	probability

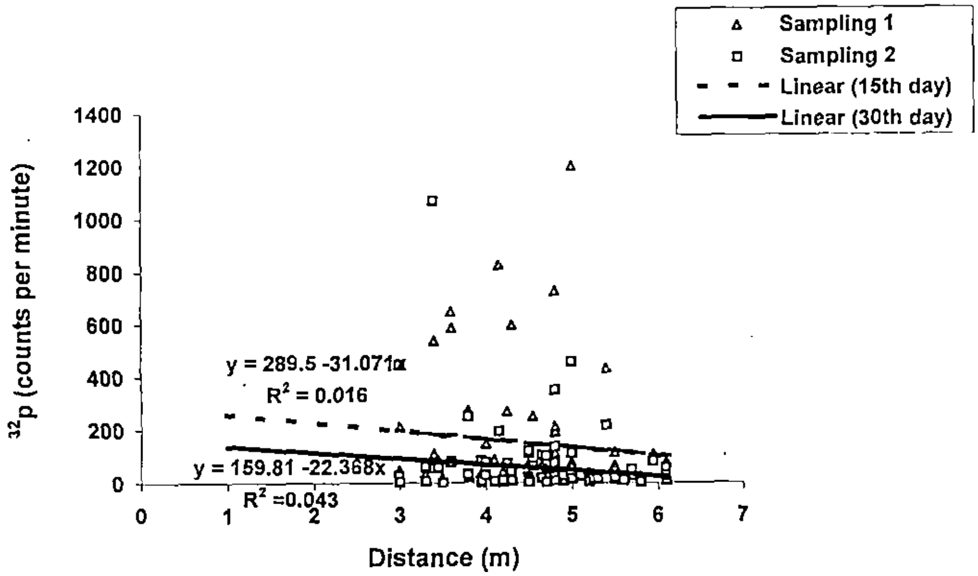


Fig. 13. ^{32}P uptake of eight years old *Ailanthus triphysa* at various distances from the treated coconut palm

Table 10. Nutrient content and ^{32}P uptake of eight years old *Ailanthus triphysa* as influenced by distance from the treated coconut palms

Parameters	Sampling	Equation $Y = a + bx$	R^2	SE	n	p
Nitrogen	1st	1.9396 - 0.0353x	0.047	0.297	94	0.034
	2nd	1.8535 - 0.0171x	0.03	0.284	94	0.090
Phosphorus	1st	0.1109 + 0.0018x	0.004	0.027	93	0.592
	2nd	0.0918 + 0.0011x	0.028	0.026	93	0.747
Potassium	1st	0.9664 - 0.0245x	0.018	0.311	98	0.526
	2nd	0.8149 + 0.0118x	0.024	0.272	98	0.726
^{32}P	1st	289.5 - 31.071x	0.016	232.14	63	0.344
	2nd	159.81 - 22.368x	0.043	156.35	63	0.099

SE	Standard error
R^2	Coefficient of determination
n	number of observations
p	probability

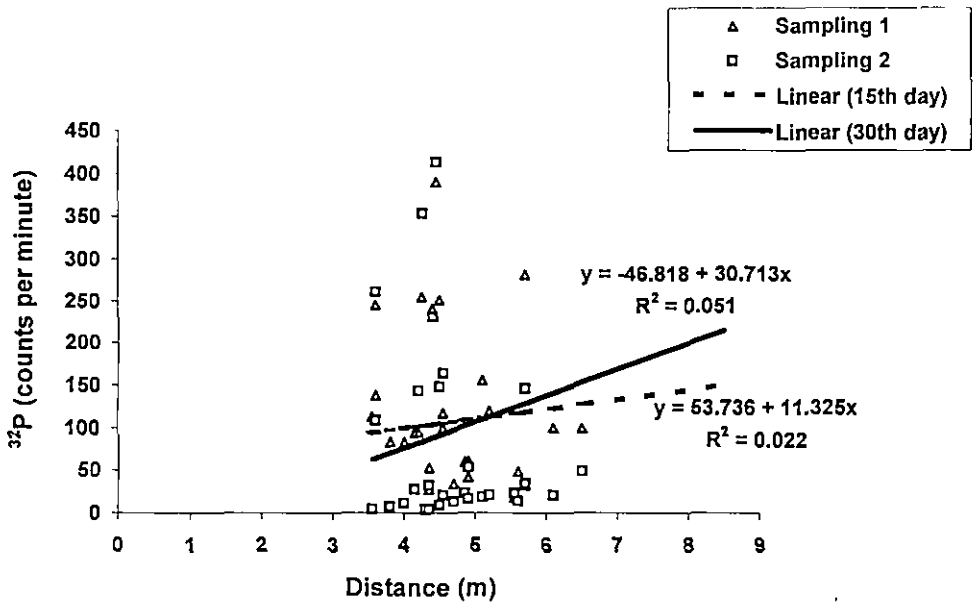


Fig. 14. ^{32}P uptake of eight years old *Grevillea robusta* at various distances from the treated coconut palm

Table 11. Nutrient content and ^{32}P uptake of eight years old *Grevillea robusta* as influenced by distance from the treated coconut palms

Parameters	Sampling	Equation $Y = a + bx$	R^2	SE	n	p
Nitrogen	1st	2.0075 - 0.0239x	0.0038	0.303	49	0.672
	2nd	1.5663 + 0.0493x	0.0246	0.244	49	0.281
Phosphorus	1st	0.131 - 0.0013x	0.001	0.024	49	0.077
	2nd	0.0944 - 0.0001x	0.001	0.024	49	0.979
Potassium	1st	1.0313 + 0.022x	0.0046	0.255	49	0.466
	2nd	1.1365 + 0.007x	0.003	0.097	49	0.698
^{32}P	1st	53.736 + 11.325x	0.022	95.58	29	0.441
	2nd	- 46.818 + 30.713x	0.051	108.55	29	0.23

SE Standard error
R^2 Coefficient of determination
n number of observations
p probability

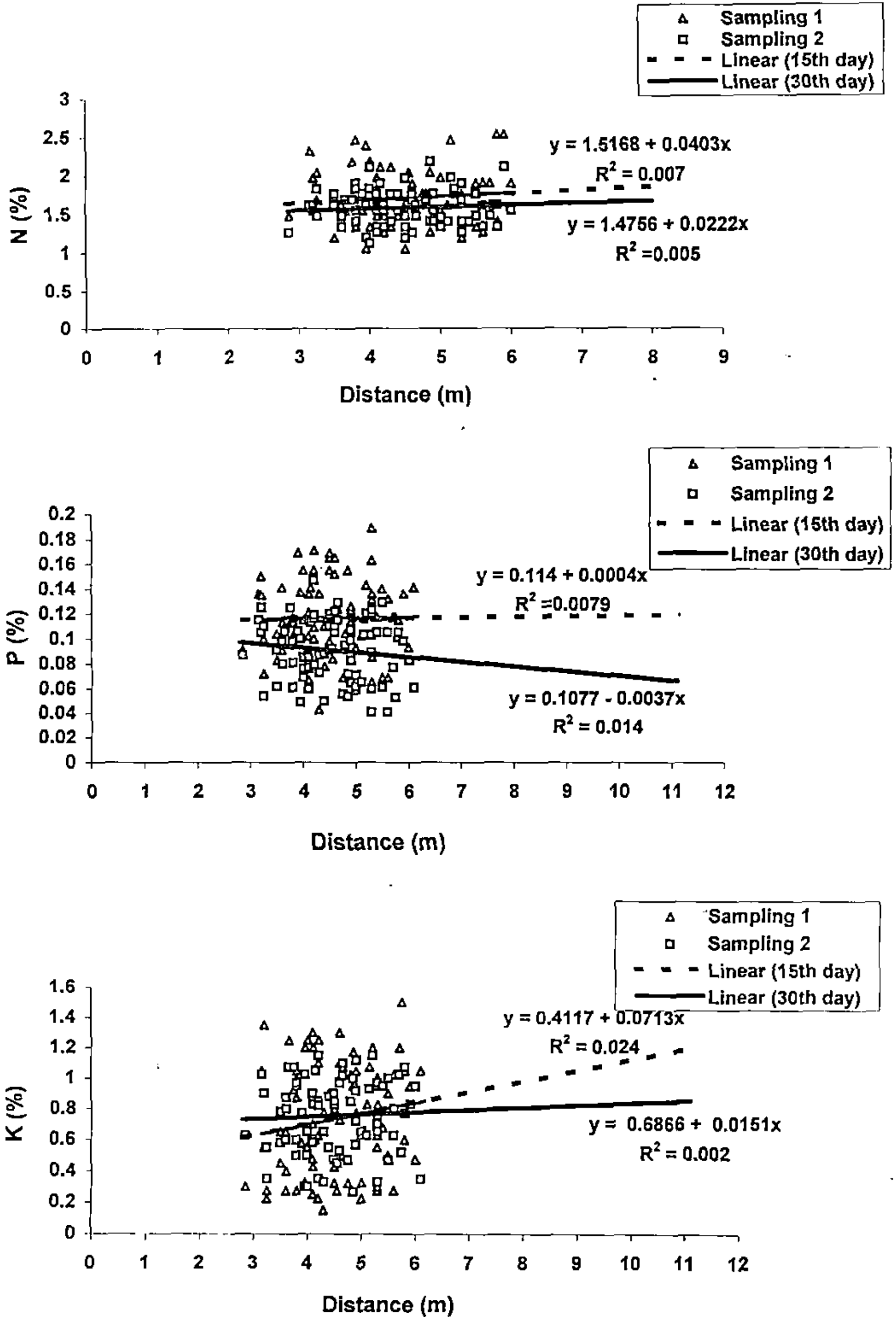


Fig. 15. Foliar nutrient content of eight years old *Vateria indica* at various distances from the treated coconut palm

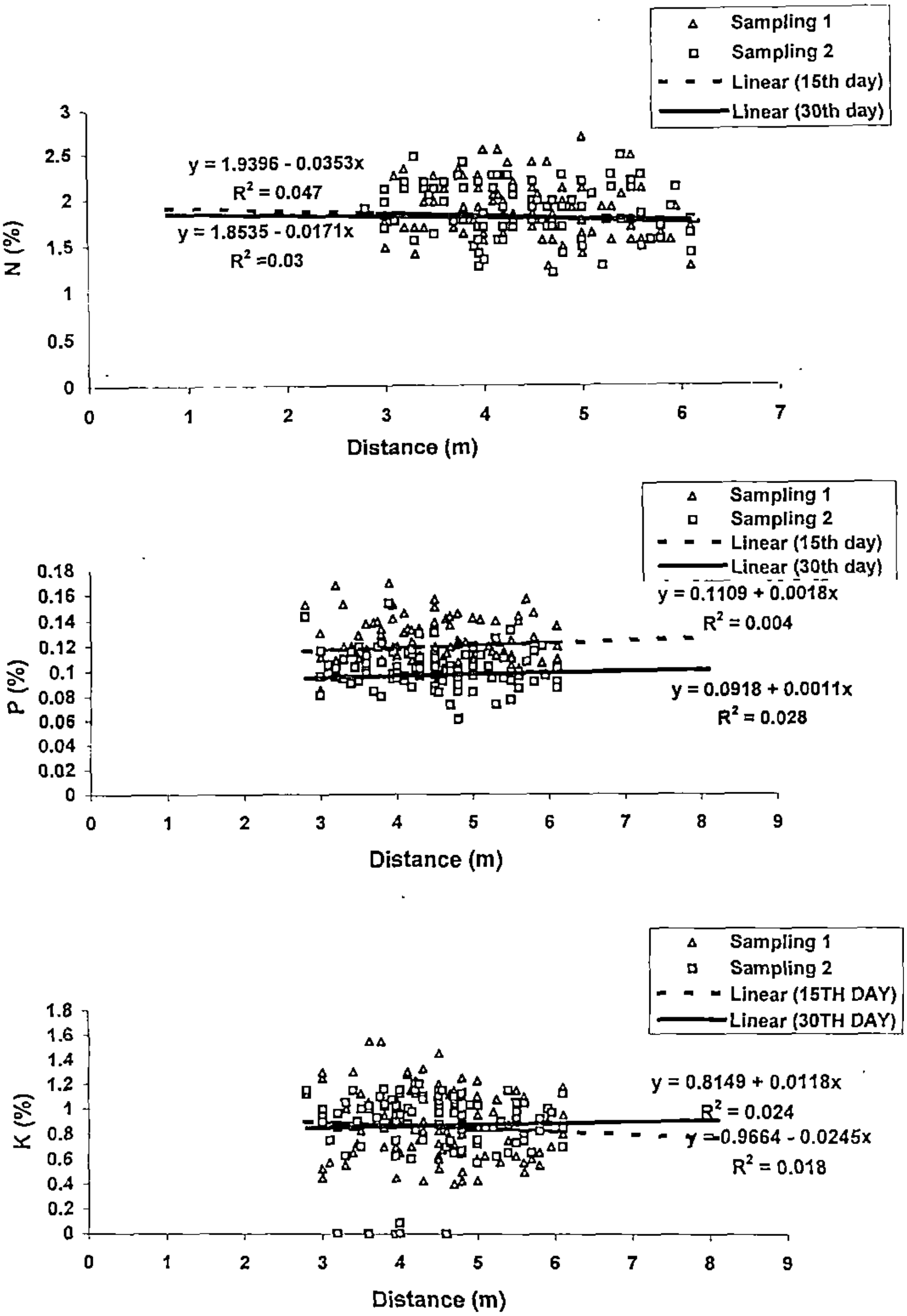


Fig. 16. Foliar nutrient content of eight years old *Ailanthus triphysa* at various distances from the treated coconut palm

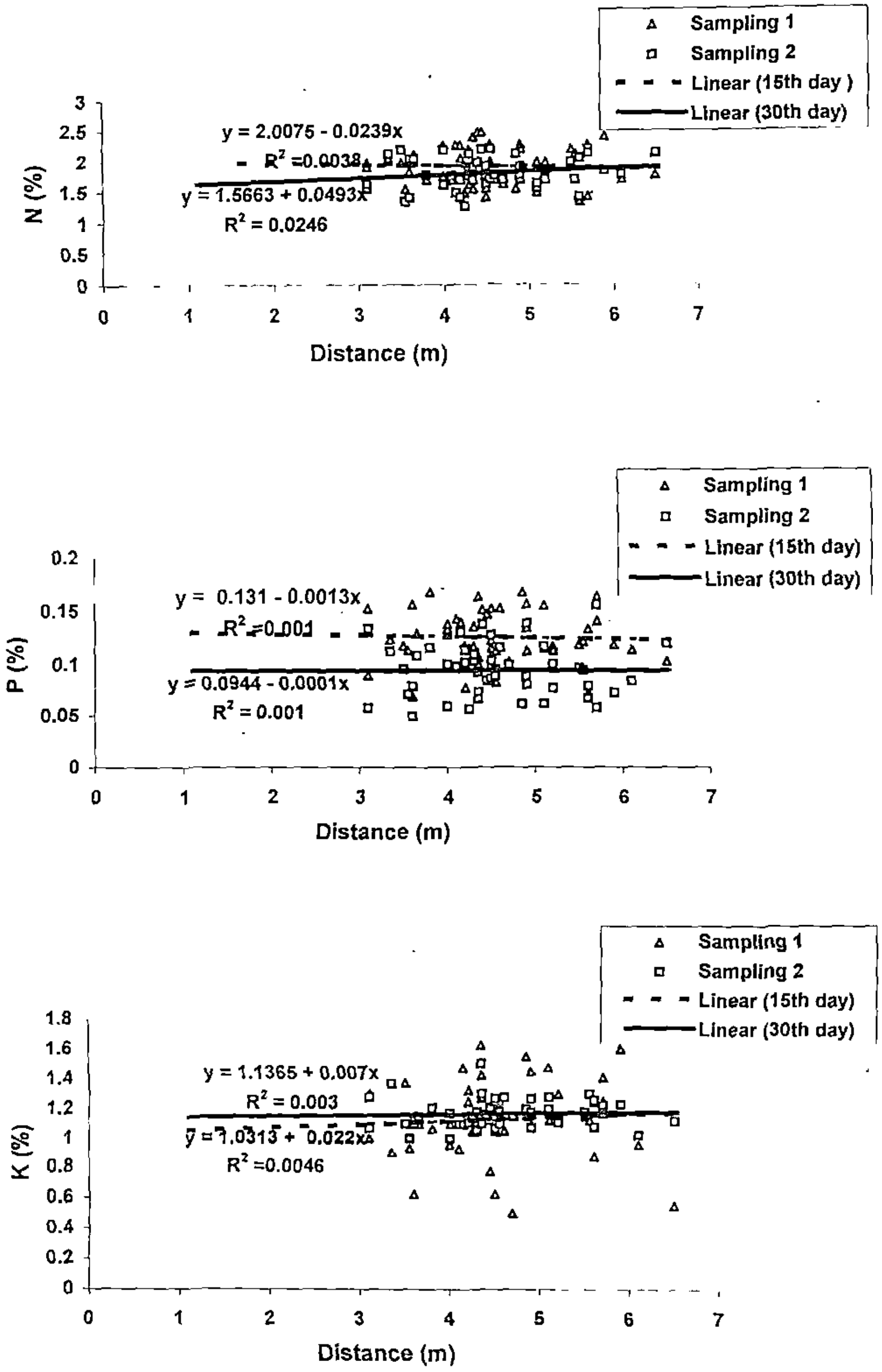


Fig. 17. Foliar nutrient content of eight years old *Grevillea robusta* at various distances from the treated coconut palm

4.6 Root distribution pattern of multipurpose trees

4.6.1 Horizontal distribution of *Vateria indica* roots

Data on rooting intensity of *Vateria indica* at different distances along the logarithmic spiral trench for different root diameter classes are shown in Figs. 18-21 and Tables 12-15. Rooting intensity (all root diameters) at a distance of 29 cm was 229, 344 and $315 m^{-2}$ respectively for small, medium and large class (Table 12, Fig.18). Rooting intensity up to 50 cm depth at different lateral distances along the logarithmic spiral trench was regressed on distance from the tree base. The negative linear relationship shows that rooting intensities decreased with increasing distance from the tree base in all the three size classes (Fig.22 and Table 16). R^2 values, however were very low (0.05 to 0.67).

Depth-wise root distribution as influenced by distance from the tree base is shown in Fig.23 and Tables 17a and 17b shows the mean rooting intensity in percentage. Regression equations linking distance from the base of vateria and rooting intensity are presented in Table 16. All root diameter classes were similar in respect of the lateral spread, although number of roots in the less than 2.5 mm class was substantially greater than the 2.5-5 mm and 5 mm classes. Overall, <2.5 mm class roots constituted 62 per cent of all roots, while 2.5 to 5 mm class roots accounted for 26 per cent and >5 mm root classes represented about 12 per cent of the total roots.

Tree-size exerted a marked influence on horizontal root distribution pattern. Large sized trees extended roots up to a minimum distance of 163 cm from

Table 12. Rooting intensity (number m^{-2}, total of all diameter roots) of eight years old *Vateria indica* as influenced by tree size, distance and depth

Size class	Distance from the base of the tree (cm)											
	29		58		112		139		144		163	
	Rooting intensity (number m $^{-2}$)											
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Small	229.33	92.54	168	71.2	52	77.38	28	45.85	0	0	0	0
Medium	344	96.87	333.33	155	181.33	87	145.33	43.07	0	0	0	0
Large	314.66	145.8	248	93.5	194.66	89.25	209.33	159.69	97.3	190.4	68	129
Depth Class (cm)												
0-10	364.44	115.5	320	180	195.55	138.2	157.77	166.13	24.4	73.33	13.33	40
10-20	351.11	140.8	302	146	146.66	95.91	144.44	132.2	20	60	8.88	26.7
20-30	317.77	91.89	237.77	79.7	173.33	123.3	122.22	82.12	40	120	46.66	140
30-40	264.44	112.2	237.77	123	137.77	94.04	95.55	76.01	71.1	213.3	31.11	93.3
40-50	182.22	73.78	151.11	59.3	60	50.99	117.77	152.46	6.66	20	13.33	40

Distance 1 was located at a distance of 0.75D from the base of the tree, where D = tree diameter
Average tests of significance – MANOVA
Distance $P<0.001$
Size by distance $P<0.001$
Depth by distance $P<0.039$
Size by depth by distance $P<0.930$
SD – Standard deviation

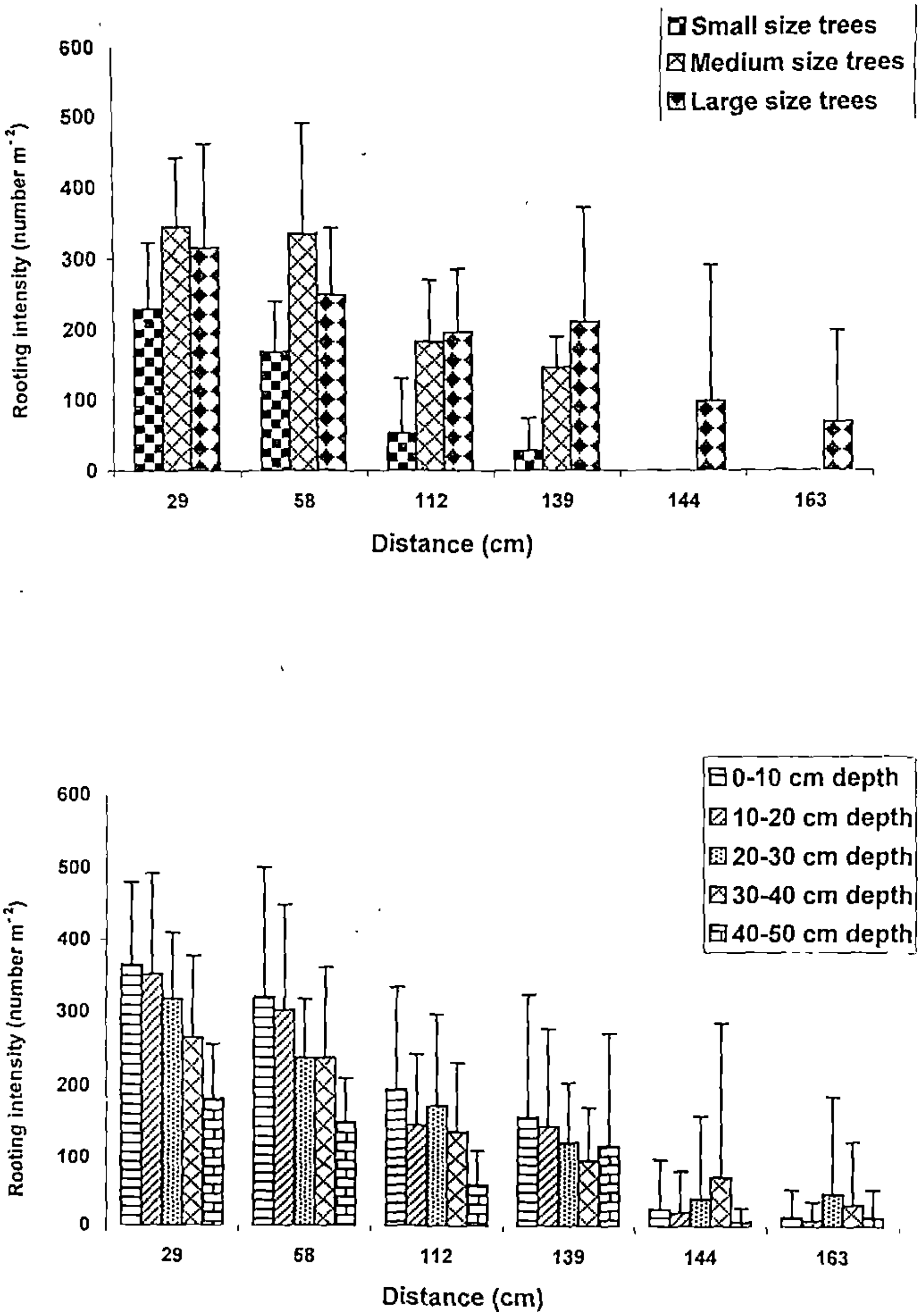


Fig. 18. Rooting intensity (number m^{-2}, total roots) of eight years old *Vateria indica* for different distances as influenced by tree size and depth

Table 13. Rooting intensity (number m^{-2}, <2.5 mm roots) of eight years old *Vateria indica* as influenced by tree size, distance and depth

Size class	Distance from the base of the tree (cm)											
	29		58		112		139		144		163	
	Rooting intensity (number m^{-2})											
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Small	144	57.66	112	64.9	34.66	53.16	18.66	30.67	0	0	0	0
Medium	210.66	58.98	225	126	114.66	58.78	76	27.46	0	0	0	0
Large	181.33	81.93	144	75.3	116	64.68	129.33	116.1	70	136.9	48	94.96
Depth class (cm)												
0-10	213.33	79.37	191	118	117.77	77.1	95.55	112.6	17.77	53.33	6.66	20
10-20	191.11	70.08	196	133	95.55	65.4	84.44	89.31	8.88	26.66	2.22	6.66
20-30	191.11	70.08	149	72.9	111.11	81.92	71.11	44.85	33.33	100	35.55	106.7
30-40	164.44	67.65	158	103	86.66	58.3	51.11	41.36	51.11	153.3	22.22	66.66
40-50	133.33	60.83	109	67.9	31.11	28.48	71.11	111.41	6.66	20	13.33	40

Distance 1 was located at a distance of 0.75D from the base of the tree , where D = tree diameter
Average tests of significance – MANOVA
Distance $P<0.001$
Size by distance $P<0.001$
Depth by distance $P<0.333$
Size by depth by distance $P< 0.874$
SD – Standard deviation

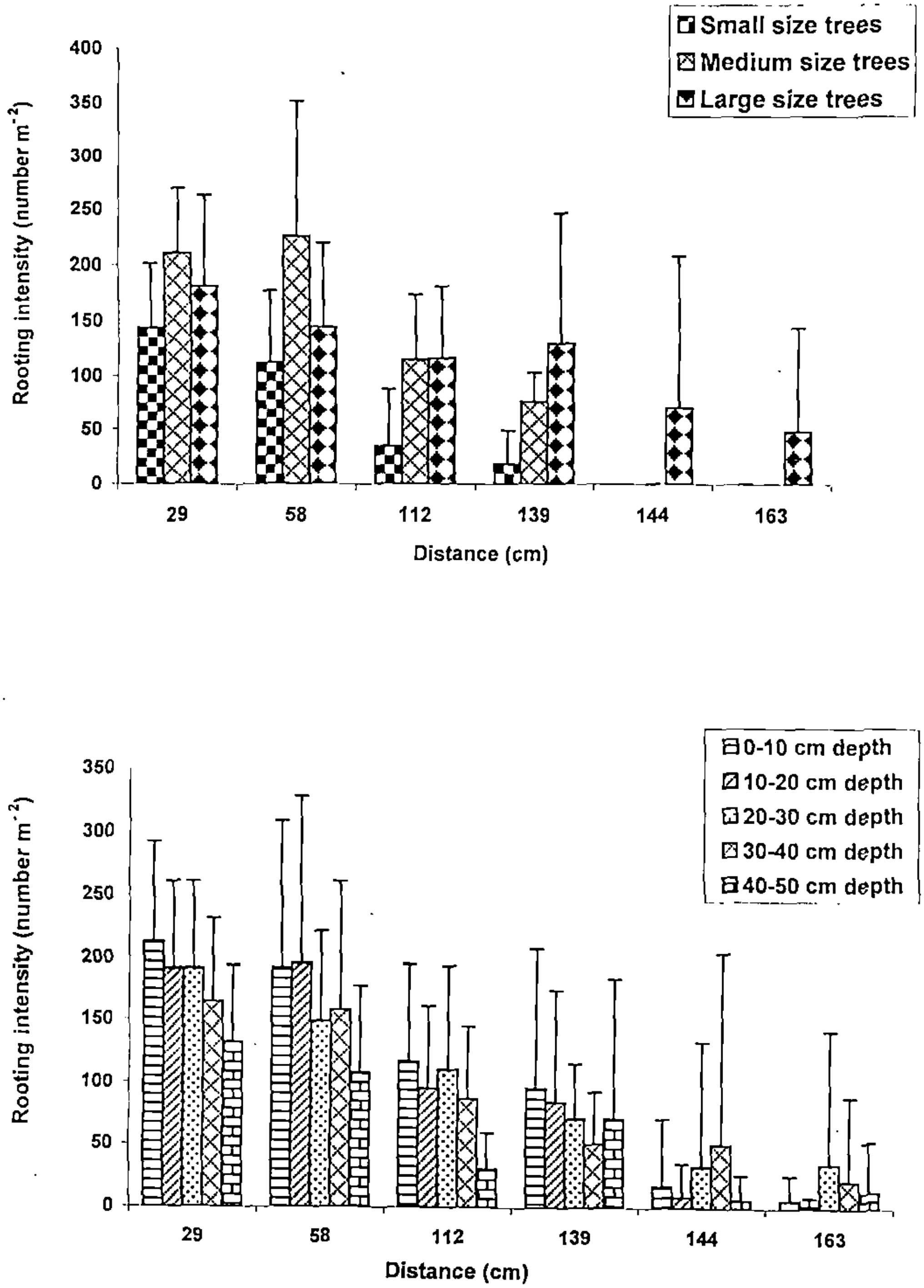
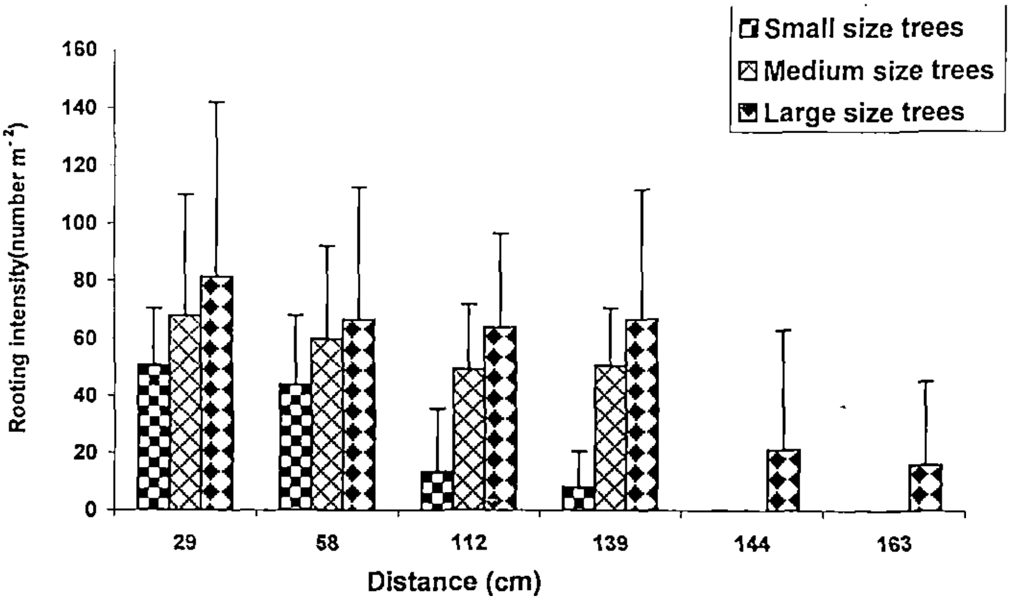


Fig. 19. Rooting intensity (number m^{-2}, <2.5 mm roots) of eight years old *Vateria indica* for different distances as influenced by tree size and depth

Table 14. Rooting intensity (number m^{-2}, 2.5-5 mm roots) of eight years old *Vateria indica* as influenced by tree size, distance and depth

Size class	Distance from the base of the tree (cm)											
	29		58		112		139		144		163	
	Rooting intensity (number m^{-2})											
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Small	50.66	19.8	44	24.14	13.33	22.25	8	12.65	0	0	0	0
Medium	68	41.95	60	32.07	49.33	22.5	50.66	19.8	0	0	0	0
Large	81.33	60.69	66.66	45.77	64	32.24	66.66	44.51	21.33	41.72	16	29.47
Depth class(cm)												
0-10	84.44	47.73	91.11	50.11	53.33	37.41	46.66	46.9	6.66	20	4.44	13.33
10-20	84.44	56.37	62.22	27.28	44.44	31.26	48.88	42.55	8.88	26.66	4.44	13.33
20-30	80	38.73	53.33	24.49	53.33	41.23	40	37.41	4.44	13.33	8.88	26.66
30-40	62.22	25.39	48.88	17.64	37.77	30.73	33.33	30	15.55	46.66	8.88	26.66
40-50	22.22	18.55	28.88	22.6	22.22	18.55	40	37.41	0	0	0	0

Distance 1 was located at a distance of 0.75D from the base of the tree , where D = tree diameter
Average tests of significance – MANOVA
Distance $P<0.001$
Size by distance $P<0.048$
Depth by distance $P<0.063$
Size by depth by distance $P<0.994$
SD – Standard deviation



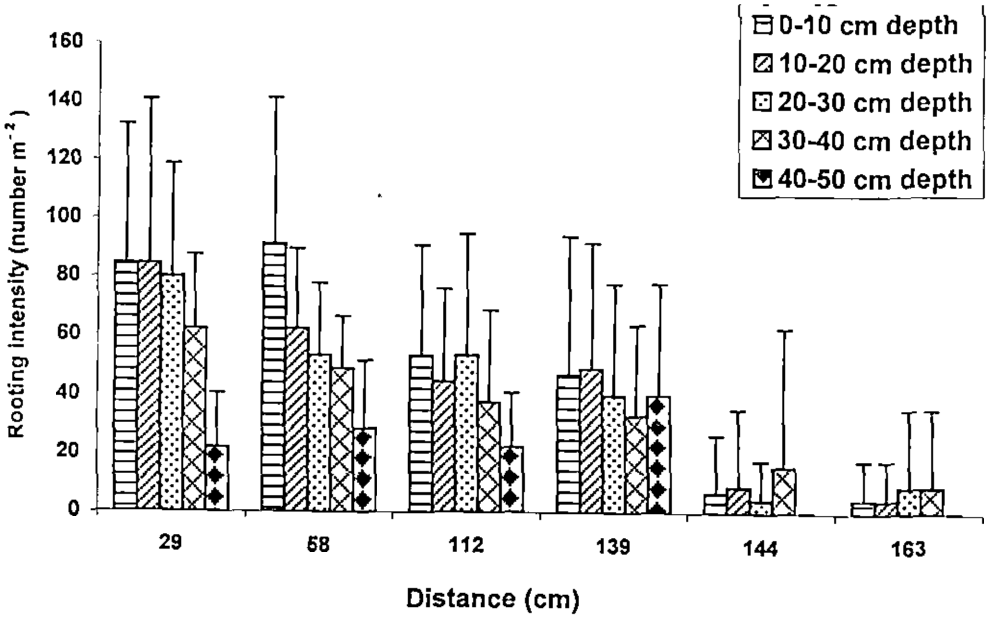
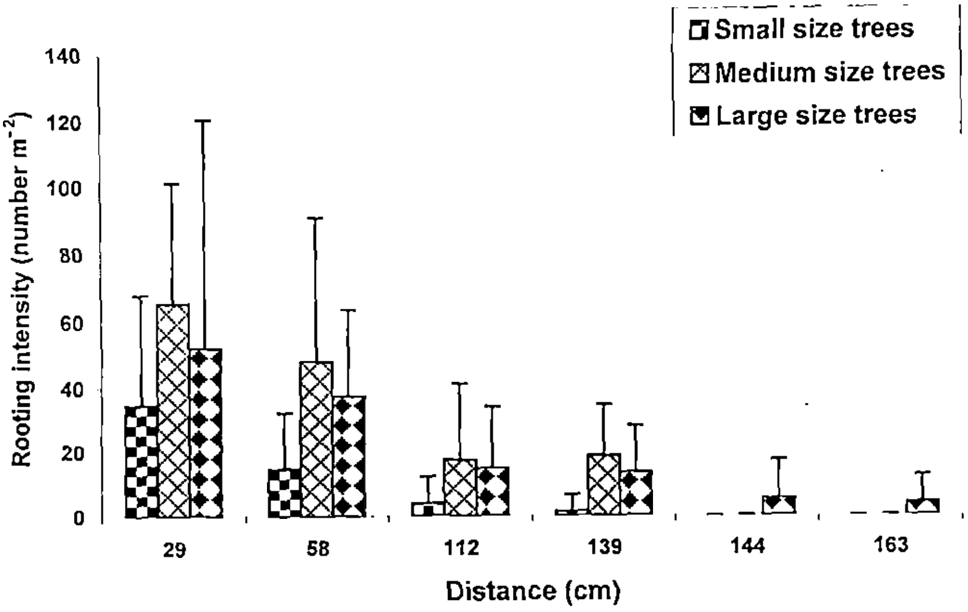


Fig. 20. Rooting intensity (number m^{-2}, 2.5 - 5.0 mm roots) of eight years old *Vateria indica* for different distances as influenced by tree size and depth

Table 15. Rooting intensity (number m^{-2}, >5 mm roots) of eight years old *Vateria indica* as influenced by tree size, distance and depth

Size class	Distance from the base of the tree (cm)											
	29		58		112		139		144		163	
	Rooting intensity (number m^{-2})											
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Small	34.66	33.35	14.66	17.67	4	8.28	1.33	5.16	0	0	0	0
Medium	65.33	35.83	48	42.63	17.33	23.74	18.7	15.97	0	0	0	0
Large	52	68.37	37.33	26.04	14.66	19.22	13.3	14.47	5.33	11.87	4	8.28
Depth class (cm)												
0-10	66.66	57.44	37.77	29.05	24.44	29.62	15.6	16.66	0	0	2.22	6.66
10-20	75.55	66.33	44.44	43.58	6.66	10.54	11.1	14.52	2.22	6.66	2.22	6.66
20-30	46.66	33.16	35.55	34.31	8.88	12.54	11.1	14.52	2.22	6.66	2.22	6.66
30-40	37.77	41.76	31.11	30.18	13.33	22.36	11.1	14.52	4.44	13.33	0	0
40-50	26.66	28.28	17.77	25.38	6.66	10.54	6.66	10.54	0	0	0	0

Distance 1 was located at a distance of 0.75D from the base of the tree , where D = tree diameter
Average tests of significance – MANOVA
Distance $P<0.001$
Size by distance $P<0.299$
Depth by distance $P<0.492$
Size by depth by distance $P<0.988$
SD – Standard deviation



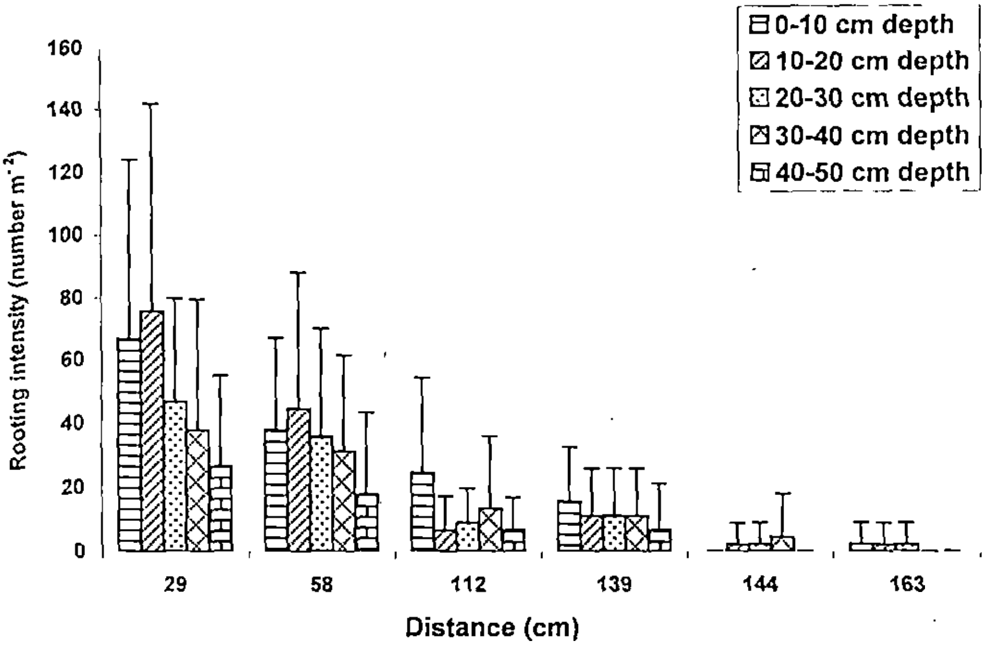


Fig. 21. Rooting intensity (number m^{-2}, >5.0 mm roots) of eight years old *Vateria indica* for different distances as influenced by tree size and depth

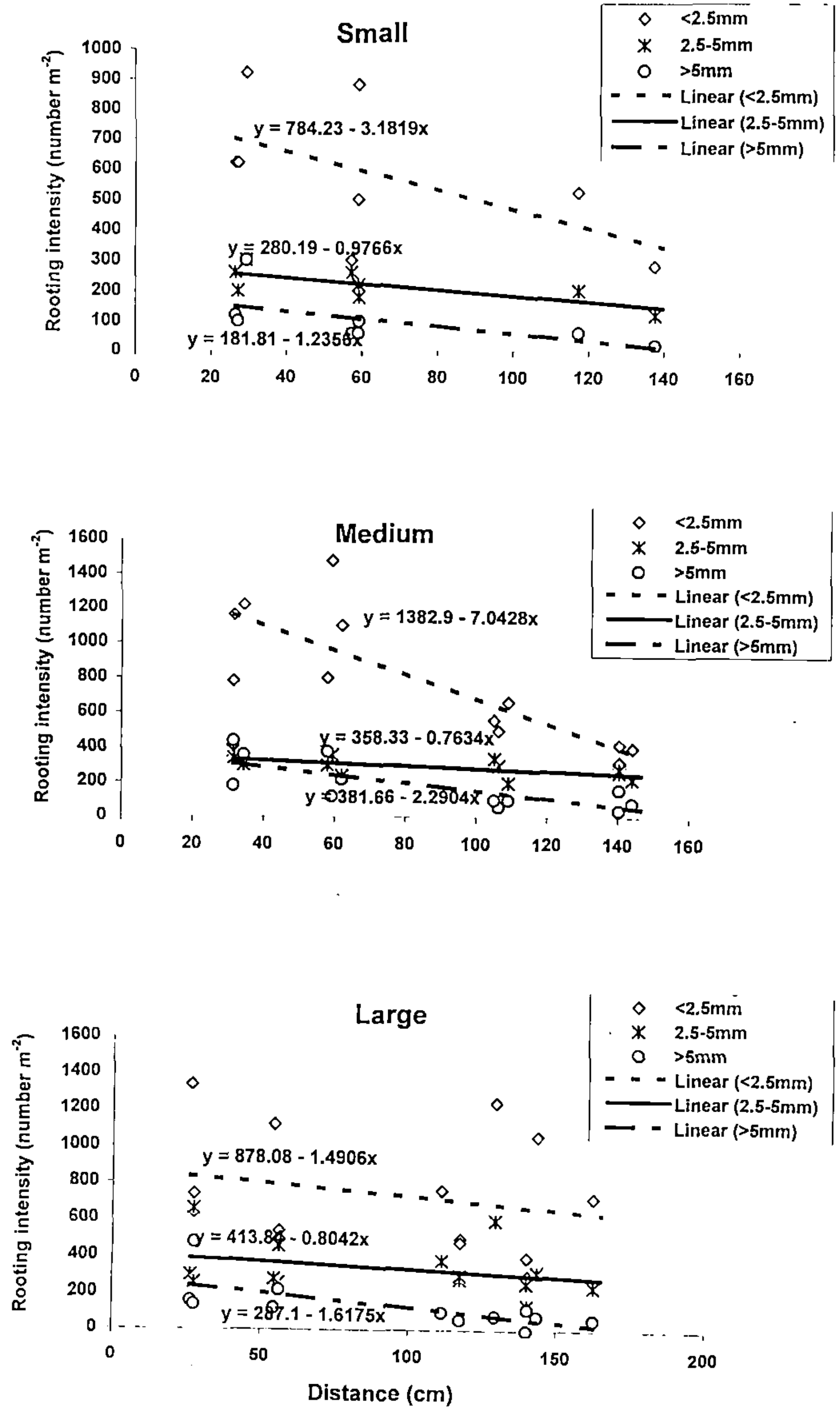


Fig. 22. *Vateria indica* rooting intensity as influenced by lateral distance for small, medium and large size trees

Table 16. Relationship between *Vateria indica* rooting intensity (number m^{-2}) and distance from the tree base

Size class	Diameter class	Equation Y= a + bx	R^2	SEE	n	p
Small	<2.5mm	784.23-3.189x	0.32	209.20	8	0.14
	2.5-5mm	280.19-0.9766x	0.53	41.25	8	0.03
	>5mm	181.8-1.2356x	0.36	73.89	8	0.11
Medium	<2.5mm	1382.9-7.0428x	0.67	224.63	12	<0.01
	2.5-5mm	358.33-0.7634x	0.35	47.21	12	0.04
	>5mm	381.66-2.2904x	0.55	95.13	12	<0.01
Large	<2.5mm	878.08-1.4906x	0.05	332.7	14	0.43
	2.5-5mm	413.84-0.8042x	0.07	142.97	14	0.33
	>5mm	287.1-1.6175x	0.47	88.21	14	<0.01

X	Cardinal distance
Y	Rooting intensity
SEE	Standard error of estimate
R^2	Coefficient of determination
n	number of observations
p	probability

the tree base, whereas in the small and medium size classes, roots extended only up to a distance of about 139 cm. In general, medium sized trees showed higher rooting intensities in all root diameter classes, up to a distance of 58 cm. Nevertheless, for 2.5 to 5 mm diameter class, the large sized trees showed higher rooting intensities (Table 14, Fig.20). MANOVA indicated statistically significant variations for distance, tree sizes, depth and their interactions. Pillai's trace, Hotellings trace and Wilk's lambda were significant (Appendix X to XIII). Dendrograms presented in Fig.24 show that there are three distinct clusters for <2.5 mm roots at 5 per cent phenon level and they largely followed the distance from the tree base (eg. < 58 cm, 58 to 139 cm and >139 cm).

4.6.2 Vertical distribution of *Vateria indica* roots

There were significant differences in rooting intensities of vateria at different soil depths (Figs.18-21 and Tables 12-15). In general, rooting intensity decreased with increasing soil depth for all the tree size classes and root diameter classes. A comparison of the data on rooting intensities (mean of all size classes) indicate that 0-10 cm recorded the highest root counts with nearly 25 per cent of the root counts (Table 17a and 17b). Overall, it followed the order: 0-10 > 10-20 > 20-30 > 30-40 and 40-50 cm layers of the soil profile. All root diameter classes showed a similar trend in this respect.

A schematic diagram showing the root distribution pattern of *Vateria indica* is represented in Fig 23. It is clear that vateria possess a prominent tap root system. Both the diatropic (syn. plagiotropic) and positropic (syn. orthotropic)

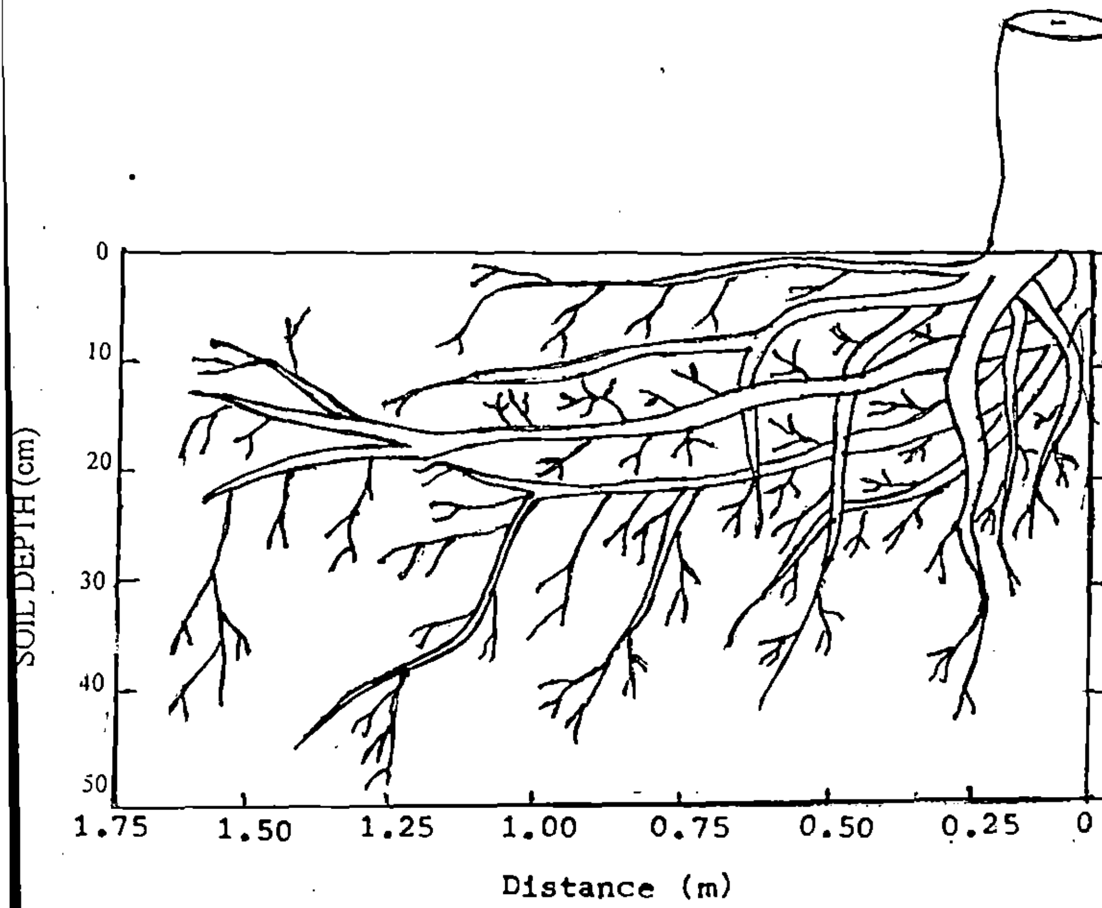
Table 17a. Mean rooting intensity (number m^{-2}) of roots of eight years old *Vateria indica* at different depth intervals and lateral distances from the base of tree

Depth (cm)	Lateral distance from the base of tree (cm)					
	29	58	112	139	144	163
0-10	364.4	320.00	195.55	157.77	24.4	13.33
10-20	351.11	302.00	146.66	144.44	20.00	8.88
20-30	317.77	237.77	173.33	122.22	40.00	46.66
30-40	264.44	237.77	137.77	95.55	71.10	31.11
40-50	182.22	151.11	60.00	117.77	6.66	13.33

Table 17b. Mean rooting intensity (%) of eight years old *Vateria indica* at different depth intervals and lateral distances from the base of tree

Depth (cm)	Lateral distance from the base of tree (cm)					
	29	58	112	139	144	163
0-10	8.36	7.35	4.4	3.6	0.56	0.30
10-20	8.06	6.94	3.36	3.32	0.46	0.20
20-30	7.29	5.4	3.97	2.8	0.92	1
30-40	6.07	5.45	3.16	2.1	1.63	0.71
40-50	4.18	3.50	1.37	2.7	0.15	0.30

Fig. 23. Root distribution pattern of *Vateria indica*



Mean (%) rooting intensity

29 cm	58 cm	112 cm	139 cm	144 cm	163 cm
8.36	7.35	4.4	3.6	0.56	0.30
8.06	6.94	3.36	3.32	0.46	0.20
7.29	5.4	3.97	2.8	0.92	1
6.07	5.45	3.16	2.1	1.63	0.71
4.18	3.50	1.37	2.7	0.15	0.30

Lateral distance from the base of tree

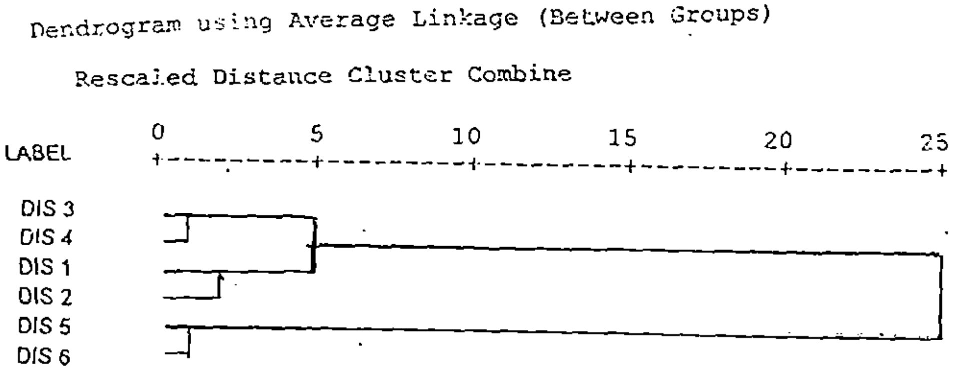


Fig. 24. Dendrogram using average linkage between groups for comparing rooting intensities at various distances of *Vateria indica* for <2.5 mm diameter roots (DIS - Distance)

Distance 1 - 29cm
Distance 2 - 58cm
Distance 3 - 112cm
Distance 4 - 139cm
Distance 5 - 144cm
Distance 6 - 163cm

roots were prominent. Also the branches of the horizontal roots were oriented vertically downward, thus giving rise to network of well ramified root system.

4.6.3 Horizontal distribution of *Ailanthus triphysa* roots

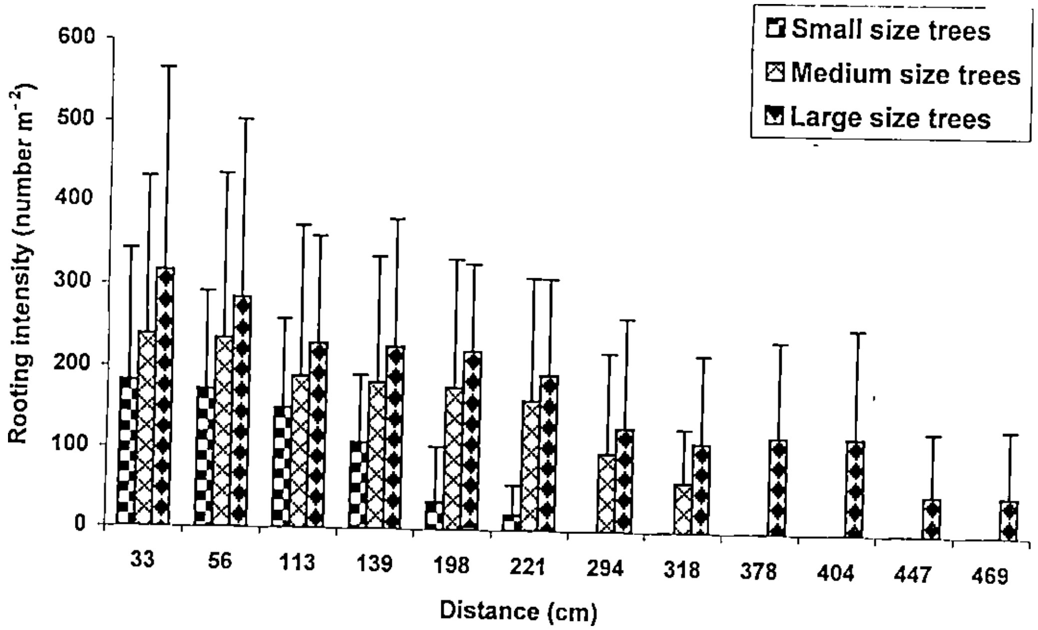
Rooting intensity of *Ailanthus triphysa* at different distances along the logarithmic spiral trench are shown in Fig.25-28 and Tables 18-21. Rooting intensity (all root diameters) at a distance of 33 cm are 182, 240 and 317m^{-2} for small, medium and large size class respectively. Rooting intensity (up to 60 cm depth) at different lateral distances along the logarithmic trench was regressed on distance from the tree base. As expected it declined with distance from the tree negatively. Negative linear equations signify this decreasing trend for all sizes classes and for all root diameter categories (Fig. 29 and Table 22). However, R^2 values were modest ranging from 0.14 to 0.61.

Depth-wise root distribution as influenced by distance from the tree base is shown in Fig.30 and Table 23a and 23b shows the mean rooting intensity in percentage. Regression equations linking distance from the base of the ailanthus tree and rooting intensities for various size class and root diameter categories are presented in Table 22. All root diameter classes were similar in respect of the lateral spread, although number of roots in less than 2.5 mm diameter was substantially greater than 2.5-5mm and >5 mm classes. Overall, <2.5 mm class roots constituted 71 per cent of all roots, while 2.5-5mm class roots constituted 20 per cent and >5mm root classes constituted 9 per cent of all roots.

Table 18. Rooting intensity (number m^{-2}, total roots) of eight years old *Ailanthus triphysa* as influenced by tree size, distance and depth.

Size class	Distance from the base of the tree (cm)																							
	33		56		113		139		198		221		294		318		378		404		447		469	
	Rooting intensity (number m^{-2})																							
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Small	182.22	160.71	172.22	119.43	150	109.81	108	83.23	33.33	70.29	18.88	37.24	0	0	0	0	0	0	0	0	0	0	0	0
Medium	240	190.72	235.55	198.53	188.88	182.43	182.22	152.91	176.66	156.16	162.22	148.86	97.77	123.83	61.11	68.07	0	0	0	0	0	0	0	0
Large	316.66	248.41	284.44	217.42	230	128.93	226.66	153.23	221.66	105.48	193.33	116.61	128.88	135.34	111.11	108.73	120	117.82	120	134.07	48.88	79.17	48.88	83.79
Depth class (cm)																								
0-10	488.88	202.01	342.22	178.17	346.66	188.41	282.22	119.35	255.55	201.68	200	158.75	137.77	182.33	91.11	110.96	53.33	110	62.22	129.79	17.77	53.33	31.11	93.33
10-20	380	194.94	404.44	162.41	248.88	75.57	248.88	144.6	195.55	147.23	186.66	164.92	93.33	128.06	82.22	104.62	40	80	48.88	114.06	17.77	53.33	17.77	53.33
20-30	300	114.84	351.11	154.3	237.77	48.41	220	148.66	137.77	98.2	182.22	139.44	97.77	122.24	82.22	108.83	64.44	130.29	66.66	132.66	22.22	66.66	20	60
30-40	208.88	96.49	184.44	47.72	191.11	103.97	180	92.19	128.88	110.96	106.66	87.74	77.77	110.2	35.55	58.97	35.55	76.66	44.44	88.19	20	60	13.33	40
40-50	86.66	36.05	88.88	42.56	100	75.49	95.55	67.66	117.77	98.2	64.44	63.85	40	51.96	46.66	62.44	40	84.85	11.11	22.6	17.77	53.33	11.11	33.33
50-60	13.33	17.32	13.33	17.32	13.33	22.36	8.88	20.28	26.66	42.42	8.88	17.64	6.66	20	6.66	14.14	6.66	20	6.66	20	2.22	6.66	4.44	13.33

Distance 1 was located at a distance of 0.75D from the base of the tree, where D = tree diameter
Average tests of significance – MANOVA
Distance $P<0.001$
Size by distance $P<0.001$
Depth by distance $P<0.001$
Size by depth by distance $P< 0.876$
SD – Standard deviation



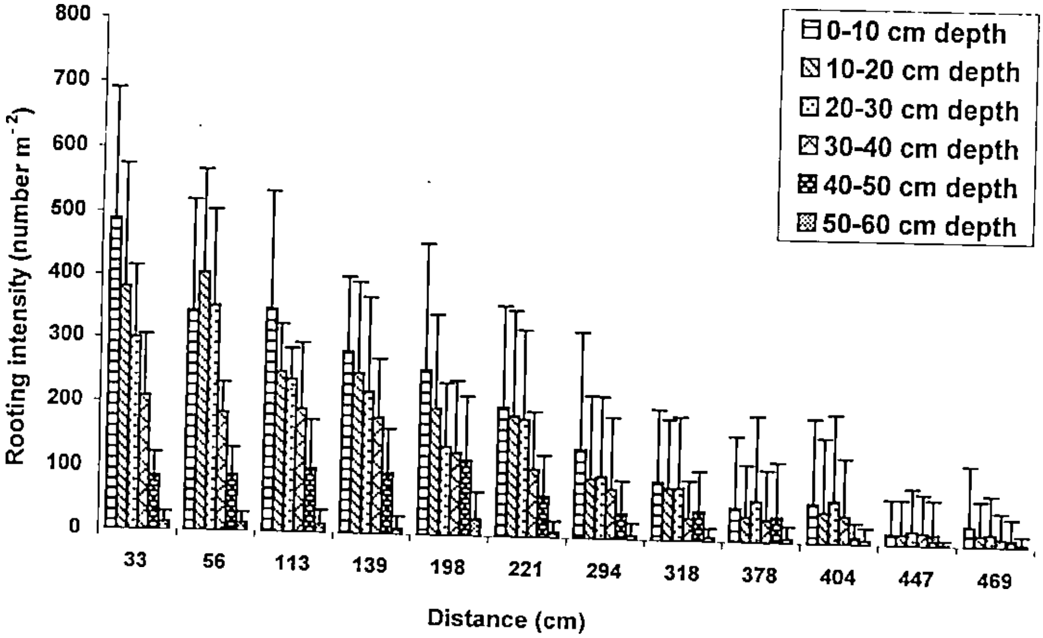
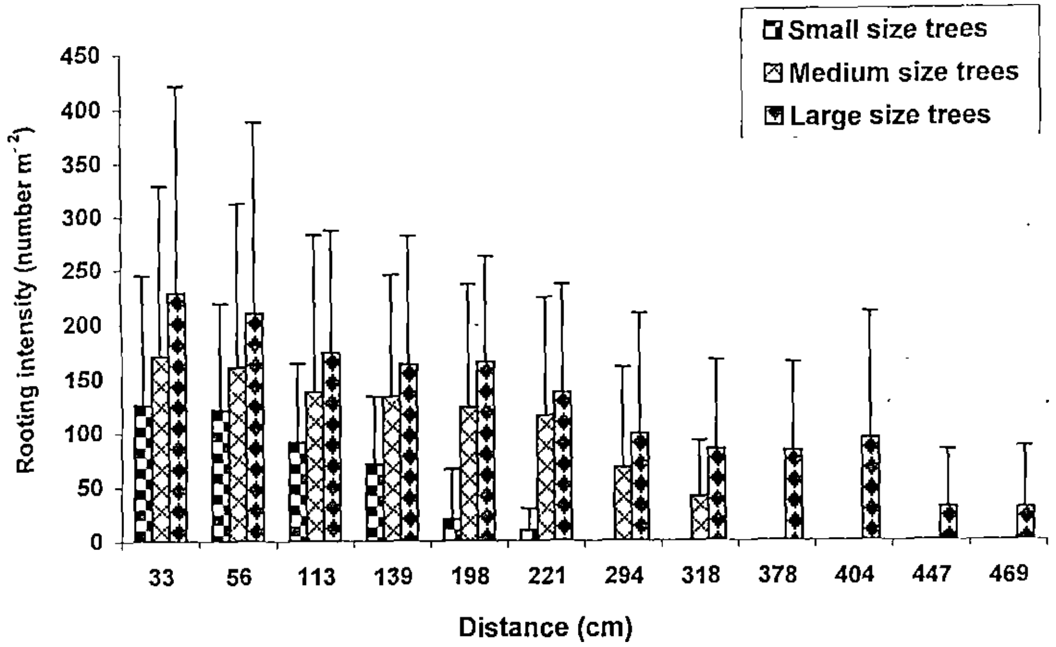


Fig. 25. Rooting intensity (number m^{-2}, total roots) of eight years old *Ailanthus triphysa* for various distances as influenced by tree size and depth

Table 19. Rooting intensity (number m^{-2}, <2.5 mm roots) of eight years old *Ailanthus triphysa* as influenced by tree size, distance and depth.

Size class	Distance from the base of the tree (cm)																							
	33		56		113		139		198		221		294		318		378		404		447		469	
	Rooting intensity (number m^{-2})																							
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Small	125.55	118.98	121.1	97.85	91.11	73.31	71.11	62.2	20	46.52	10	19.7	0	0	0	0	0	0	0	0	0	0	0	0
Medium	171.11	158.1	161.1	151.3	137.77	144.52	133.33	111.3	123.33	112.35	115.55	107.93	67.77	92.58	41.11	51.55	0	0	0	0	0	0	0	0
Large	228.88	192.59	210	177.73	174.44	112.05	163.33	117.7	165.55	96.23	136.66	98.75	98.88	110.1	84.44	82.19	83.33	81.52	94.44	115.2	31.11	53.23	30	57.08
Depth class (cm)																								
0-10	364.44	194.62	257.8	171.01	260	156.52	204.44	100.9	191.11	152.02	155.55	129.52	113.3	151.7	73.33	91.1	33.33	66.33	46.66	107.7	11.11	33.33	22.22	66.66
10-20	264.44	161.49	291.1	148.3	184.44	60.64	180	117.9	133.33	110.45	117.77	115.95	66.66	88.88	55.55	72.64	33.33	67.82	37.77	92.97	8.88	26.66	11.11	33.33
20-30	200	81.85	240	123.69	157.77	40.55	144.44	98.88	84.44	74.68	131.11	109.59	73.33	95.91	55.55	75.35	42.22	87.43	60	119.2	15.55	46.66	11.11	33.33
30-40	146.66	86.02	126.7	47.95	128.88	109.13	131.11	74.23	93.33	91.1	73.33	64.03	48.88	72.18	22.22	45.21	22.22	45.21	28.88	62.53	15.55	46.66	4.44	13.33
40-50	62.22	132.31	62.22	36.66	66.66	65.57	68.88	64.11	97.77	89.69	42.22	44.06	28.88	42.55	37.77	56.07	31.11	68.63	8.88	17.63	11.11	33.33	11.11	33.33
50-60	13.33	17.32	6.66	10	8.88	14.52	6.66	14.14	17.77	25.38	4.44	8.8	2.22	6.6	6.66	14.14	4.44	13.33	6.66	20	0	0	0	0

Distance 1 was located at a distance of 0.75D from the base of the tree, where D = tree diameter
Average tests of significance – MANOVA
Distance $P<0.001$
Size by distance $P<0.001$
Depth by distance $P<0.001$
Size by depth by distance $P< 0.908$
SD – Standard deviation



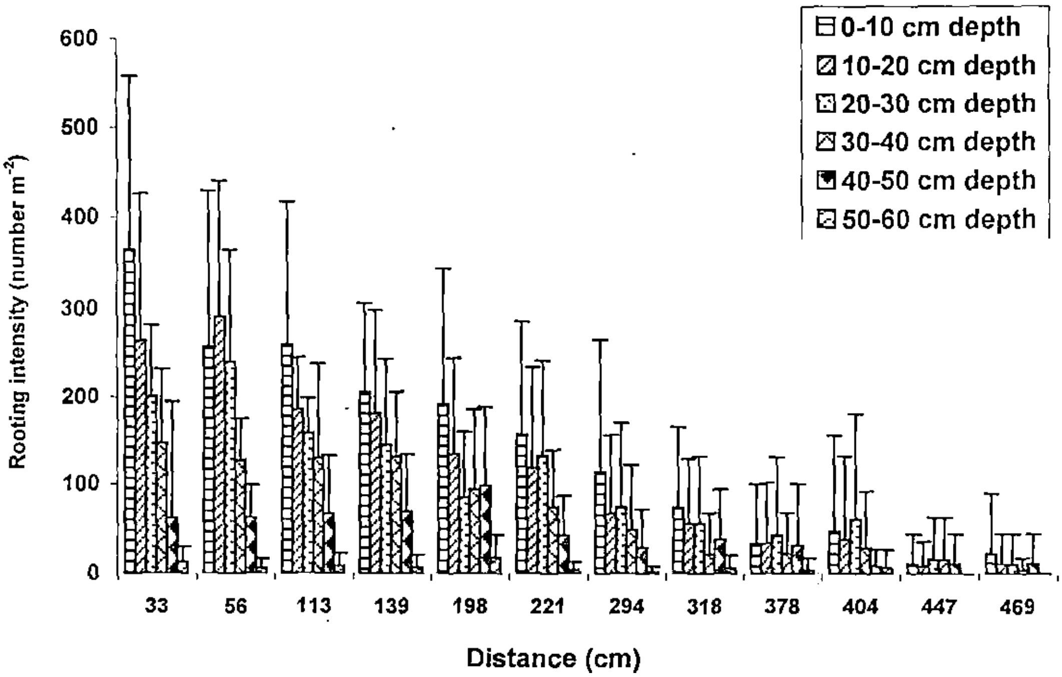
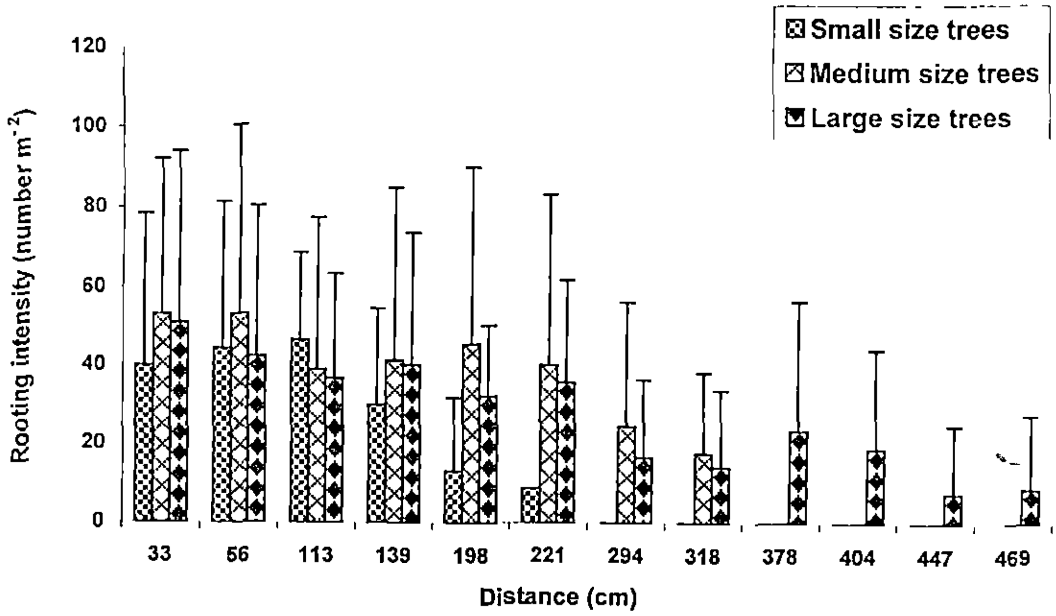


Fig. 26. Rooting intensity (number m^{-2}, <2.5 mm roots) of eight years old *Ailanthus triphysa* for various distances as influenced by tree size and depth

Table 20. Rooting intensity (number m^{-2}, 2.5 - 5.0 mm roots) of eight years old *Ailanthus triphysa* as influenced by tree size, distance and depth.

Size class	Distance from the base of the tree (cm)																							
	33		56		113		139		198		221		294		318		378		404		447		469	
	Rooting intensity (number m^{-2})																							
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Small	40	33.6	44.44	38.53	46.66	36.94	30	21.96	13.33	24.73	8.88	18.43	0	0	0	0	0	0	0	0	0	0	0	0
Medium	53.33	38.8	53.33	47.02	38.88	38.48	41.11	43.64	45.55	44.35	40	42.84	24.44	31.84	17.77	20.45	0	0	0	0	0	0	0	0
Large	51.11	42.96	42.22	38.12	36.66	26.78	40	33.6	32.22	18.32	35.55	26.17	16.66	19.7	14.44	19.16	23.33	33.07	18.88	25.17	7.77	16.99	8.88	18.43
Depth class (cm)																								
0-10	73.33	20	57.77	29.05	71.11	34.8	60	20	55.55	54.56	35.55	26.03	15.55	19.43	13.33	17.32	17.77	40.55	13.33	28.28	2.22	6.66	4.44	13.33
10-20	80	41.23	73.33	42.42	40	22.36	57.77	41.76	42.22	33.82	55.55	52.7	24.44	39.72	17.77	23.33	4.44	8.81	8.88	17.63	6.66	20	0	0
20-30	71.11	33.33	82.22	47.37	65.44	29.62	55.55	38.44	35.55	21.85	40	30	17.77	23.33	17.77	25.38	13.33	28.78	4.44	13.33	4.44	13.33	4.44	13.33
30-40	42.22	23.33	40	26.45	46.66	28.28	33.33	17.32	31.11	22.6	22.22	18.55	20	24.49	11.11	14.52	6.66	14.14	8.88	20.27	2.22	6.66	6.66	20
40-50	22.22	12.01	24.44	16.66	22.22	18.55	15.55	13.33	15.55	13.33	16.55	21.85	4.44	8.81	4.44	8.81	4.44	13.33	2.22	6.66	0	0	0	0
50-60	0	0	2.22	6.66	0	0	0	0	2.22	6.66	0	0	0	0	0	0	0	0	0	0	0	0	2.22	6.66

Distance 1 was located at a distance of 0.75D from the base of the tree, where D = tree diameter
Average tests of significance – MANOVA
Distance $P<0.001$
Size by distance $P<0.001$
Depth by distance $P<0.001$
Size by depth by distance $P< 0.648$
SD – Standard deviation



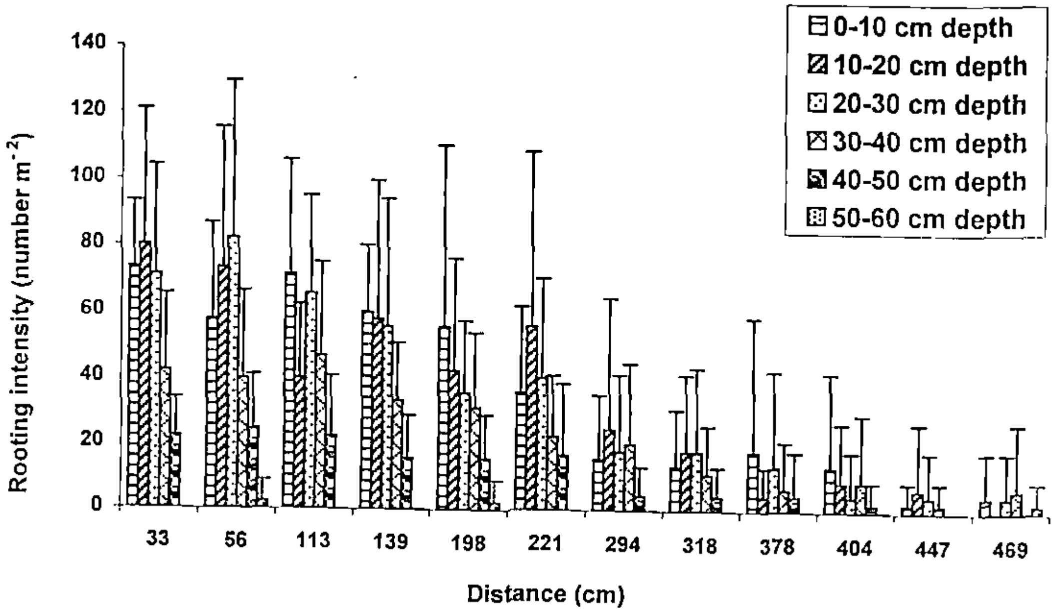
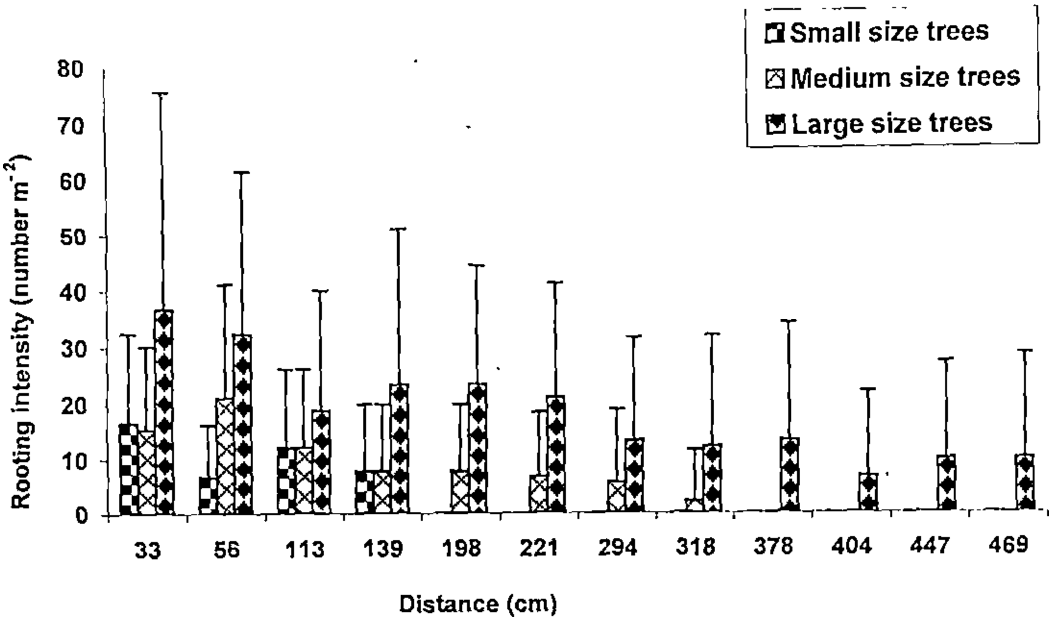


Fig. 27. Rooting intensity (number m^{-2}, 2.5 - 5.0 mm roots) of eight years old *Ailanthus triphysa* for various distances as influenced by tree size and depth

Table 21. Rooting intensity (number m^{-2}, >5 mm roots) of eight years old *Ailanthus triphysa* as influenced by tree size, distance and depth.

Size class	Distance from the base of the tree (cm)																							
	33		56		113		139		198		221		294		318		378		404		447		469	
	Rooting intensity (number m^{-2})																							
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Small	16.66	15.71	6.66	9.7	12.22	13.95	7.77	12.15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Medium	15.55	14.64	21.11	19.96	12.22	13.95	7.77	12.15	7.77	12.15	6.66	11.88	5.55	13.38	2.22	9.42	0	0	0	0	0	0	0	0
Large	36.66	38.95	32.22	29.21	18.88	21.11	23.33	27.65	23.33	20.86	21.11	19.96	13.33	18.14	12.22	19.57	13.33	20.57	6.66	15.33	10	17.14	10	18.47
Depth class (cm)																								
0-10	51.11	36.2	26.66	17.32	15.55	8.81	17.77	12.01	8.88	10.54	8.88	10.54	8.88	14.52	4.44	13.33	2.22	6.66	2.22	6.66	4.44	13.33	4.44	13.33
10-20	35.55	19.43	40	34.64	24.44	19.43	11.11	14.52	20	22.36	13.33	22.36	2.22	6.66	8.88	17.63	2.22	6.66	2.22	6.66	2.22	6.66	6.66	20
20-30	28.88	24.72	28.88	17.63	15.55	16.66	20	36.05	17.77	23.33	11.11	14.52	6.66	14.14	8.88	20.27	8.88	20.27	2.22	6.66	2.22	6.66	4.44	13.33
30-40	20	17.32	17.77	21.08	15.55	16.66	15.55	19.43	4.44	8.81	11.11	22.6	8.88	20.27	2.22	6.66	6.66	20	6.66	20	2.22	6.66	2.22	6.66
40-50	2.22	6.66	2.22	6.66	11.11	22.6	11.11	20.27	4.44	13.33	6.66	14.14	6.66	14.14	4.44	13.33	4.44	13.33	0	0	6.66	20	0	0
50-60	0	0	4.44	8.81	4.44	8.81	2.22	6.66	6.66	14.14	4.44	8.81	4.44	13.33	0	0	2.22	6.66	0	0	2.22	6.66	2.22	6.66

Distance 1 was located at a distance of 0.75D from the base of the tree, where D = tree diameter
Average tests of significance – MANOVA
Distance P<0.001
Size by distance P<0.120
Depth by distance P<0.001
Size by depth by distance P< 0.352
SD – Standard deviation



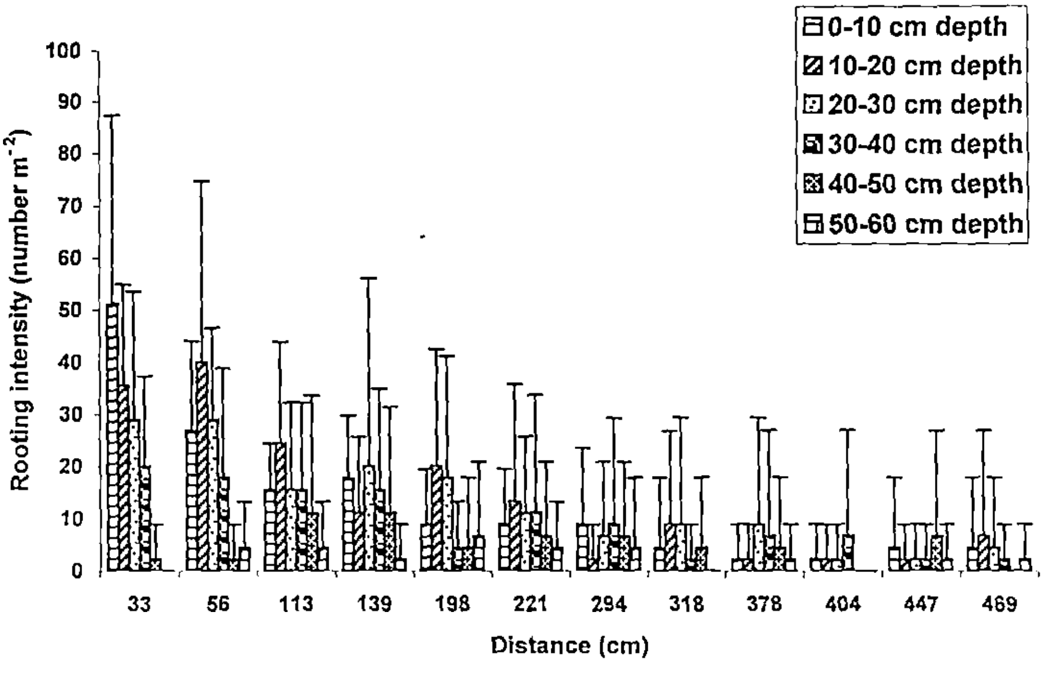


Fig. 28. Rooting intensity (number m^{-2}, >5.0 mm roots) of eight years old *Ailanthus triphysa* for various distances as influenced by tree size and depth

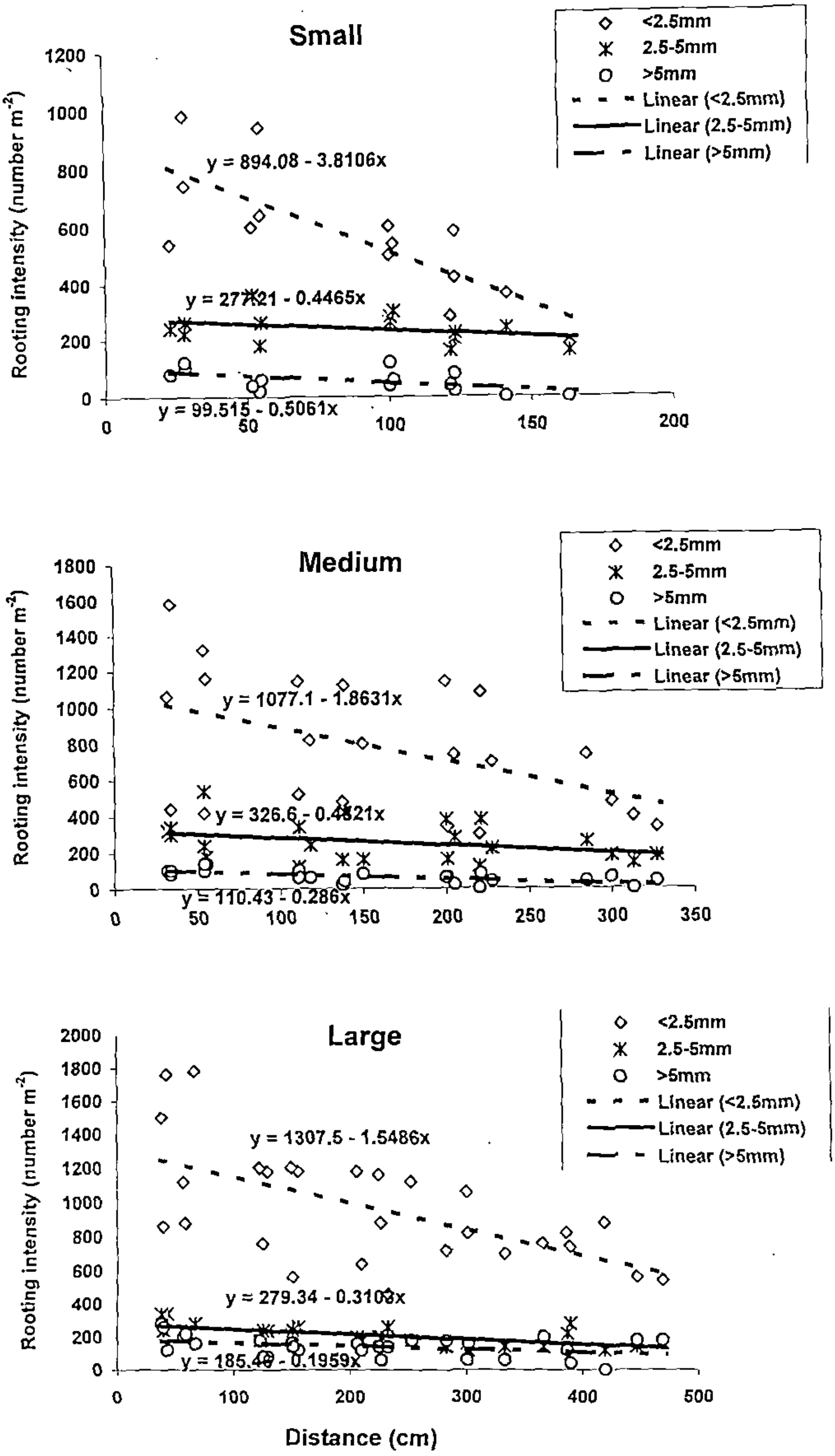


Fig. 29. Ailanthus triphysa rooting intensity as influenced by lateral distance for small, medium and large size trees

Table 22. Relationship between *Ailanthus triphysa* rooting intensity (number m^{-2}) and distance from the tree base

Size class	Diameter class	Equation Y= a + bx	R^2	SEE	n	p
Small	<2.5mm	894.08-3.8106x	0.61	144.4	14	<0.01
	2.5-5mm	277.21-0.4465x	0.14	53.3	14	0.18
	>5mm	99.51-0.506x	0.33	34.02	14	0.02
Medium	<2.5mm	1077.1-1.8631x	0.23	332.81	22	0.02
	2.5-5mm	326.6-0.4321x	0.14	104.92	22	0.08
	>5mm	110.43-0.286x	0.49	28.41	22	<0.01
Large	<2.5mm	1307.5-1.5486x	0.36	276.77	28	<0.01
	2.5-5mm	279.34-0.3103x	0.46	44.74	28	<0.01
	>5mm	185.46-0.1959x	0.15	60.88	28	0.03

X	Cardinal distance
Y	Rooting intensity
SEE	Standard error of estimate
R^2	Coefficient of determination
n	number of observations
p	probability

Size of the ailanthus trees showed marked variations on the horizontal root distribution pattern. Large sized trees extended roots up to a 469 cm, medium sized trees up to 318 cm and small sized ones up to 221 cm. Large sized trees recorded the highest rooting intensities. In the case of 2.5-5 mm diameter root class, however, medium-sized trees showed higher rooting intensities. MANOVA indicated statistically significant variations for distance, tree sizes, depth and their interactions. Pillai's trace, Hotellings trace and Wilk's lambda were significant (Appendix XIV-XVII).

4.6.4 Vertical distribution of *Ailanthus triphysa* roots

There were significant differences in rooting intensities of ailanthus for different root diameter classes along the soil profile depth (Figs.25-28 and Tables 18-21). Generally, rooting intensities decreased with increasing soil depth for all size classes and root diameter classes. A comparison of data on mean rooting intensities indicate that surface depth of 0-10 cm recorded the highest root counts with nearly 28 per cent of the mean root counts (Table 23a, 23b). Overall, it followed the order 0-10 > 10-20 > 20-30 > 30-40 > 40-50 and 50-60 cm horizon of the soil profile. The pattern was similar for all root diameter classes.

Hierarchial cluster analysis using average linkage between rooting intensities and distances from the base of the tree formed three distinct clusters except for the >5.0 mm root diameter category (Figs.31-34). In general, rooting intensities up to 56 cm lateral distance formed one cluster, while the roots up to 220 cm and that beyond 220cm formed the remaining two clusters. As regards to

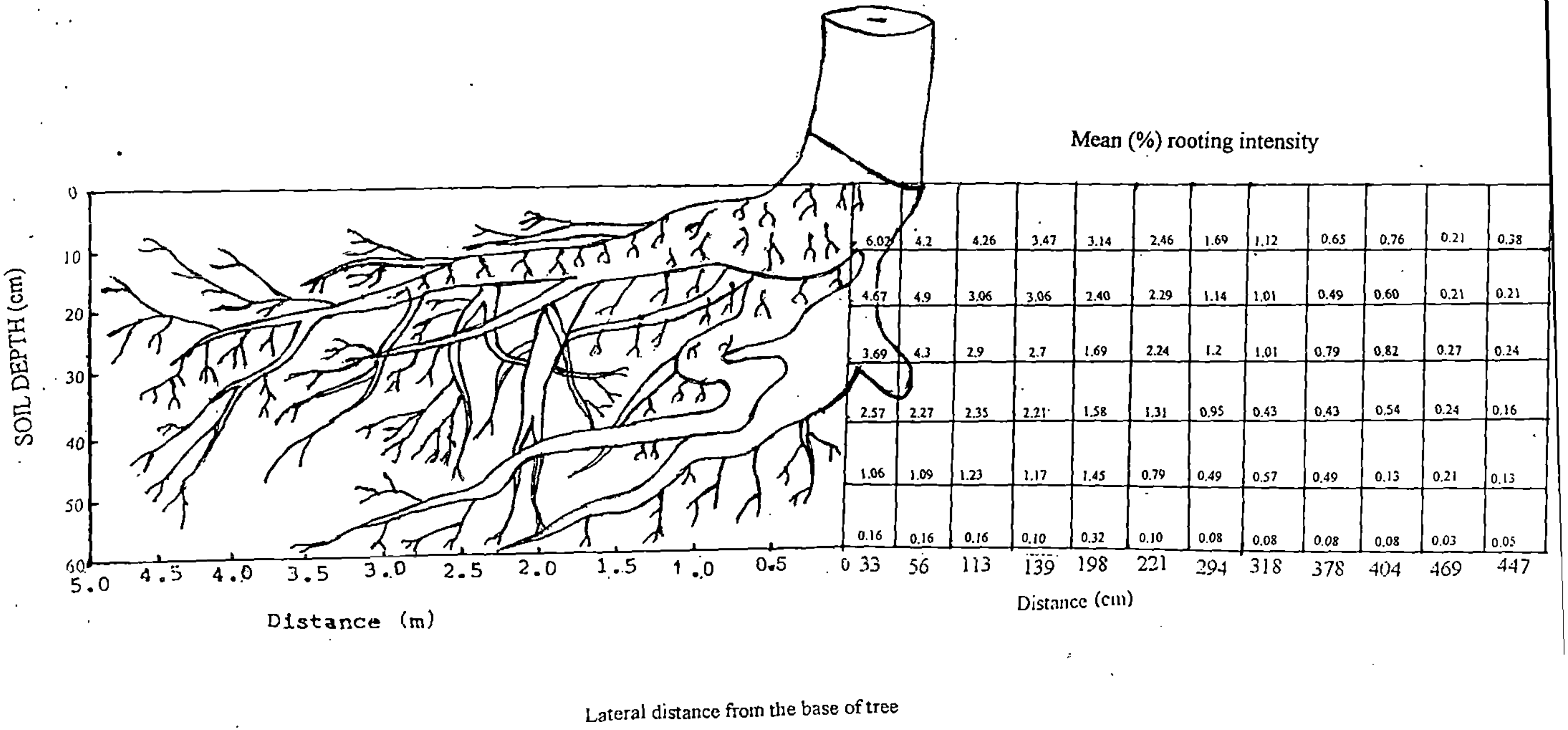
Table 23a. Mean rooting intensity (number m^{-2}) of eight years old *Ailanthus triphysa* at different depth intervals and lateral distances from the base of tree

Dept (cm)	Lateral distance from the base of tree (cm)											
	33	56	113	139	198	221	294	318	378	404	447	469
0-10	488.88	342.22	346.66	282.22	255.55	200.00	137.77	91.11	53.33	62.22	17.77	31.11
10-20	380.00	404.44	248.88	248.88	195.55	186.66	93.33	82.22	40.00	48.88	17.77	17.77
20-30	300.00	351.1	237.77	220.00	137.77	182.22	97.77	82.22	64.44	66.66	22.22	20.00
30-40	208.88	184.44	191.11	180.00	128.88	106.66	77.77	35.55	35.55	44.44	20.00	13.33
40-50	86.66	88.88	100.00	95.55	117.77	64.44	40.00	46.66	40.00	11.11	17.77	11.11
50-60	13.33	13.33	13.33	8.88	26.66	8.88	6.66	6.66	6.66	6.66	2.22	4.44

Table 23b. Mean rooting intensity (%) of eight years old *Ailanthus triphysa* at different depth intervals and lateral distances from the base of tree

Depth (cm)	Lateral distance from the base of tree (cm)											
	33	56	113	139	198	221	294	318	378	404	447	469
0-10	6.02	4.2	4.26	3.47	3.14	2.46	1.69	1.12	0.65	0.76	0.21	0.38
10-20	4.67	4.9	3.06	3.06	2.40	2.29	1.14	1.01	0.49	0.60	0.21	0.21
20-30	3.69	4.3	2.9	2.7	1.69	2.24	1.2	1.01	0.79	0.82	0.27	0.24
30-40	2.57	2.27	2.35	2.21	1.58	1.31	0.95	0.43	0.43	0.54	0.24	0.16
40-50	1.06	1.09	1.23	1.17	1.45	0.79	0.49	0.57	0.49	0.13	0.21	0.13
50-60	0.16	0.16	0.16	0.10	0.32	0.10	0.08	0.08	0.08	0.08	0.03	0.05

Fig. 30. Root distribution pattern of Ailanthus triphysa



33	56	113	139	198	221	294	318	378	404	469	447
6.02	4.2	4.26	3.47	3.14	2.46	1.69	1.12	0.65	0.76	0.21	0.38
4.67	4.9	3.06	3.06	2.40	2.29	1.14	1.01	0.49	0.60	0.21	0.21
3.69	4.3	2.9	2.7	1.69	2.24	1.2	1.01	0.79	0.82	0.27	0.24
2.57	2.27	2.35	2.21	1.58	1.31	0.95	0.43	0.43	0.54	0.24	0.16
1.06	1.09	1.23	1.17	1.45	0.79	0.49	0.57	0.49	0.13	0.21	0.13
0.16	0.16	0.16	0.10	0.32	0.10	0.08	0.08	0.08	0.08	0.03	0.05

the larger root diameter class (>5 mm), all distances beyond the 33 cm lateral distance formed one cluster and that up to 33 cm constituted a solitary cluster.

Tree size x distance (from the tree base) interaction was significant. Hierarchial cluster analysis using average linkage between rooting intensities, tree sizes and distances formed four clusters (5% phenon levels; Figs.35-38). In general, the combinations involving large tree sizes and short distances (up to 56 cm from the base) formed a homogenous category, except for the 2.5 to 5.0 mm root size class. Likewise, rooting intensities of large tree sizes at distances 293 to 404 cm, small sizes at 139 to 294 cm and medium size at 294 cm formed a single cluster. Large trees at 113-198 cm and medium trees at 33 to 56 cm were similar in respect of the rooting densities. Small-tree rooting intensity up to 113 cm, medium sized tree rooting intensity from 113 to 221cm and large sized tree rooting intensity 221 cm constituted the third cluster; while all the remaining combinations together formed the fourth cluster. Implicit in this is the significant tree-size x distance interaction is the fact that tree sizes exert a strong control over rooting intensity at different lateral distances while large trees have more roots at all distances, small and medium sized trees had similar rooting intensities at intermediate distance. All root diameter classes followed this general trend, despite some variability was found as in the case of 2.5-5 mm root size class (Fig.37).

A schematic diagram showing the root distribution pattern of *Ailanthus triphysa* is represented in Fig.30. From the excavation study, it is clear that *Ailanthus triphysa* has a ramified tap root system. The diatropic root growth

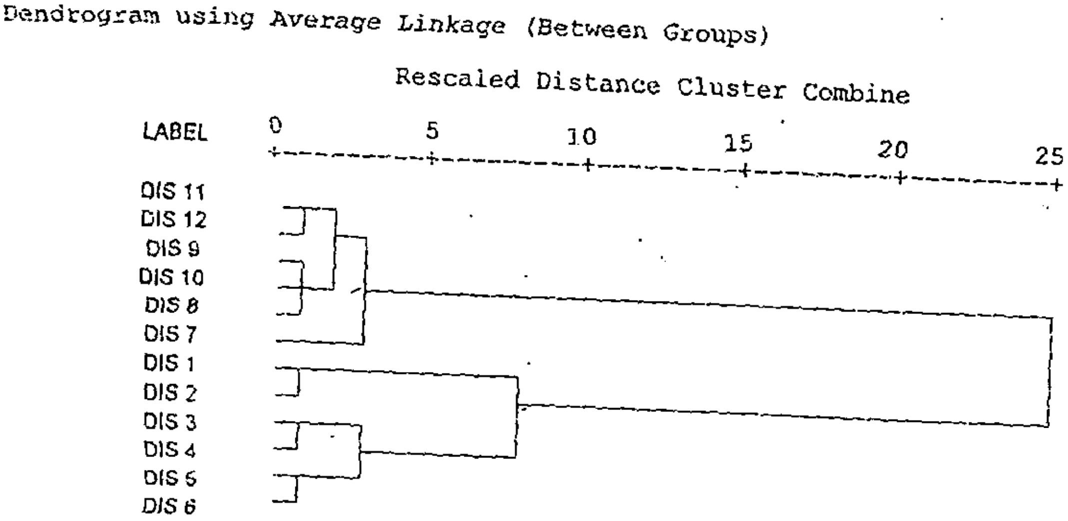


Fig. 31. Dendrogram using average linkage between groups for comparing rooting intensities of *Ailanthus triphysa* at different distances (total roots) (DIS - Distance)

*Distance 1 - 33.2cm
Distance 2 - 56.3cm
Distance 3 - 113.3cm
Distance 4 - 139cm
Distance 5 - 198.3cm
Distance 6 - 220.73cm
Distance 7 - 293.7cm
Distance 8 - 318cm
Distance 9 - 378.35cm
Distance 10 - 403.65cm
Distance 11 - 447.3cm
Distance 12 - 469.3cm

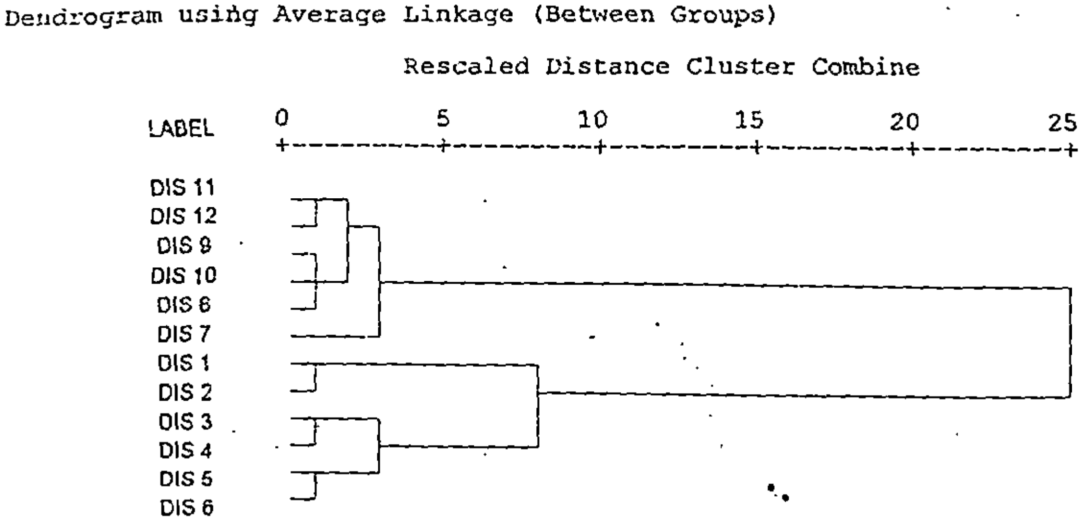


Fig. 32. Dendrogram using average linkage between groups for comparing rooting intensities for different distances of *Ailanthus triphysa* for <2.5 mm diameter roots (DIS - Distance)

*Distance 1 - 33.2cm
Distance 2 - 56.3cm
Distance 3 - 113.3cm
Distance 4 - 139cm
Distance 5 - 198.3cm
Distance 6 - 220.73cm
Distance 7 - 293.7cm
Distance 8 - 318cm
Distance 9 - 378.35cm
Distance 10 - 403.65cm
Distance 11 - 447.3cm
Distance 12 - 469.3cm

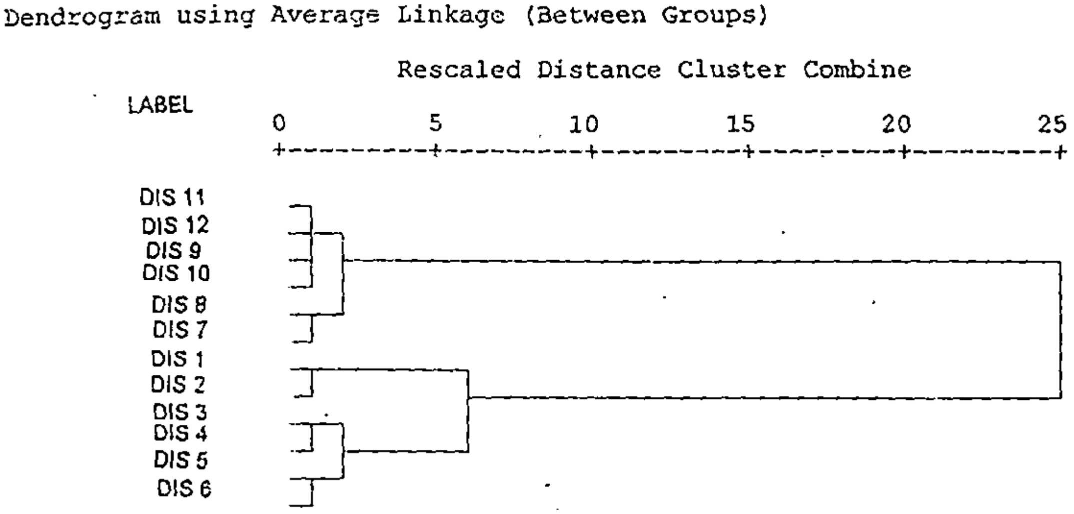


Fig. 33. Dendrogram using average linkage between groups for comparing rooting intensities for different distances of *Ailanthus triphysa* for 2.5 - 5.0 mm diameter roots (DIS - Distance)

*Distance 1 - 33.2cm
Distance 2 - 56.3cm
Distance 3 - 113.3cm
Distance 4 - 139cm
Distance 5 - 198.3cm
Distance 6 - 220.73cm
Distance 7 - 293.7cm
Distance 8 - 318cm
Distance 9 - 378.35cm
Distance 10 - 403.65cm
Distance 11 - 447.3cm
Distance 12 - 469.3cm

Dendrogram using Average Linkage (Between Groups)

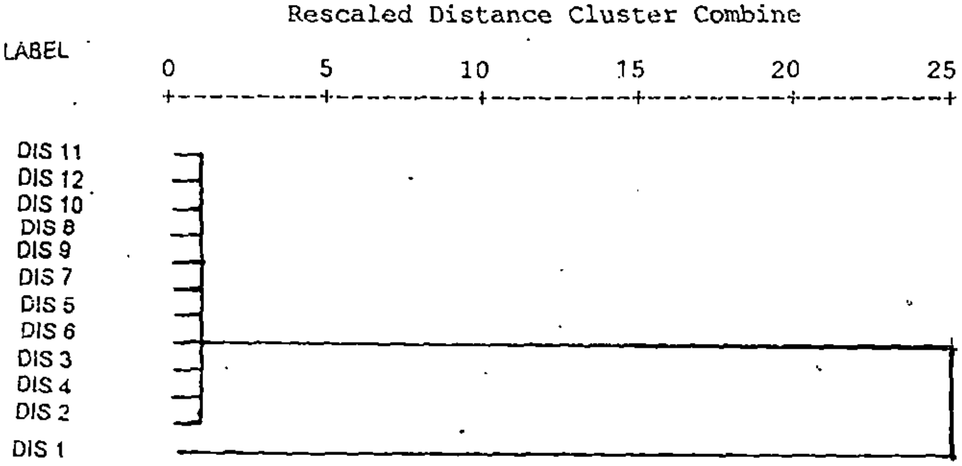


Fig. 34. Dendrogram using average linkage between groups for comparing rooting intensities for different distances of *Ailanthus triphysa* for >5.0 mm diameter roots (DIS - Distance)

*Distance 1 - 33.2cm
Distance 2 - 56.3cm
Distance 3 - 113.3cm
Distance 4 - 139cm
Distance 5 - 198.3cm
Distance 6 - 220.73cm
Distance 7 - 293.7cm
Distance 8 - 318cm
Distance 9 - 378.35cm
Distance 10 - 403.65cm
Distance 11 - 447.3cm
Distance 12 - 469.3cm

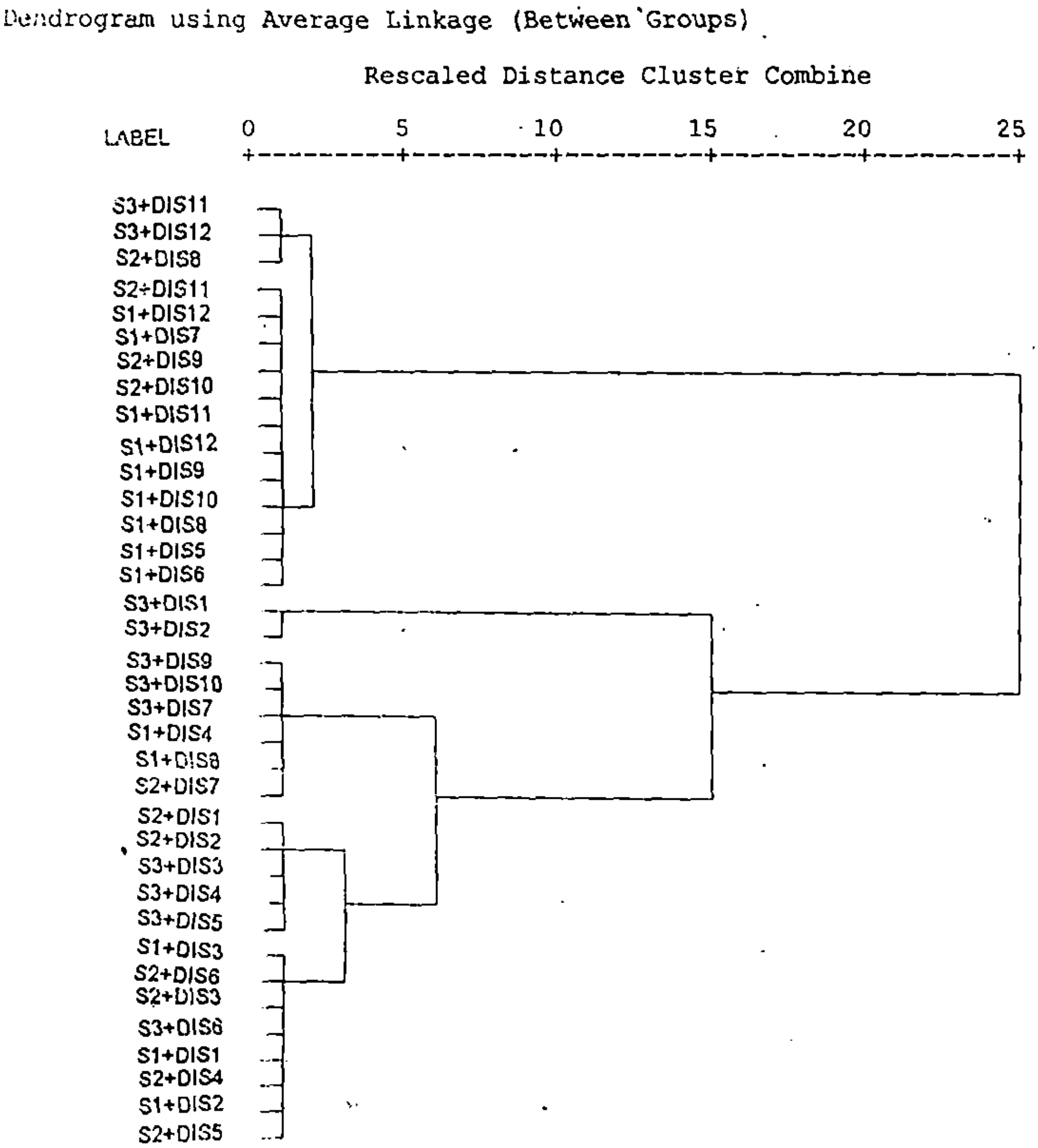


Fig. 35. Dendrogram using average linkage between groups for comparing rooting intensities for different sizes and different distances of *Ailanthus triphysa* for roots of all diameter classes (S - Size, DIS - Distance)

*Distance 1 - 33.2cm
Distance 2 - 56.3cm
Distance 3 - 113.3cm
Distance 4 - 139cm
Distance 5 - 198.3cm
Distance 6 - 220.73cm
Distance 7 - 293.7cm
Distance 8 - 318cm
Distance 9 - 378.35cm
Distance 10 - 403.65cm
Distance 11 - 447.3cm
Distance 12 - 469.3cm

Dendrogram using Average Linkage (Between Groups)

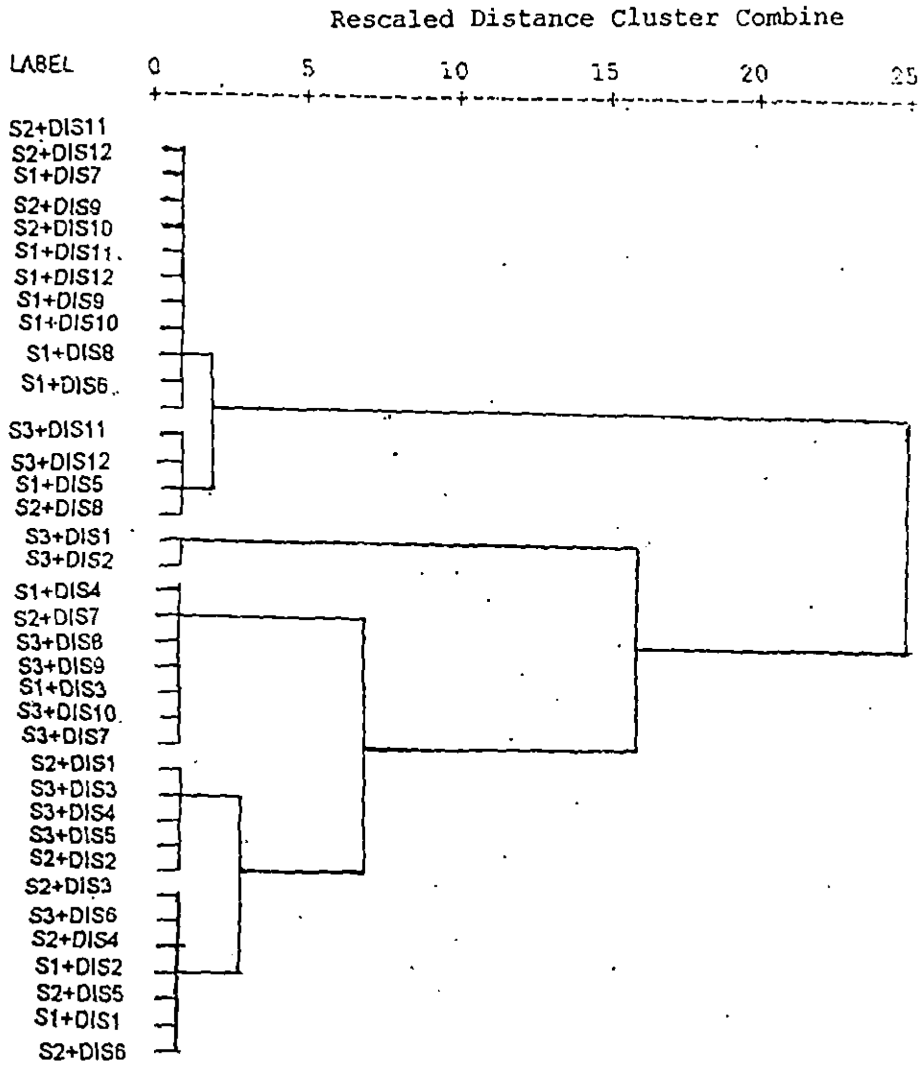


Fig. 36. Dendrogram using average linkage between groups for comparing rooting intensities for different sizes and different distances of *Ailanthus triphysa* for <2.5 mm diameter roots (S - Size, DIS - Distance)

S1- Small
S2- Medium
S3- Large
Distance 1 - 33.2cm
Distance 2 - 56.3cm
Distance 3 - 113.3cm
Distance 4 - 139cm
Distance 5 - 198.3cm
Distance 6 - 220.73cm
Distance 7 - 293.7cm
Distance 8 - 318cm
Distance 9 - 378.35cm
Distance 10 - 403.65cm
Distance 11 - 447.3cm
Distance 12 - 469.3cm

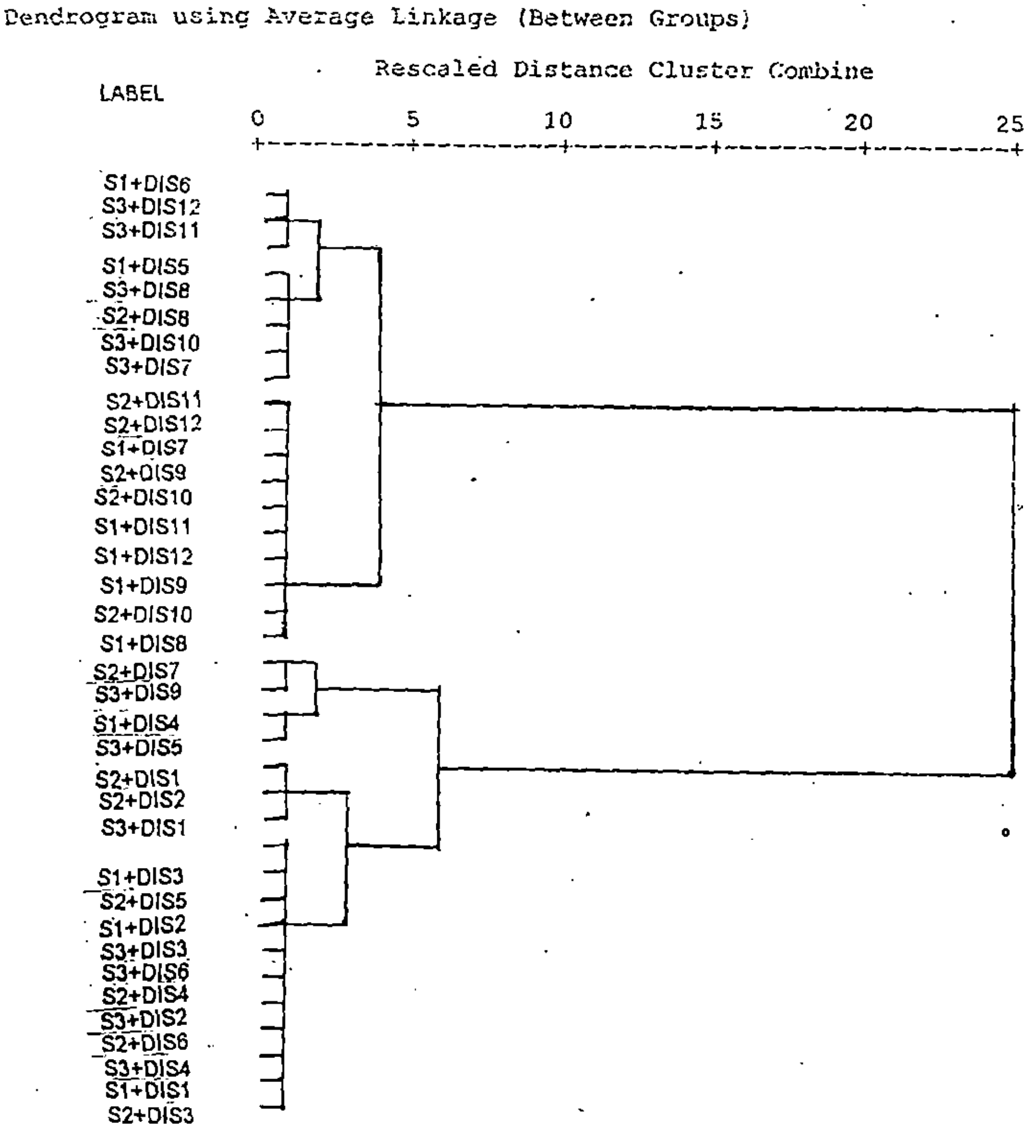


Fig. 37. Dendrogram using average linkage between groups for comparing rooting intensities for different sizes and different distances of *Ailanthus triphysa* for 2.5 - 5.0 mm diameter roots (S - Size, DIS - Distance)

S1- Small
S2- Medium
S3- Large
Distance 1 - 33.2cm
Distance 2 - 56.3cm
Distance 3 - 113.3cm
Distance 4 - 139cm
Distance 5 - 198.3cm
Distance 6 - 220.73cm
Distance 7 - 293.7cm
Distance 8 - 318cm
Distance 9 - 378.35cm
Distance 10 - 403.65cm
Distance 11 - 447.3cm
Distance 12 - 469.3cm

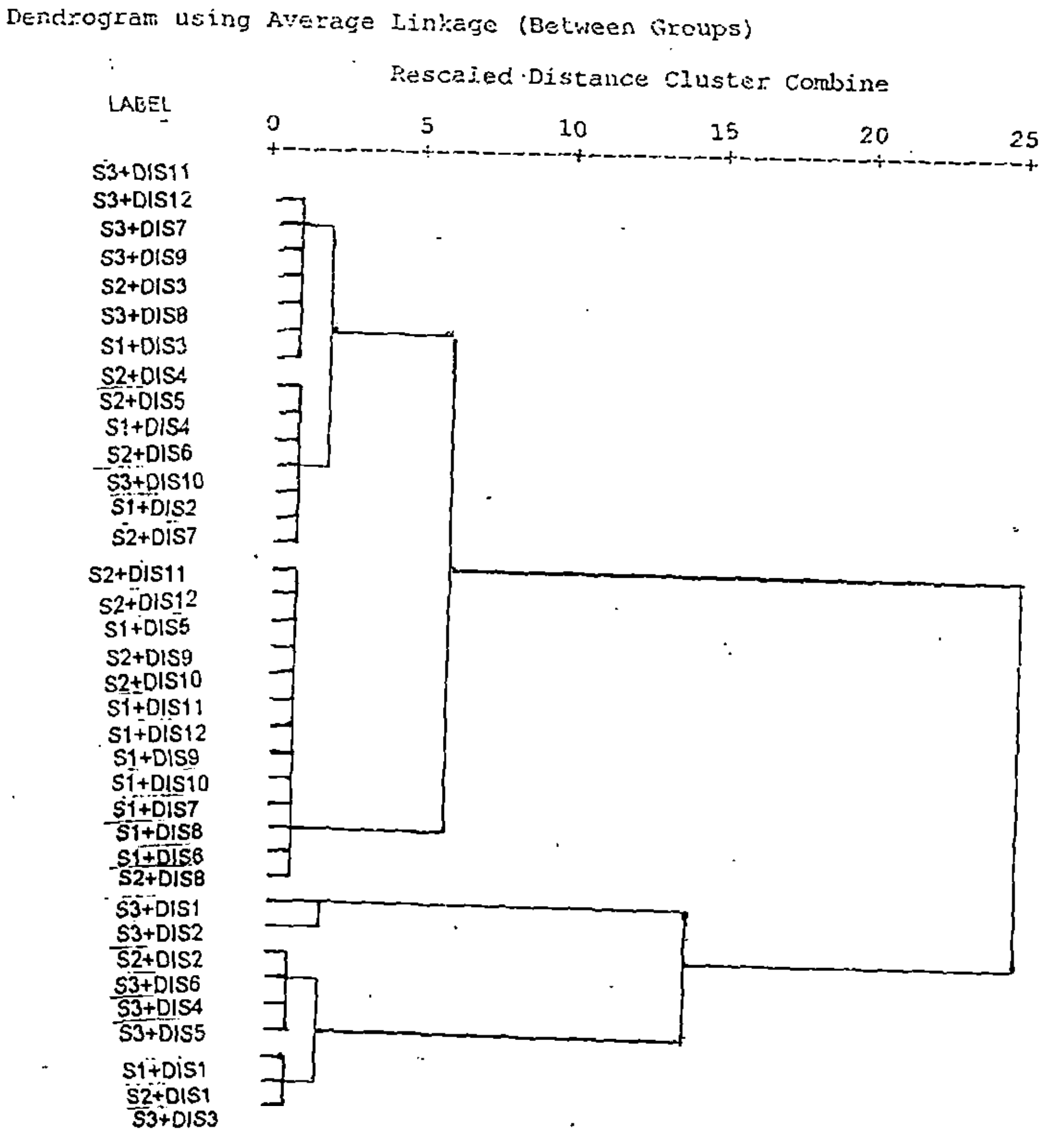


Fig. 38. Dendrogram using average linkage between groups for comparing rooting intensities for different sizes and different distances of *Ailanthus triphysa* for >5.0 mm diameter roots (S - Size, DIS - Distance)

S1- Small
S2- Medium
S3- Large
Distance 1 - 33.2cm
Distance 2 - 56.3cm
Distance 3 - 113.3cm
Distance 4 - 139cm
Distance 5 - 198.3cm
Distance 6 - 220.73cm
Distance 7 - 293.7cm
Distance 8 - 318cm
Distance 9 - 378.35cm
Distance 10 - 403.65cm
Distance 11 - 447.3cm
Distance 12 - 469.3cm

pattern is prominent. The branches developing from the horizontal roots, however, showed positropic growth and they were further branched and formed a network of roots.

4.6.5 Horizontal distribution of *Grevillea robusta* roots

Data on rooting intensity of *Grevillea robusta* at different lateral distances along the logarithmic spiral trench are shown in Figs.39-42 and Tables 24-27. Rooting intensities (all diameter roots) at a distance of 25 cm from the tree was 191, 237 and 303 m^{-2} respectively for small, medium and large size class. Total rooting intensity up to 50 cm depth at different lateral distances along the logarithmic spiral trench was regressed on distance from the tree base. There was a general decrease in rooting intensities with increasing distance from the tree base for all the tree sizes and root diameter classes (Fig.43 and Table 28). However, R^2 values were modest (0.02 to 0.66).

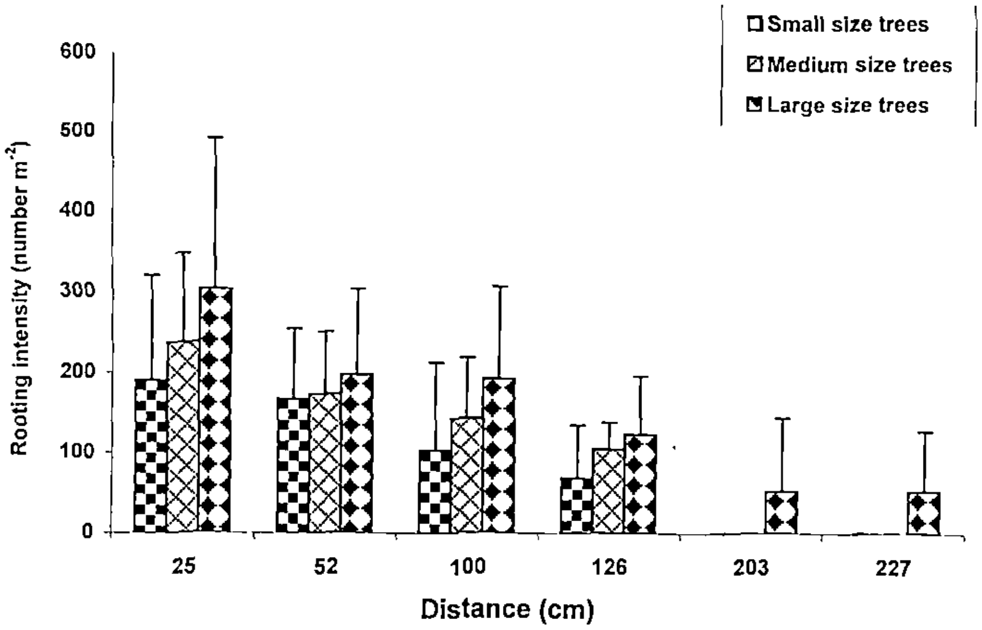
Depth wise root distribution as influenced by distance from the tree base are given in Fig.44, Tables 29a and 29b shows the mean rooting intensity in percentage. Regression equations linking distance from the base of grevillea and rooting intensity for various size categories of grevillea are presented in Table 28. All root diameter classes were similar in respect of lateral spread. Number of roots in the less than 2.5mm diameter was substantially greater than 2.5-5 mm and >5 mm classes. Overall, <2.5 mm roots constituted 61 per cent of all roots, while 2.5-5mm class roots constituted 29 per cent and >5mm root classes constituted 10 per cent of all roots.

Size of grevillea trees showed marked variablity in the horizontal root distribution pattern. Large sized trees extended roots up to 227 cm, medium and

Table 24. Rooting intensity (number m^{-2}, total of all diameter roots) of eight years old *Grevillea robusta* as influenced by tree size, distance and depth

Size class	Distance from the base of the tree(cm)											
	25		52		100		126		203		227	
	Rooting intensity(number m^{-2})											
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Small	190.66	129.8	166.66	87.39	102.66	109.8	68	66.46	0	0	0	0
Medium	237.33	110.28	173.33	76.96	142.66	75.16	104	33.12	0	0	0	0
Large	302.66	187.59	197.33	105.52	192	113.3	122.7	72.45	52	90.96	52	74.7
Depth class (cm)												
0-10	333.33	85.44	262.22	97.69	204.44	88.75	146.7	67.82	15.6	46.66	22.22	66.66
10-20	364.44	194.36	224.44	51.74	188.88	119.2	126.7	67.82	31.1	93.33	17.77	53.33
20-30	231.11	73.56	177.77	30.73	175.55	101.4	102.2	48.41	24.4	73.33	20	60
30-40	204.44	125.6	171.11	59.25	115.55	88.75	77.77	35.27	6.66	20	8.88	26.66
40-50	84.44	45.58	60	37.41	44.44	34.31	37.77	27.28	8.88	26.66	8.88	26.66

Distance 1 was located at a distance of 0.75D from the base of the tree , where D = tree diameter
Average tests of significance – MANOVA
Distance $P<0.001$
Size by distance $P<0.550$
Depth by distance $P<0.001$
Size by depth by distance $P<0.989$
SD – Standard deviation



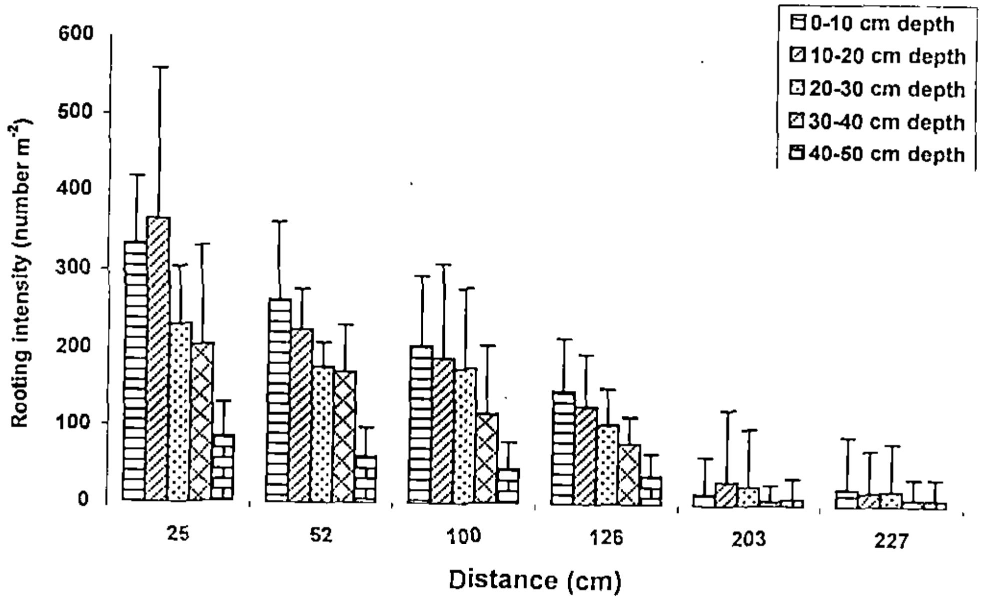
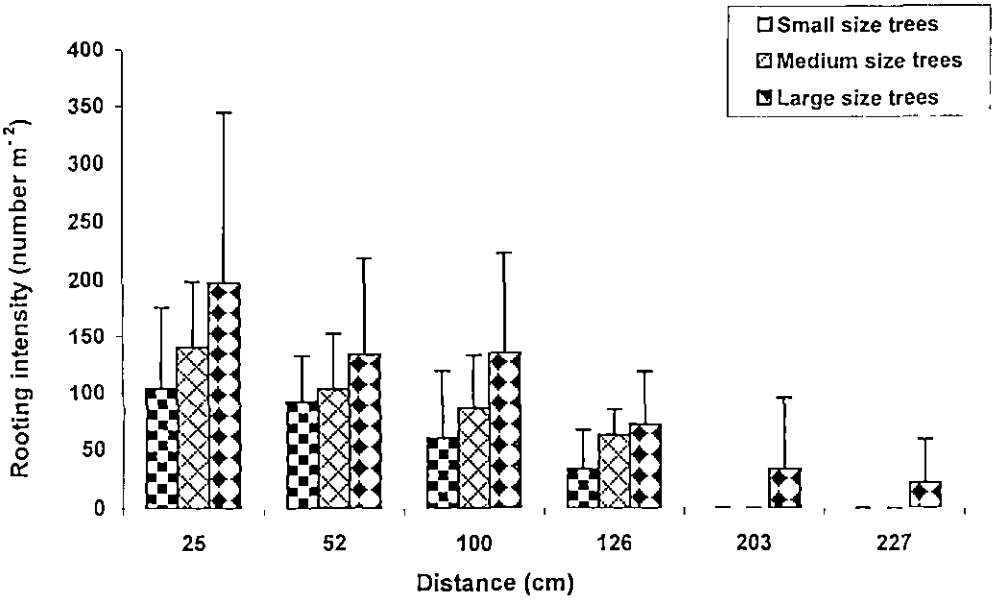


Fig. 39. Rooting intensity (number m^{-2}, total roots) of eight years old *Grevillea robusta* for various distances as influenced by tree size and depth

Table 25. Rooting intensity (number m^{-2}, <2.5 mm roots) of eight years old *Grevillea robusta* as influenced by tree size, distance and depth

Size class	Distance from the base of the tree (cm)											
	25		52		100		126		203		227	
	Rooting intensity (number m^{-2})											
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Small	104	71.8	92	40.56	60	59.03	33.33	33.52	0	0	0	0
Medium	140	58.6	102.66	49.49	86.66	46.39	62.66	22.5	0	0	0	0
Large	197.33	147	133.33	84.74	134.66	87.33	72	46.47	33.3	61.3	21.33	37.39
Depth class (cm)												
0-10	206.66	81.9	162.22	85.69	122.22	56.96	86.66	41.23	8.88	26.7	13.33	40
10-20	211.11	155	142.22	35.27	131.11	96.49	71.11	43.72	22.2	66.7	6.66	20
20-30	140	53.9	102.22	32.31	113.33	60.83	62.22	32.31	15.6	46.7	8.88	26.66
30-40	120	84.9	104.44	29.62	71.11	62.53	37.77	15.63	4.44	13.3	4.44	13.33
40-50	57.77	43	36.35	19.43	32.1	22.60	22.22	15.63	4.44	13.33	2.22	6.66

Distance 1 was located at a distance of 0.75D from the base of the tree, where D = tree diameter
Average tests of significance – MANOVA
Distance P<0.001
Size by distance P<0.176
Depth by distance P<0.001
Size by depth by distance P<0.777
SD – Standard deviation



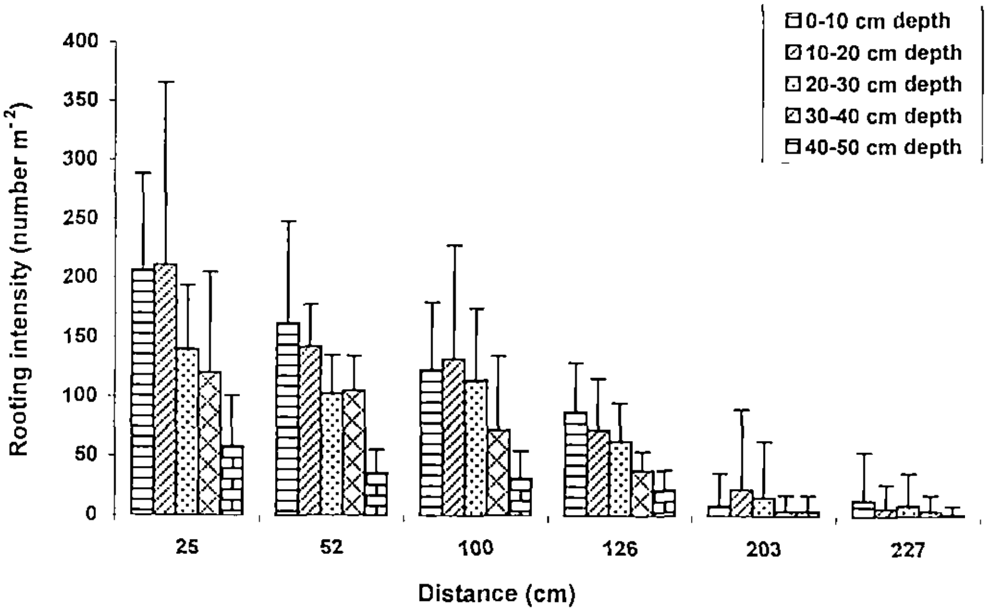
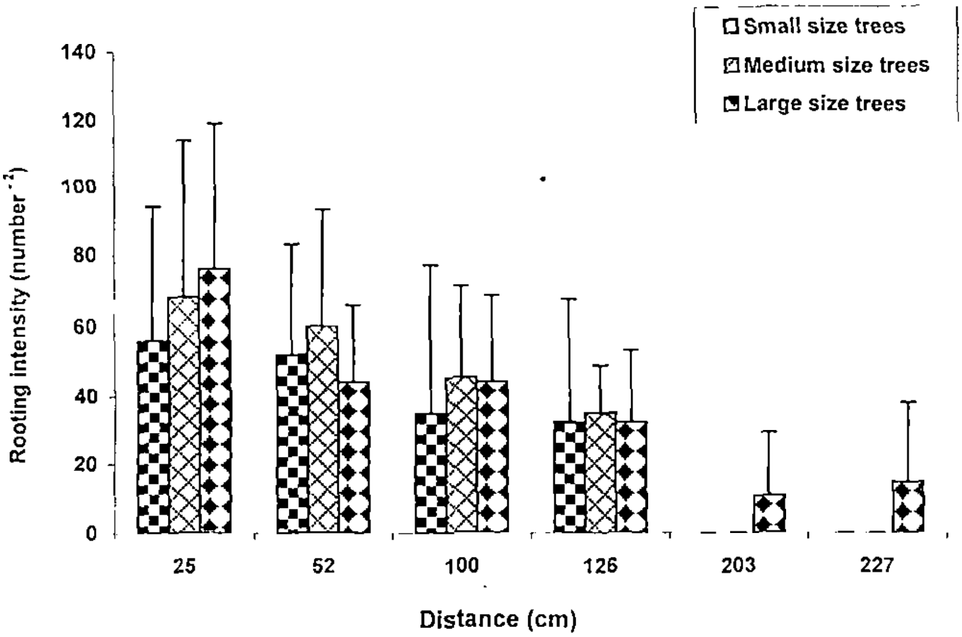


Fig. 40. Rooting intensity (number m^{-2}, <2.5 mm roots) of eight years old *Grevillea robusta* for various distances as influenced by tree size and depth

Table 26. Rooting intensity (number m^{-2}, 2.5-5mm roots) of eight years old *Grevillea robusta* as influenced by tree size, distance and depth

Size class	Distance from the base of the tree (cm)											
	25		52		100		126		203		227	
	Rooting intensity (number m^{-2})											
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Small	56	37.95	52	30.98	34.66	42.4	32	35.29	0	0	0	0
Medium	68	45.85	60	32.95	45.33	25.59	34.66	14.07	0	0	0	0
Large	76	42.89	44	21.64	44	24.14	32	21.11	10.66	18.3	14.66	23.25
Depth class (cm)												
0-10	82.22	32.32	71.11	31.79	57.77	30.73	48.88	34.8	6.66	20	6.66	20
10-20	100	45.82	57.77	27.28	51.11	24.72	37.77	21.08	2.22	6.66	6.66	20
20-30	73.33	37.41	62.22	23.33	51.11	42.55	28.88	17.63	2.22	6.66	4.44	13.33
30-40	57.77	29.05	48.88	22.6	33.33	20	33.33	22.36	2.22	6.66	2.22	6.66
40-50	20	17.32	20	10	13.33	14.14	15.55	13.33	4.44	13.33	4.44	13.33

Distance 1 was located at a distance of 0.75D from the base of the tree, where D = tree diameter
Average tests of significance – MANOVA
Distance $P<0.001$
Size by distance $P<0.242$
Depth by distance $P>0.001$
Size by depth by distance $P<0.672$
SD – Standard deviation



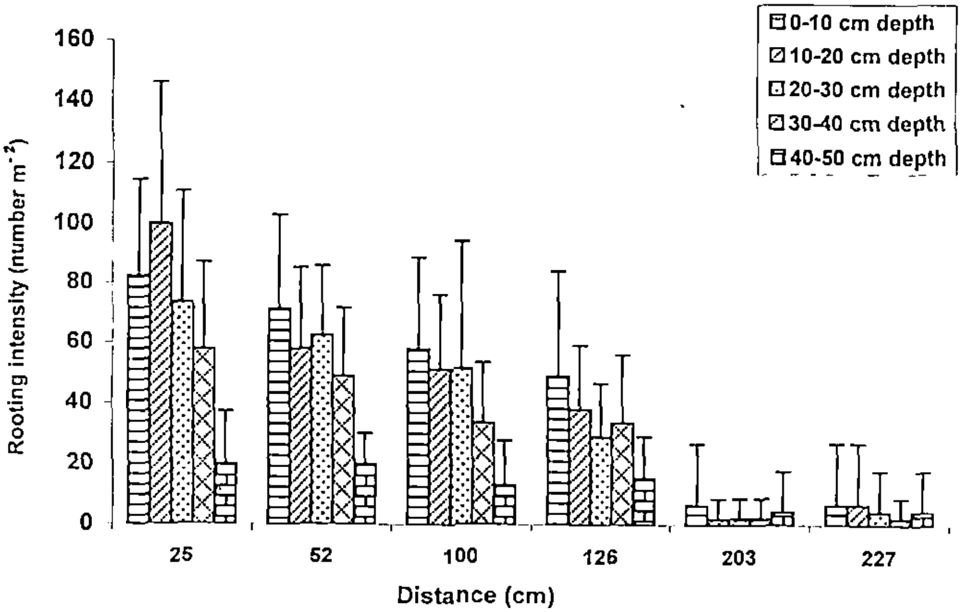
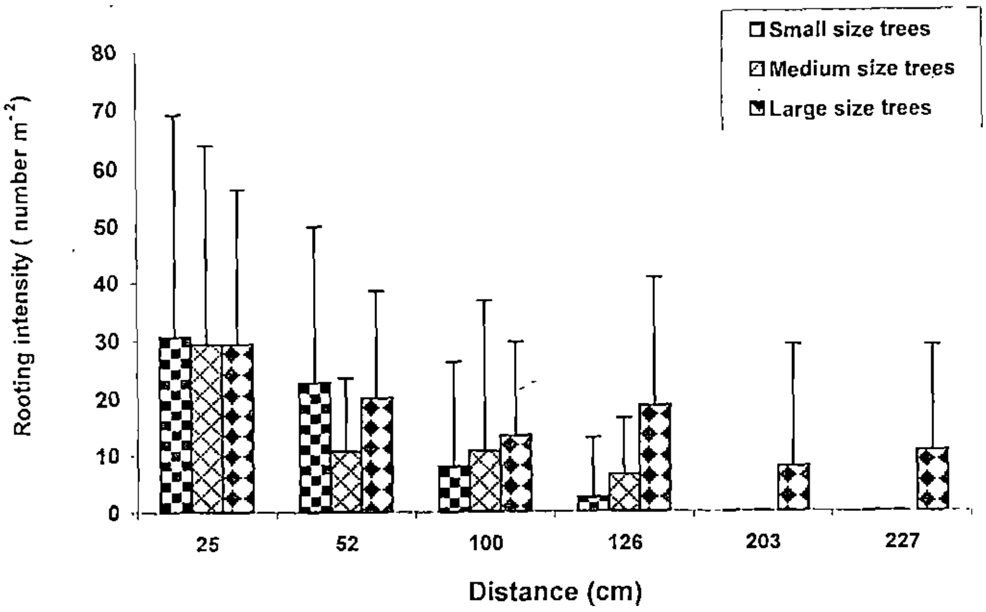


Fig. 41. Rooting intensity (number m^{-2}, 2.5 - 5.0 mm roots) of eight years old *Grevillea robusta* for various distances as influenced by tree size and depth

Table 27. Rooting intensity (number m^{-2}, >5mm roots) of eight years old *Grevillea robusta* as influenced by tree size, distance and depth

Size class	Distance from the base of the tree(cm)											
	25		52		100		126		203		227	
	Rooting intensity(number m^{-2})											
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Small	30.66	38.44	22.66	27.11	8	18.2	2.66	10.4	0	0	0	0
Medium	29.33	34.53	10.66	12.79	10.66	26.04	6.66	9.75	0	0	0	0
Large	29.33	27.11	20	18.51	13.33	16.32	18.66	22	8	21.11	10.66	18.3
Depth class (cm)												
0-10	44.44	28.28	28.88	16.66	24.44	14.14	11.11	14.5	0	0	2.22	6.66
10-20	53.33	42.42	24.44	26.03	6.66	10	17.77	23.3	6.66	20	4.44	13.33
20-30	17.77	12.01	13.33	10	11.11	20.27	11.11	20.3	6.66	20	6.66	20
30-40	26.66	28.28	17.77	27.28	11.11	20.27	6.66	10	0	0	2.22	6.66
40-50	6.66	14.14	4.44	13.33	0	0	0	0	0	0	2.22	6.66

Distance 1 was located at a distance of 0.75D from the base of the tree , where D = tree diameter
Average tests of significance – MANOVA
Distance $P<0.001$
Size by distance $P<0.621$
Depth by distance $P<0.034$
Size by depth by distance $P<0.313$
SD – Standard deviation



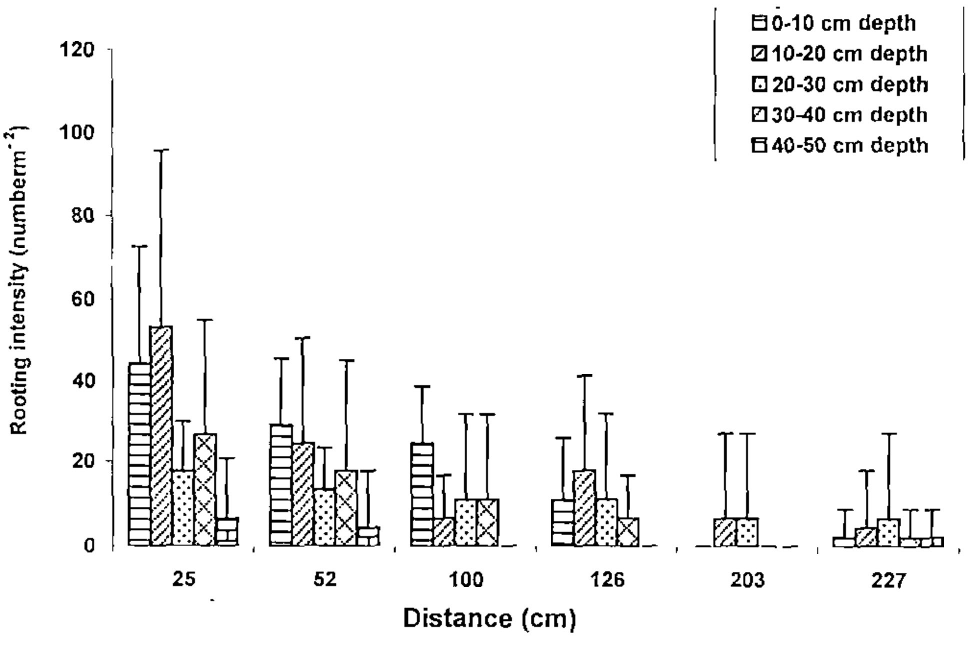


Fig. 42. Rooting intensity (number m^{-2}, >5.0 mm roots) of eight years old *Grevillea robusta* for various distances as influenced by tree size and depth

Table 28. Relationship between *Grevillea robusta* rooting intensity (number m^{-2}) and distance from the tree base

Size class	Diameter class	Equation Y= a + bx	R^2	SEE	n	p
Small	<2.5mm	569.57-2.313x	0.66	66.15	10	<0.01
	2.5-5mm	279.9-0.3054x	0.027	74.10	10	0.64
	>5mm	174.8-1.3448x	0.59	44.68	10	<0.01
Medium	<2.5mm	748.58-3.5737x	0.66	106.40	12	<0.01
	2.5-5mm	382.33-1.6907x	0.65	51.38	12	<0.01
	>5mm	141.19-0.9608x	0.43	45.98	12	0.02
Large	<2.5mm	973.52-3.0149x	0.43	243.03	14	<0.01
	2.5-5mm	333.98-0.8977x	0.40	72.65	14	<0.01
	>5mm	111.07-0.012x	0.002	46.56	14	0.86

X	Cardinal distance
Y	Rooting intensity
SEE	Standard error of estimate
R^2	Coefficient of determination
n	number of observations
p	probability

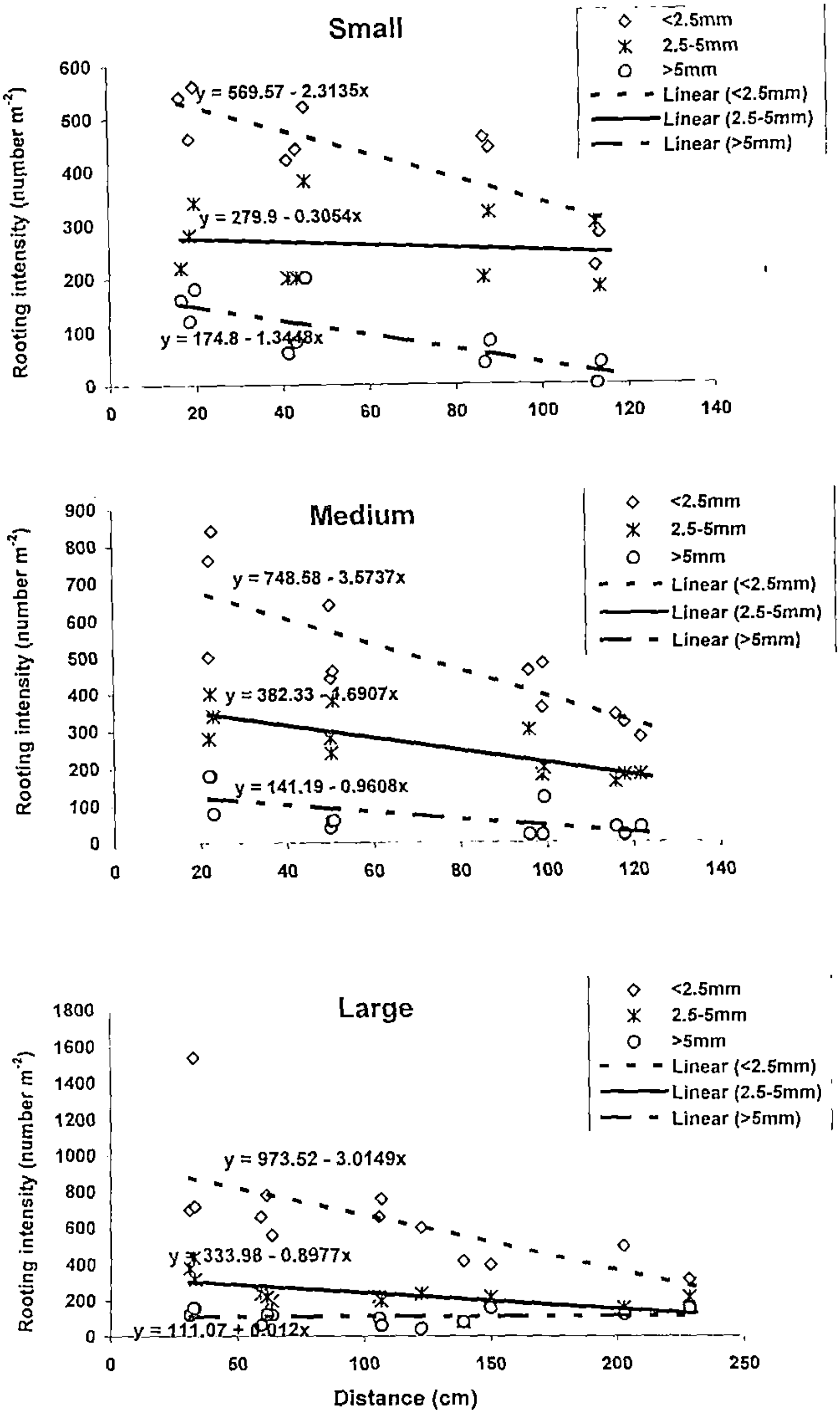


Fig . 43. *Grevillea robusta* rooting intensity as influenced by lateral distance for small, medium and large size trees small size trees had roots only up to 126 cm. Large sized trees also recorded highest rooting intensities in all the three root diameter classes. MANOVA indicated statistically significant variations for distance, tree sizes, depth and their interactions. Pillai's trace, Hotellings trace and Wilks lambda were significant (Appendix XVIII to XXI).

4.6.6 Vertical distribution of *Grevillea robusta* roots

There were significant differences in *Grevillea robusta* rooting intensities for different root classes along the profile depth (Figs. 39-42 and Tables 24-27). A comparison of data on rooting intensities (mean of all size classes) at different depths indicate that a surface depth of 0-10 cm recorded the highest root counts with nearly 28 per cent of mean root counts (Table 29a and 29b), overall it decreased in the order: 0-10 > 10-20 > 20-30 > 30-40 and 40-50 cm horizon of soil profile. This pattern was common for all the root diameter classes.

Hierarchial cluster analysis using average linkage between rooting intensities and different distances formed four clusters (Fig.45). Distance between 203 and 227 cm with fewer rooting intensities formed one cluster, distance from 52 to 100 cm with medium rooting intensity formed a second cluster and the distances of 126 cm and 25 cm formed the two remaining solitary clusters. A similar trend was observed in the case of other root size classes too (Fig.46-48).

A schematic diagram showing the root distribution pattern of *Grevillea robusta* represented in Fig.44. From the excavation study it was clear that grevillea taproots were less developed. The diatropic (syn. plagiotropic) root growth pattern is prominent. The vertical and horizontal roots were further branched and, thus formed a strong network.

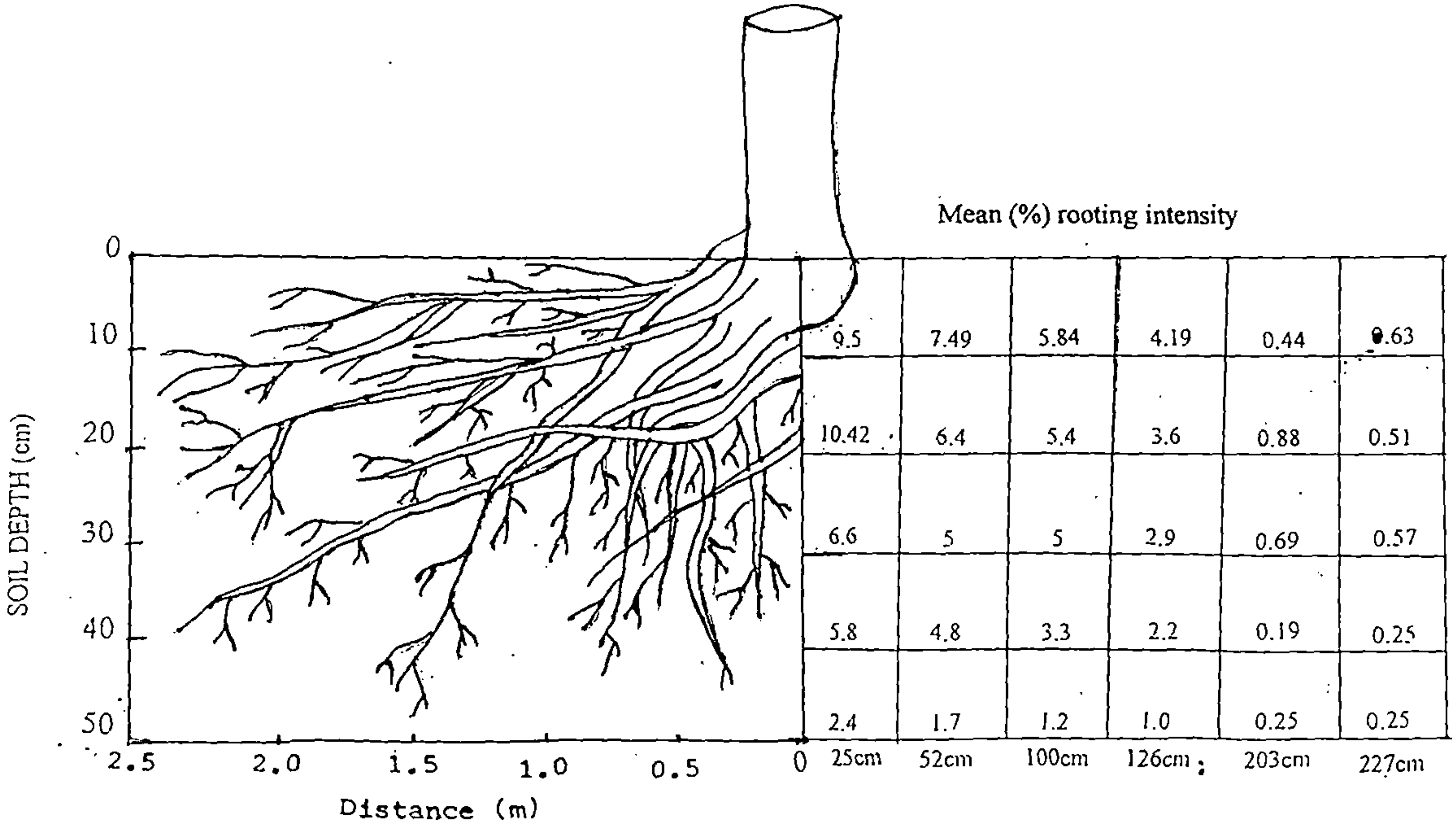
Table 29a. Mean rooting intensity (number m^{-2}) of eight years old *Grevillea robusta* at different depth intervals and lateral distances from the base of tree

Depth (cm)	Lateral distance from the base of tree (cm)					
	25	52	100	126	203	227
0-10	333.33	262.22	204.44	146.7	15.6	22.22
10-20	364.44	224.44	188.88	126.7	31.1	17.77
20-30	231.11	177.77	175.55	102.2	24.4	20.00
30-40	204.44	171.11	115.55	77.77	6.66	8.88
40-50	84.44	60.00	44.44	37.77	8.88	8.88

Table 29b. Mean rooting intensity (%) of eight years old *Grevillea robusta* at different depth intervals and lateral distances from the base of tree

Depth (cm)	Lateral distance from the base of tree (cm)					
	25	52	100	126	203	227
0-10	9.5	7.49	5.84	4.19	0.44	0.63
10-20	10.42	6.4	5.4	3.6	0.88	0.51
20-30	6.6	5	5	2.9	0.69	0.57
30-40	5.8	4.8	3.3	2.2	0.19	0.25
40-50	2.4	1.7	1.2	1.0	0.25	0.25

Fig. 44, Root distribution pattern of *Grevillea robusta*



25cm	52cm	100cm	126cm	203cm	227cm
9.5	7.49	5.84	4.19	0.44	0.63
10.42	6.4	5.4	3.6	0.88	0.51
6.6	5	5	2.9	0.69	0.57
5.8	4.8	3.3	2.2	0.19	0.25
2.4	1.7	1.2	1.0	0.25	0.25

Lateral distance from the base of tree

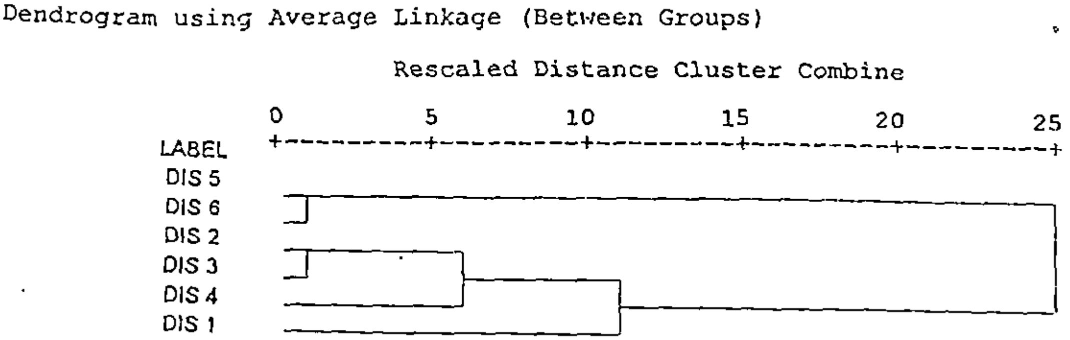


Fig. 45. Dendrogram using average linkage between groups for comparing rooting intensities at various distances of *Grevillea robusta* for total of all diameter roots (DIS - Distance)

Distance 1 - 25cm
Distance 2 - 52cm
Distance 3 - 100cm
Distance 4 - 126cm
Distance 5 - 203cm
Distance 6 - 227cm

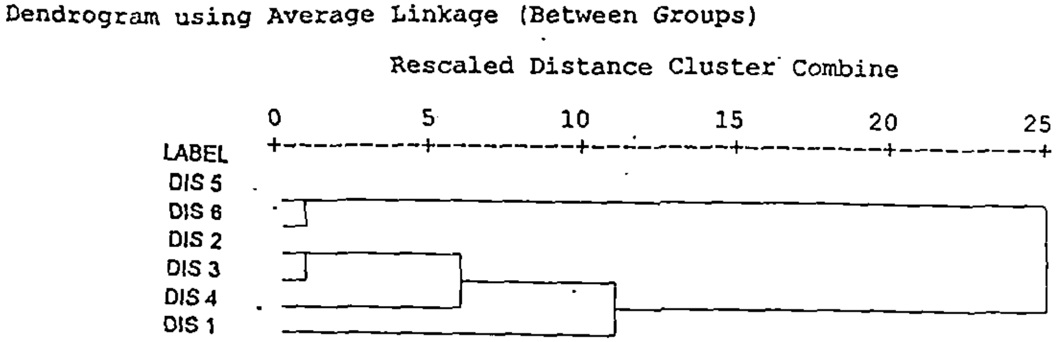


Fig. 46. Dendrogram using average linkage between groups for comparing rooting intensities at various distances of *Grevillea robusta* for <2.5 mm diameter roots (DIS - Distance)

Distance 1 - 25cm
Distance 2 - 52cm
Distance 3 - 100cm
Distance 4 - 126cm
Distance 5 - 203cm
Distance 6 - 227cm

Dendrogram using Average Linkage (Between Groups)

Rescaled Distance Cluster Combine

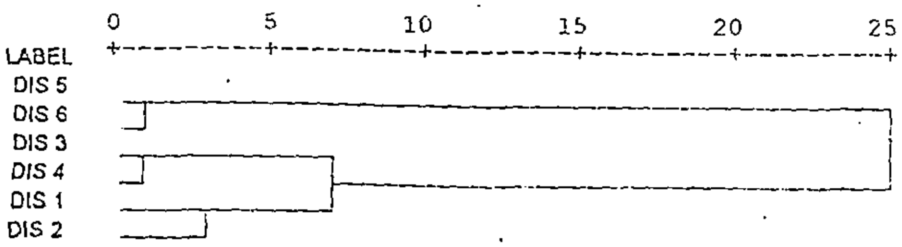


Fig. 47. Dendrogram using average linkage between groups for comparing rooting intensities at various distances of *Grevillea robusta* for 2.5 - 5.0 mm diameter roots (DIS - Distance)

Distance 1 - 25cm
Distance 2 - 52cm
Distance 3 - 100cm
Distance 4 - 126cm
Distance 5 - 203cm
Distance 6 - 227cm

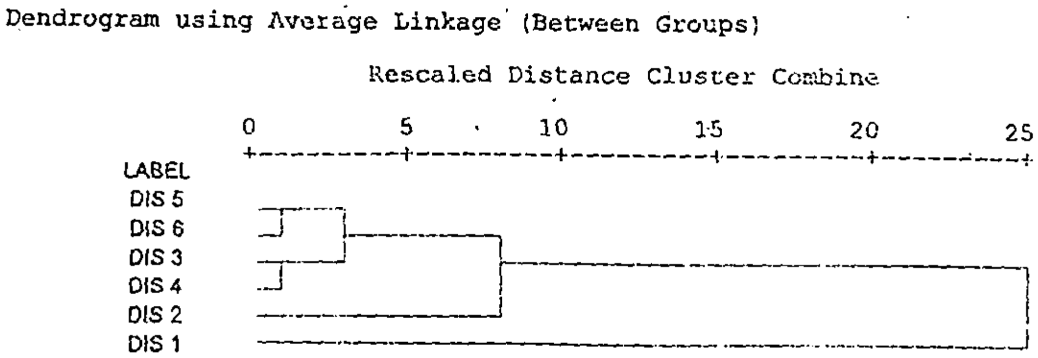


Fig. 48. Dendrogram using average linkage between groups for comparing rooting intensities at various distances of *Grevillea robusta* for >5.0 mm diameter roots (DIS - Distance)

Distance 1 - 25cm
Distance 2 - 52cm
Distance 3 - 100cm
Distance 4 - 126cm
Distance 5 - 203cm
Distance 6 - 227cm

Discussion

5. DISCUSSION

5.1 Coconut yield and productivity

Non-significant variations in the coconut yield (Table 1, Fig.8 and 9) imply that planting multipurpose trees in the interspaces of 14 years-old coconut plantations is unlikely to affect the coconut performance, till the MPTs are 8 years-old. Kumar (1997) also observed similar results till the interplanted MPTs were about 50 months of age. In general, intercropping is designed to increase income generation and land use efficiency. The present result suggest that mixing dicot trees in the coconut plantations may enhance returns to the growers without adversely affecting the main crop yield until the trees are about 8-years old. Many previous workers (Liyanage *et al.*, 1993; Nair, 1983; Nair and Sreedharan, 1986) however, have reported complementary effects of interplanted trees on coconut yield. Anilkumar and Pillai (1988) observed greater coconut yield due to intercropping clove and cocoa. Kumar (1994) also observed better yield for coconut intercropped with *Ailanthus triphysa*, as compared to sole stands. Nevertheless, such positive effects of intercropping on yield were not manifested in the present study.

Foliar nutrient concentration of 22 year-old coconut (Table 2) palms also indicate that there have been no significant reduction in the nutrient concentrations of coconut palms on account of MPT interplanting or its planting geometry. Kumar (1997) also reported similar findings when the coconut trees were 18 years of age and the same trend continued up to 23 years of palm age.

5.2 Soil properties under coconut and interplanted multipurpose trees

Although the differences between monospecific coconut and the rest were not significant, there were significant variations in soil organic carbon and available P concentrations among the MPTs. Ailanthus and grevillea showed higher organic carbon and available P levels than vateria (Table 3). Several previous workers (Anilkumar and Wahid, 1989; Wahid *et al.*, 1975; Vergara and Nair, 1985) also observed variations in the soil nutrient enrichment potentials of MPTs. Differential litterfall rates (Kumar *et al.*, 1998) may be plausible explanation in this respect. Nelliat *et al.* (1976) reported similar findings in coconut-cocoa system. They found that it was due to periodic shedding of cocoa leaves probably increased the rhizospheric microbial activity. Anilkumar (1987) suggested that an increase in organic carbon content may be due to the degeneration of coconut roots.

Block effects were significant except for organic carbon. As normal, the more fertile block showed higher NPK contents. Application of fertilizers and manures as part of the present study probably may have exerted a complementary influence in this respect.

5.3 Multipurpose tree growth

A comparison of the data on tree growth characteristics of eight-years-old multipurpose trees grown in the interspaces of coconut palms showed marked variations (Tables 4 to 7 and Figs 10 and 11). Ailanthus recorded greater height and radial growth rates. Intially, however, vateria trees showed faster height growth and mean annual increments. Mean annual increment for ailanthus height was 1.02 m yr^{-1} at 111 months after planting and that of DBH was 1.45 cm yr^{-1}. The values presently reported are higher than that of George (1993), Jamaludheen (1994) and Thomas (1996). They reported that mean annual increment for tree height were 0.66, 0.51 and 0.85 m yr^{-1} and that of DBH from 0.96, 0.51 and 1.28 cm yr^{-1} at 5, 8 and 48 months of age respectively. For vateria and grevillea mean annual height increments were 0.93 and 0.79 m yr^{-1} and DBH, 1.17 and 0.94 cm yr^{-1} respectively, at 111 months of age.

Hardwood and Getahun (1990) found that an annual increment of 2 m in height and 2 cm in dbh for grevillea are probable on good soils under favourable climates. Although for tropical soils with medium to high rainfall, they reported a height increment of one meter per annum. Present data, however, showed a lower height increment a (0.79 m yr^{-1}). Lott *et al.* (2000) observed that tree height, leaf area and biomass yield were reduced initially in an agroforestry combination. Also the effects of subcanopy performance of MPTs may be species specific, but such generalisations are impossible in the absence of monospecific MPT treatments.

Growth rates of multipurpose trees are generally dependent on genetic factors, variations in shade tolerance, soil characteristics and/or interspecific interactions between MPTs and the coconut overstorey. *Vateria* being shade tolerant comes up well as an understorey component in its natural habitat. Shading of coconut, therefore, provided a favourable environment which, inturn, stimulated vateria growth. Ailanthus being less tolerant initially showed lower growth rate. But once it reached the top canopy level, its growth rates accelerated.

Planting geometry did not exert any influence on tree growth till the trees attained eight years of age. Kumar (1997) also reported similar findings when the trees were of four years of age. Despite his suggestion to the effect that MPT growth rates may change as the tree increases in size and their requirement for site resources increases, but no such effect was evident even after eight years of age.

5.4 Tracer studies on root interactions

5.4.1 Root activity of coconut

Soil injection of ^{32}P was used to assess the nature and extent of root competition between coconut palms and neighbouring multipurpose trees. The study was carried out during the north-east monsoon season when soil moisture availability was not limiting and the extent of absorption of ^{32}P could be considered to reflect the amount of root activity (Wahid *et al.*, 1989). Therefore, root activity characterisation at this time may probably represent root interactions of the largest possible magnitude.

^{32}P was applied to the coconut palms covering its effective forage space, and absorption of radiotracer by not only the treated palm but also the neighbouring multipurpose trees were monitored through radioassay of the leaf samples of the respective species. Coconut palms treated similarly with ^{32}P but without intercrops served as controls (monoculture situation) for evaluation of relative uptake of ^{32}P by the palm in sole and mixed cropping situations.

In general, ^{32}P uptake by coconut palms decreased from 15 to 30 days after application (Table 8). However, Kumar *et al.* (1999) reported that ^{32}P absorption increased initially at 30 days and then decreased after 45 days when the coconut palms were 18 years of age and MPTs four years of age. Ashokan *et al.* (1988) also observed a decrease in ^{32}P uptake by elephant foot yam (*Amorphallus compnulatus* Blume) when it was grown in association with banana (*Musa* (AAB) 'Mysore') and/or cassava (*Manihot esculanta* Crantz).Temporal variations in ^{32}P uptake pattern may reflect changes in root activities in response to changes in the physical environment.

Interplanting of multipurpose trees did not seem to affect the recovery of ^{32}P by coconut. Implicit in this is the non-competitive root interactions between coconut palms and the interplanted multipurpose trees. Kumar *et al.* (1999) observed similar results when the multipurpose trees were four years of age. Apparently this trend continued up to 8 years of MPT age. Planting geometry and species x planting geometry interactions were also not significant.

5.4.2 ^{32}P recovery by coconut along a soil fertility gradient

Despite significant block-wise variations in soil fertility (Table 3) and coconut productivity (Table 1), differences in foliar ^{32}P recovery of coconut palms along the soil fertility gradient were not apparent (Table 8). Although ^{32}P recovery was more at the higher end of the fertility gradient, differences were not statistically significant. Soil fertility variations, therefore, are unlikely to influence the pattern of coconut ^{32}P uptake pattern and thus the magnitude of root competition.

Competition is the 'condition where two organisms or two species, draw upon a common pool of resource' (Grubb, 1992), and variations in the intensities of above and below ground competition associated with soil fertility may underlie changes in community structure of natural vegetation. However, two contrasting hypotheses blur the picture concerning the nature and magnitude of competitive interactions along a fertility gradient (Wilson and Tilman, 1993). The first is that competition may be most intensive in productive (nutrient-rich soils) habitats because such habitats support high growth rates and large amount of biomass that result in pre-emption of space and light. In this view, both above and below ground competition may increase with soil fertility (Campbell *et al.*, 1991; Pysek and Leps, 1991). In contrast, Newman (1973) noted that habitats with low soil resource availability (nutrient-poor soils) may have low standing crop, and root competition in such habitats may be intense.

Although many workers (Grime, 1973; Tilman, 1982; Wilson and Tilman, 1991, 1993; Grubb, 1994) have addressed the question of whether the effects of root competition are more severe on nutrient-rich or nutrient-poor soils, this paradox still remains unresolved. In a study of three temperate grasses, Wilson and Tilman (1991) showed that the intensity of competition, measured as the suppression of transplants by neighbours did not vary significantly with nitrogen availability. Such a result was found by Burschel and Schmalz (1965) for seedlings of *Fagus sylvatica* in an old stand of that species. Most previous studies, however, represent the natural ecosystems (Grubb, 1994; Wilson and Tilman, 1991). Reports on the nature and magnitude of interspecific competition in managed mixed species systems in general are scarce. Therefore, in the present study below ground competition in mixed species systems involving coconut and multipurpose trees along a fertility gradient was evaluated using ^{32}P soil injection technique. It has been amply demonstrated that this technique is ideally suited for characterising interspecific competition in mixed species systems involving woody perennials (George *et al.*, 1996; Jamaludheen *et al.*, 1997; Thomas *et al.*, 1998; Kumar *et al.*, 1999; Divakara *et al.*, 2001).

The results suggest a general non-dependence of below ground competition, measured as ^{32}P uptake, on soil fertility variations caused by adding moderate quantities of nutrients (89, 57 and 214 kg N, P_2O_5 and K_2O ha^{-1} in case of good management block and 61, 30 and 121 kg N,P_2O_5 and K_2O ha^{-1} for average management block). Thus, it can not be deduced that root competition is more on nutrient-rich than on nutrient-poor soils. While the soil fertility variations control the potential productivity, it has perhaps little or no influence on the magnitude of interspecific root competition in such systems. Furthermore, root competition in managed land use systems is largely controlled by species attributes, especially the density and root architecture. The inter-dependence of below ground and above ground competitive interactions, however, may compound this notion.

5.4.3 ^{32}P recovery by neighbouring multipurpose trees

Multipurpose trees interplanted in the coconut garden absorbed considerable amounts of the radio-label applied in the coconut basins (Table 9 to 11 and Figs. 12 to 14). In the case of vateria and ailanthus, ^{32}P absorption declined linearly with increasing distance from the coconut palms, but *Grevillea robusta* showed a slightly different trend. ^{32}P uptake by multipurpose trees, thus signifies root interference between multipurpose trees and coconut. Excavation studies indicate that the MPT root spread ranged from 163 to 469 cm laterally (Tables 12, 18 and 24). From the root spread data it can be inferred that the MPT root spread was enough to stray into the nearby coconut basin and capture site resources and/or cross nutrition (Kumar *et al,* 1999).

As regards to root competition in mixed species systems, Trenbath (1976) observed that the advantages in some mixed cropping situations is due to difference in rooting patterns, which occur due to mutual avoidance of different root systems. However, Clements *et al.* (1929) observed in mixed farming systems roots of several species frequently intermingle and also in intercropping systems, roots of two or more species share same space and compete for moisture and nutrients. The present study shows that vateria and ailanthus showed such competitive effects when intercropped with coconut. This may be because of the surface concentration of their feeder roots. In this context, many workers (Sankar *et al.*, 1988; Ruhigwa *et al.*, 1992; Jamaludheen *et al.*, 1997; Thomas *et al.*, 1998 and Divakara *et al.*, 2001) found that concentration of feeder roots in the surface horizon of the soil profile.

However, the uptake of ^{32}P applied in the coconut basins by the MPTS did not seem to have influenced coconut ^{32}P recovery. This, in turn, suggests that the higher rooting intensity of the interplanted MPTs may have favoured an overall higher nutrient recovery in the coconut-MPT system. Such favourable effects of intercropping are well recognised (Vandermeer, 1989).

5.5 Root distribution pattern of *Vateria indica*

The data on vateria root distribution shows that the roots extended upto a distance of 163 cm (Tables 12 to 15, Figs.18 to 21). As expected, large size trees showed greater root spread. Many previous workers have observed that lateral spread of tree root system is a function of the crown spread (Tomlinson *et al.*, 1998; Divakara *et al.*, 2001; Kumar and Divakara, 2001). Present results generally conform to the findings from these studies.

Vertical distribution of vateria is similar to that of other tree species found in the locality (Divakara *et el.*, 2001; Jamaludheen *et el.*, 1997). Rooting intensity was highest in 0-10 cm soil horizon with 25 per cent of the root counts. Most of the roots were confined to top 50 cm of soil as reported previously (George *et al.*, 1996; Jamaludheen *et al.*, 1997; Kumara *et al.*, 1999). Many workers from elsewhere too have observed similar findings. For instance, Schroth and Zech (1995) in the humid West Africa found maximum root of nine legume in the upper 10 cm layer. Lehman *et al.* (1998), also observed consistently higher root length density in the top soil at 0-15 cm depth for *Acacia saligna* stands in northern Kenya. He postulated that in mixed species systems involving annuals and woody perennials, tree root systems expanded more into subsoil and got confined below the tree canopy.

5.5.1 Root architecture of vateria

Vateria possesses a prominent tap root system. Root systems in the present study were only partially excavated on one side with the assumption that it mirrors the opposite side. Both diatropic and positropic roots were prominent. Initial root development appears to be under genetic control, although modified by soil and plant factors (Hermann, 1977; Sutton, 1980). Root growth is also dependent on nutrient and soil moisture availability. Low moisture availability and/or presence of a "root floor" such as a hard pan (Oldeman, 1990) tend to impede root spread/deeper root penetration, thus blocking the architectural development of whole root systems. In vateria, many of the horizontal roots were oriented vertically downward. Presence of coconut roots in the surface layers of the soil profile (Anilkumar and Wahid, 1988) may have favoured this deep root penetration. Similar observations in the case of mixed herbaceous crop production system has been reported by Schroth (1995). Deep rooted plants make available subsoil resources to the associated crops with shallower root systems through "nutrient pumping" (Emerman and Dawson, 1996; Schroth, 1999).

5.6 Root distribution pattern of *Ailanthus triphysa*

The data show that *Ailanthus triphysa* roots extended upto a distance of 469 cm (Tables 18 to 21 and Figs.25 to 28); implying a much larger horizontal root spread than the two other focal species in this study. Tree size appear to be a major determinant. Larger tees showed greater lateral spread, followed by medium sized trees and smaller trees.

Vertical distribution of ailanthus roots is similar to that of vateria and that fewer roots were present below 50 cm soil depth. Also rooting intensity was highest in 0-10 cm soil horizon with 28 per cent of the root counts. In Douglas fir also, most root activity was found in the 20 cm layer depending on soil aeration and fertility (Fogel and Hunt, 1979; Hermann, 1977).

Results of hierarchial cluster analysis linking rooting intensities and distances (Figs.31-34) formed three clusters, cluster segregation was mainly based on increasing distance from the tree base (Table 22, Fig.29). Tree size x distance interaction (Figs.35-38) was significant. Tree size exerted a strong control over rooting intensity at different lateral distances. Larger trees obviously had higher rooting intensities at all distances.

5.6.1 Root architecture of *Ailanthus triphysa*

Ailanthus triphysa has a well ramified root system, with a less prominent tap root (Fig.30) and a prominent diatropic root growth pattern. The branches developing from horizontal roots showed positropic growth. Furthermore, root spread was strongly related to tree size. This has important implications in the context of intercropping, suggesting greater competitive interactions at close proximity of larger trees. It can be deduced from (Fig.30) that proximity of other species/individuals favours competitive downward displacement of *Ailanthus triphysa* roots.

5.7 Root distribution pattern of *Grevillea robusta*

For *Grevillea robusta* also, (Tables 24 to 27, Figs.39-42) the size appears to be determinent of root spread. Larger trees showed greater spread of roots up to 227 cm while medium and small sized trees root spread was 126 cm.

Vertical root distribution was similar to that of vateria. Here also, 0-10 cm soil horizon recorded highest rooting intensity with 28 per cent of the root counts. . Results of the hierarchial cluster analysis show that distances had a profound influence on rooting intensities, with most roots present near base of the tree and declining with increasing distance (Fig.45-48).

From the excavation studies it was clear that the grevillea tap roots are less developed (Fig.44) and the diatropic root growth pattern is prominent. The vertical and horizontal roots were branched and thus formed a strong network.

5.8 Implications of interplanting multipurpose trees in coconut plantations

As a general rule, MPT intercropping in coconut based production systems in the tropics could only be acceptable, if the coconut yields were little affected and that the MPTs formed a valuable system component. The present results show no determental effect of MPT interplanting on coconut yield over a wide range of soil fertility/plantation management regimes studied. Being 23 years old, the palm crowns are held higher than associated MPT crowns, This probably explains the non-interferance of MPTs on coconut productivity.

Multiple cropping and/or mixed farming practices are also expected to increase the productivity of the root (wilt) affected coconut palms (Amma *et al.*, 1983). This is particularly significant in the Kerala context, where the root (wilt) disease has been prevalent in about 4,10,000 ha of the state causing an annual estimated loss of 968 million nuts (Bavappa *et al.*, 1986). The results of this study thus indicate that integrated land use systems involving MPTs and plantation crops are ideally suited for improved resource capture and productivity, especially in senile/disease infested coconut stands.

The prospects of long-term solutions to intercropping questions, as opposed to the present medium term trends, can however, be obtained only from further research; as changing interactions between MPTs are, likely to favour the former, as the system matures. The MPTs are, thus, likely to affect coconut productivity eventually. That is, the current pattern of resource use changes with the development of larger crowns and their emergence above the palm crowns; below ground interactions are also important. Presently, however, the interplanted MPTs exert only a modest influence on ^{32}P absorption by coconut. Given that coconut productivity should not be adversely affected, the adoption of MPTs that encourage complementarity with coconut is critical. Thus, the extent to which coconut-MPT interactions influence the economic potential of the system may depend on the choice of species; and may imply a trade-off between maximisation of coconut productivity and overall system productivity/economic returns.

Introduction of MPTs into the coconut production system not only lowers the understorey PPFD levels, but also reduces the planting density of understorey crops (Kumar, 1997). The extent of such reduction, however, may depend on MPT planting geometry. A concentrated planting system such as the double row system may, therefore, be preferable. Ideally, MPT planting density in agroforestry systems should be manipulated to maximise productivity and economic returns. However, data are not available on the influence of differing MPT densities in the coconut interspaces on the productivity of various system components. Hence more research is needed to optimise MPT densities and/or their thinning schedules in the coconut-based production systems. Regular pruning encourages the proliferation of fine roots near the soil surface, decreasing spatial niche separation between tree and crop roots and hence the potential for lack of complementarity in the use of below ground resources (Van Noordwijk and Purnomosidhi, 1995). Spatial isolation of the MPT root systems through periodic trenching may reduce competition for below ground resources in mixed species systems involving woody perennials (Divakara *et al.*, 2001). On a final note, species mixtures such as coconut + MPTs affirm spatial complementarity in resource use, as the components occupy different niches.

Summary

6. SUMMARY

A field experiment involving coconut (*Cocos nucifera* L.) and three multipurpose trees (*Ailanthus triphysa* (Dennst.) Alston., *Grevillea robusta* A. Cunn and *Vateria indica* L.) was conducted at the Instructional Farm, Vellanikkara from 1992 onwards. Broad objectives of the study included evaluating coconut productivity as affected by the interplanted multipurpose tree and assessing the performance of selected multipurpose trees in coconut based agrisilviculture systems. To assess the magnitude of root competition between coconut and multipurpose tree species along a soil fertility gradient, and to characterize the root distribution pattern of multipurpose trees, another experiment was super imposed on the pre-existing trial plots. Root competition between the coconut palms and interplanted MPTs was evaluated using the ^{32}P soil injection technique and root distribution pattern of MPTs was characterised by the logarthmic spiral trench method.

Sailent results are as follows:

1. Interplanted multipurpose trees in the coconut plantation did not affect the nut yield of coconut until the trees attained eight years of age.
2. Multipurpose tree species showed marked variations in soil organic carbon and available P concentrations. Ailanthus and grevillea plots in general had higher organic carbon and available P level than vateria, which may be due to the increased litter addition of the former.

3. Vateria, ailanthus and grevillea showed marked variability in their growth patterns. Ailanthus recorded highest tree height and basal stem diameter, followed by vateria and grevillea.
4. ^{32}P uptake by coconut was not adversely affected by multipurpose trees as signified by non-significant block effects, planting geometry and species x planting geometry interactions.
5. ^{32}P recovery by neighbouring multipurpose trees showed that the tree roots extended considerably into the coconut rhizosphere. However, it did not cause any significant alterations in the ^{32}P uptake pattern of coconuts even though the multipurpose trees absorbed substantial quantities of the applied ^{32}P.
6. Excavation studies indicate that most roots of the multipurpose tree are concentrated near to the tree base. Furthermore, rooting intensity declined linearly with distance. Tree size was a cardinal determinant of the MPT root distribution pattern; large sized trees showed greater root spread compared to medium and small trees. In vateria, large sized trees extended roots up to a distance of 163 cm, for ailanthus, the maximum root spread was 469 cm and for grevillea it was 227 cm.
7. Vertical distribution of roots implies that more roots are found in the 0-10 cm soil horizon with really 25 per cent of the vateria roots and 28 per cent of ailanthus and grevillea roots.
8. Studies on root architecture indicate that vateria and ailanthus have well developed and a ramified root systems. Grevillea, however, had a less

developed tap root system. Nevertheless roots were further branched and formed a strong network.

9. MPTs exerted only a modest influence on ^{32}P absorption by coconut. Implicit in this is the non-interfering nature of the MPTs. Furthermore, integrated land use systems involving MPTs and coconut are ideally suited for improved resource capture and overall increased system productivity.

References

REFERENCES

Abraham, K. 1993. Light infilteration studies in coconut-based homestead situations. M.Sc. thesis, College of Horticulture, Kerala Agricultural University, Thrissur, Kerala, India pp.60-61

Amma, P.G.K., Cecil, R.S., Pillai, N.G., Mathew, A.S. and Nambiar, P.T.N. 1983. Performance of Dwarf x Tall hybrid coconut in root (wilt) affected areas of Kerala under different fertiliser levels. Proc. PLACROSYM-V. pp.405-410. Central Plantation Crops Research Institute, Kasaragod, Kerala, India

Andrews, R.E. and Newman, E.I. 1970. Root density and competition for nutrients. *Oecol. Plant.* 5:319-334

Anilkumar, K.S. 1987. Chemistry of coconut rhizosphere. M.Sc.(Ag.) thesis, Kerala Agricultural University, Thrissur, Kerala, India pp.60-65

Anilkumar, K.S. and Wahid, P.A. 1988. Root activity pattern of coconut palm. *Oleagineux* **43**:337-342

Anilkumar, A.S. and Pillai, S.J. 1988. Prospects of mixed cropping cocoa and clove with coconuts. *Indian Cocoa Arecanut Spices J.* **12**(2):36-37

Anilkumar, K.S. and Wahid, P.A. 1989. Impact of long term inorganic fertilization on soil nutrient availability and nutrition of coconut palm. *Oleagineux* **44**(b):281-284

Arachchi, L.P.V. and Liyanage, M. des. 1998. Soil physical conditions and root growth in coconut plantations interplanted with nitrogen fixing trees in Sri Lanka. *Agrofor. Syst.* **39**:305-318

Ashokan, P.K., Wahid, P.A. and Sreedharan, C. 1988. Relative uptake of ^{32}P by cassava, banana, elephant foot yam and groundnut in intercropping systems. *Pl. Soil* **109**:23-30

Asia Pacific Coconut Community (APCC). 1999. APCC Statistical Year Book, APCC Publications, Jakarta, Indonesia p.1 and 75

Austin, M.P. 1986. The theoretical basis of vegetation science. Trends Ecol. Evolution **1**:161-164

Bai, E.K.L. and Nair, R.V. 1982. Shade response of some common rainfed intercrops. Proc. 5th Annual Symp. On Plantation Crops. Indian Society of Plantation Crops pp.394-401

Balakrishnamurti, T.S. 1977. Studies on root activity of coconut using radioactive phosphorus. International Symposium on Improving Crop and Animal Productivity by Nuclear and Allied Techniques. Indian Agricultural Research Institute, New Delhi. *Abstract* pp.63-64

Barley, K.P. 1970. The configuration of root system in relation to nutrient uptake. *Adv. Agron.* **22**:159-210

Bavappa, K.V.A., Jayasankar, N.P., Radha, K. and Rethinam, P. 1986. Coconut root (wilt) disease - Present Status of Research and Management. Tech. Bull. No.14, Central Plantation Crops Research Institute, Kasaragod, Kerala, India p.10

Bertness, M.D. 1991. Zonation of spartina patens and spartina alterniflora in a New England Salt marsh. *Ecology* **72**:138-148

Bohm, W. 1979. Methods of Studying Root Systems. Springer-Verlag, Berlin p.188

Bojappa, K.M. and Singh, R.N. 1974. Root activity of mango by radiotracer technique using ^{32}P. *Indian J. agric. Sci.* **44**:175-180

Bray, R.H. and Kurtz, L.T. 1945. Determination of total organic and available forms of phosphorus in soils. *Soil Sci.* **59**:39-45

Bowen, J.E. 1973. Kinetics of Zn absorption by excised roots of two sugarcane clones. *Pl. Soil* **39**:125-129

*Burschel, P. and Schmalz, J. 1965. Untersuchungen uber die Bedeutung von Unkrautern and Wurzelkonkurrenz fur junge Buche. Forstwiss. Cbl. **84**:210-264

Callaghan, T.V. 1988. Physiological and demographic implications of modular construction in cold environments. In A.J.Davy, M.J. Hutchings and A.R.Watkinson, editors. Plant population ecology, Blackwell Scientific, Oxford, England pp.111-135

Campbell, B.D., Grime, J.P., Mackey, J.M.L. and Jalili, A. 1991. The quest for a mechanistic understanding of resource competition in plant communities: the role of experiments. *Funct. Ecol.* **5**:241-253

*Clements, F.E., Weaver, J.E. and Hanson, H. 1929. Plant Competition: An analysis of community function. Carnegie. Inst. Washington, Publication No.398, USA pp.45-48

Coker, E.G. 1959. Root development of apple trees in grass and clean cultivation. *J. Hortic. Sci.* **34**:111-121

Coley, P.D. 1987. Interspecific variation in plant anti- herbivore properties: the role of habitat quality and rate of disturbance. *New Phytologist* **106**(Supplement):251-263

Dagar, J.C. and Kumar, V. 1992. Agroforestry in Bay Island. *Indian For.* **118**:411-415

Dhyani, S.K., Narain, P. and Singh, R.K. 1990. Studies on the root distribution of five multipurpose tree species in Doon Valley, India. *Agrofor. Syst.* **12**:149-161

Divakara, B.N., Kumar, B.M., Balachandran, P.V. and Kamalam, N.V. 2001. Bamboo hedgerow systems in Kerala India: Root distribution and competition with trees for phosphorus. *Agrofor. Syst.* **51**(3):189-200

Emerman, S.H. and Dawson, T.E. 1996. Hydraulic lift and its influence on the water content of the rhizosphere: an example from sugar maple, Acersaccharum. *Oecologia.* **108**, 273-278

Everitt, S. 1974. Cluster Analysis. Heineman Educational, London, UK pp.78-85

Fogel, R. and Hunt, G. 1979. Fungal and arboreal biomass in western oregon Douglas-fir ecosystem: Distribution patterns and turn over. *Can. J. For. Res.* **9**:245-256

George, S.J. 1993. Biomass production and resource partitioning in silvi-pastural systems. M.Sc.(For.) thesis, Kerala Agricultural University, Thrissur, Kerala, India pp.136-139

George, S.J., Kumar, B.M., Wahid, P.A. and Kamalam, N.V. 1996. Root competition for phosphorus between the tree and herbaceous components of silvopastoral systems in Kerala, India. *Pl. Soil* **179**:189-196

Ghosh, S.P., Mohankumar, B., Kabeerathumma, S. and Nair, G.M. 1989. Prouctivity, soil fertility and soil erosion under cassava based agroforestry systems. *Agrofor. Syst.* **8**:67-82

Gillepsie, A.R. 1989. Modelling nutrient flux and interspecies root competition in agroforestry inter plantings. *Agrofor. Syst.* **8**:257-265

Government of Kerala (GOK). 2000. Data Book on Agriculture, Agriculture division, State Planning Board pp.87-88

Grime, J.P. 1973. Competitive exclusion in herbaceous vegetation. *Nature* **242**:344-347

Grime, J.P. 1979. Plant strategies and vegetation processes. John Wiley and Sons, Chichester, England pp.8-9

Grubb, P.J. 1985. Plant populations and vegetation in relation to habitat disturbance and competition: Problems of generalisation, J.White (ed.). The Population Structure of Vegetation. Dr.W.Junk, The Hague, The Netherlands pp.595-621

Grubb, P.J. 1992. A positive distrust in simplicity: lessons from plant defences and from competition among plants and among animals. *J. Ecol.* **57**:175-212

Grubb, P.J. 1994. Root competition in soils of different fertility: a paradox resolved? *Phytocoenologia* **14**:495-505

Hardwood, E.C. and Getahun, A. 1990. *Grevillea robusta* - Australian tree finds success in Africa. *Agrofor. Today* **2**(1):8-10

Harper, J.L. 1961. Approaches to study plant competition. *Symp. Soc. Exp. Biol.* **15**:1-39

Hermann, R.K. 1977. Growth and production of tree roots: A review. In the Belowground Ecosystem: A Synthesis of Plant-Associated Processes. Marshal, J.K. (ed.), Range. Sci. Dep. Sci. Ser. No.26, Colorado State Univ., Ft. Collins, Co, pp.7-28

*Huguet, J.G. 1973. Nouvelle me'thods d'etude de l'enracment des vegetaux pe'rennes a'partir d'une tranche'e spirale. *Ann. Agron.* **24**:707-731

Huston, M.A. 1979. A general hypothesis of species diversity. American Naturalist **113**:81-101

Huxley, P.A. 1982. Woody plants and land use. In: The Use of Nuclear Techniques in Improving Fertilizer and Water Management Practices for Tree Crops. Proceedings of the Consultants Meeting, IAEA, Vienna. pp.9-24

IAEA, 1975. Root Activity Patterns of Some Tree Crops. Tech. Rep. Series, International Atomic Energy Agency, Vienna. **170**:154

Inostrosa, S.I. and Fournier, O.L.A. 1982. Efecto alelopatico de *Gliricidia sepium* (Jacq.) Steud (madero negro). *Rev. Biol. Trop.* **30**:35-39

Jackson, M.L. 1958. Soil Chemical Analysis. Prentice Hall of India (Pvt.) Ltd., New Delhi p.498

Jamaludheen, V., Kumar, B.M., Wahid, P.A. and Kamalam 1997. Root distbution pattern of the wild jack tree (*Artocarpus hirsutus* Lamk.) as studied by ^{32}P soil injection method. *Agrofor. Syst.* **35**:329-336

Jamaludheen, V. 1994. Biomass production and root distribution pattern of selected fast growing multipurpose tree species. M.Sc.(For.) thesis, Kerala Agricultural University, Thrissur, Kerala, India p.109

Jonsson, K., Fidjeland, L., Mashembe, J.A. and Hogberg, P. 1988. The vertical distribution of fine roots of five tree species and maize in Morogoro, Tanzania. *Agrofor. Syst.* **6**:63-69

KAU, 1996. Package of Practices Recommendations - Crops 1996. Kerala Agricultural University, Thrissur, Kerala, India pp.211-213

Keddy, P.A. 1989. Competition. Chapman and Hall. London, England pp.70-75

Kessler, J.J. and Breman, H. 1991. The potential of agroforestry to increase primary production in Sahelian and Sudanian zones of West Africa. *Agrofor. Syst.* **13**:41-62

Kidd, C.V. and Pimental, D. 1992. Integrated resource management, In: Agroforestry for Development, Academic Press, San Diego, USA p.233

Kolesnikov, V.A. 1971. The Root System of Fruit Plants. Mir Publishers, Moscow p.269

Kumar, B.M. 1994. Agroforestry- Principles and practices. Thampan, P.K. (ed.), Trees and Tree Farming, Peekay Tree Research Foundation, Cochin, India pp.25-64

Kumar, B.M. 1999. Agroforestry in the Indian Tropics. *Indian J. Agrofor.* **1**(1):47-62

Kumar, B.M. and Divakara, B.N. 2001. Proximity, clump size and root distribution pattern in bamboo: A case study of *Bambusa arundinacea* (Retz.) Willd., Poaceae, in the Ultisols of Kerala, India. *J. Bamboo Rattan* **1**(1):43-58

Kumar, B.M., George, S.J., Jamaludheen, V. and Suresh, T.K. 1998. Comparison of biomass production, tree allometry and nutrient use efficiency of multipurpose trees grown in wood lot and silvopastoral experiments in Kerala, India. *For. Ecol. Manage.* **112**:145-163

Kumar, S.S. 1997. Functional dynamics of an agrisilvcultural system involving coconut palms, multipurpose trees and Kacholam. M.Sc.(For.) thesis, Kerala Agricultural University, Thrissur, Kerala, India pp.35-42, 92-94

Kumar, S.S., Kumar, B.M., Wahid, P.A., Kamalam, N.V. and Fishers, R.F. 1999. Root competition for phosphorus between coconut, multipurpose trees and *kacholam* (*Kaempferia galanga*) in Kerala, India. *Agrofor. Syst.* **46**:131-146

Latha, E.V. 1994. Evaluation of Kacholam (*Kaempferia galanga* L.) types for morphological variability and yield. M.Sc. thesis, College of Horticulture, Kerala Agricultural University, Thrissur, Kerala, India pp.93-96

Lehmann, J., Peter, I., Steglich, C., Gebauer, G., Hewe, B. and Zech, W. 1998. Below ground interactions in agroforestry. *For. Ecol. Manage.* **111**:157-169

Lehmann, J. and Zech, W. 1998. Fine root turnover in irrigated hedgerow intercropping in northern Kenya. *Pl. Soil* **198**:19-31

Liyanage M. des., Jayasundara, H.P.S. and Perera, K.C.P. 1990. Studies on the biomass productivity of selected multipurpose trees. Gunasena, H.P.M. (ed.), Proc. of the Ist Regional Workshop on Multipurpose Trees, Kandy, Sri Lanka pp.27-36

Liyanage M. des., Jayasundara, H.P.S. and Gunasekera, T.G.L.G. 1993. Leucaena as a multipurpose tree for coconut plantations in Sri Lanka. *J. Trop. For. Sci.* **6**(2):91-97

Lott, J.E., Howard, S.B., Ong, C.K. and Black, C.R. 2000. Long term productivity of a *Grevillea robusta* based overstorey agroforestry system in semi-arid Kenya. II Crop growth and system performance. *For. Ecol. Manage.* **139**:187-201

Mc Cown, R.L. and Williams, W.A. 1968. Competition for nutrients and light between the annual grassland species *Bromus mollis* and *Erodium botrys. Ecology* **49**:981-990

Menon, K.S. and Nayar, T.V.R. 1978. Effect of intercropping with tuber crops in root (wilt) affected coconut gardens. Nelliat, E.V. (ed.), PLACROSYM I. Proceedings of the Annual Symposium on Plantation Crops, CPCRI, Kasargod, India pp.416-426

Mohsin, F., Singh, R.P., Jattan, S.S. and Singh, K. 2000. Root studies in a Eucalyptus hybrid plantation at various ages. *Indian For.* p.1165-1174

*Mooney, H.A. 1977. Convergent evolution in Chile and California. Dowden Hutchinson and Ross, Stroudsberg, Pennsylvania, USA pp.17-19

Moser, E.B., Saxton, A.M. and Pezeshki, S.R. 1990. Repeated measures analysis of variance: application to tree research. *Can. J. For. Res.* **20**:524-535

Nair, P.K.R. 1978. Plant community interactions in crop combinations with coconuts. Proc. Int. Conf. Cocoa and Coconuts. The Incorporated Society of Planters, Kualalumpur pp.606-620

Nair, P.K.R. 1983. Agroforestry with coconuts and other tropical plantation crops. Huxley, P.A. (ed.), Plant Research and Agroforestry, ICRAF, Nairobi, Kenya. pp.79-102

Nair, P.K.R. 1984. Soil productivity aspects of agroforestry. International Council of Research in Agroforestry, Nairobi, Kenya p.85

Nair, P.K.R. 1985. Classification of Agroforestry Systems. *Agrofor. Syst.* 3:97-128

Nair, P.K.R. 1989. Agroforestry defined. Nair, P.K.R. (ed.), Agroforestry Systems in Tropics, Kluwer Academic Publishers, Dordrecht, Netherlands, p.13

Nair, M.A. and Sreedharan, C. 1986. Agroforestry farming systems in the homesteads of Kerala, Southern India. *Agrofor. Syst.* 4:339-363

Nair, P.K.R., Varma, R., Nelliat, E.V. and Bavappa, K.V.A. 1975. Beneficial effects of crop combination of coconut and cocoa. *J. Agric. Met.* **45**:165-171

Nair, P.K.R. and Varghese, T. 1976. Crop diversification in coconut plantations. *Indian Fmg.* **25**(11):17-26

Nelliat, E.V., Gopalasundaram, P., Varghese, P.T. and Sivaraman, K. 1976. Mixed cropping in coconut. In Multiple Cropping in Coconut and Arecanut Gardens. (ed. Nelliat, E.V. and Bhat, K.S.). Central Plantation Crops Research Institute, Kasaragod, India pp.28-33

Newman, E.I. 1973. Competition and diversity in herbaceous vegetation. *Nature* **244**:310

Newman, E.I. 1983. Interaction between plants by O.L.Lange, P.S.Nobel, C.B.Osmond and H.Ziegler (eds.). Physiological Plant Ecology. III. Responses to the chemical and biological environment. Springer-Verlag, Berlin, Germany pp.679-710

Oksanen, L., Fretwell, S.D., Arrud, J. and Niemala, P. 1981. Exploitation ecosystems in gradients of primary productivity. Am. Naturalist **118**:240-261

Oldeman, A.A.R. 1990. Forests: Elements of Silvology. Springer-Verlag, Berlin, Heidelberg, New York. p.207

Ong, C.K., Corlett, J.E., Singh, R.P. and Black, C.R. 1991. Above and below ground interactions in agroforestry systems. *For. Ecol. Manage.* **45**:45-57

*Page, E.R. and Gerwitz, A. 1974. Mathematical models, based on diffusion equations, to describe root systems of isolated plants, row crops and swards. *Pl. Soil* **41**:243-254

Pant, M.M. 1980. The impact of social of social forestry on the national economic of India. *Intl. Tree Crops J.* **3**:69-92

Pysek, P. and Leps, J. 1991. Response of a weed community to nitrogen fertilisation: a multivariate analysis. *J. Veg. Sci.* **2**:237-244

Racz, G.J., Rennie, D.A. and Hutcheon, W.L. 1964. The ^{32}P injection method for studying the root system of wheat. *Can. J. Soil Sci.* p. 44 and 100

Ramanujam, T., Muraleedharan Nair, G. and Indira, P. 1984. Growth and development of cassava (*Manihot esculenta* Crantz) genotypes under shade in a coconut garden. *Turrialba* **34**(3):267-274

Rao, M.R., Ong, C.K., Pathak, P. and Sharma, M.M. 1991. Productivity of annual cropping and agroforestry systems on a shallow Alfisol in semi-arid India. *Agrofor. Syst.* **15**:51-63

Rao, M.R., Muraya, P. and Huxley, P.A. 1993. Observations of some tree root systems in agroforestry intercrop situations, and their graphical representation. *Expt. Agric.* **29**:183-194

Rao, M.R., Nair, P.K.R. and Ong, C.K. 1998. Biophysical interactions in tropical agroforestry systems. *Agrofor. Syst.*, **38**:3-50

Rennie, D.A. and Halstead, E.H. 1965. A ^{32}P injection method for quantitative estimation of the distribution and extent of cereal grain roots. In: Isotopes and Radiation in Soil-Plant Nutrition Studies. Proceedings of the Ankara Symposium, 1965. International Atomic Energy Agency, Vienna. p.489

Ruhigwa, B.A., Gichuru, M.P., Maverbari, B. and Tariah, M. 1992. Root distribution of *Acacia barteri, Alchornia cornifolia, Cassia siamea* and *Gmelina arborea* in ultisol. *Agrofor. Syst.* **19**:67-78

Samraj, P. 1977. The blue gum (*Eucalyptus globulus* Labill) tree an ideal species for farm forestry in the higher hills of Nilgiris. *Soil Conser. Digest* **5**(2):48-52

Sankar, S.J. 1985. Studies on the root activity pattern of black pepper (*Piper nigrum* L.) employing radiotracer technique. M.Sc.(Ag.) thesis, Kerala Agricultural University, Thrissur, Kerala, India p.132

Sankar, S.J., Wahid, P.A. and Kamalam, N.V. 1988. Absorption of soil applied radiophosphorus by black pepper vine and support tree in relation to their root activities. *J. Plant. Crops* **16**:73-87

Schroth, G. and Zech, W. 1995. Root length dynamics in agroforestry with *Gliricidia sepium* as compared to sole cropping in the semi-deciduous rainforest of West Africa. *Plant Sci.* **170**:297-306

Schroth, G. 1995. Tree root characteristics as criteria for species selection and systems design in agroforestry. *Agrofor. Syst.* **30**:161-173

Schroth, G. 1999. A review of belowground interaction in agroforestry, focussing on mechanisms and management options. *Agrofor. Syst.* **43**:5-34

Schroth, G., Poidy, N., Morshauser, T. and Zech, W. 1994. Effects of different methods of soil tillage and biomass application on crop yields and soil properties in agroforestry with high tree competition. *Agric. Ecosys. Environ.* **52**:129-140

Scroth, G., Kolbe, D., Balle,P., Zech, W. 1995.Searching for criteria for the selection of efficient tree species for fallow improvement, with special reference to carbon and nitrogen.Fertil. Res. **42**:297-314

Sharma, S.K., Verma, C.M. and Ahuja, L.D. 1980. Production of ground storey (grass) component in afforested areas in arid regions of India. *Annals of Arid Zone* 19(3):283-288

Singh, S.P. 1989. Wasteland Development. Agricos Publishing Academy, New Delhi pp.61-63

Singh, R.P., Ong, C.K. and Saharan, N. 1989. Above and below ground interactions in an alley-cropping in semi-arid India. *Agrofor. Syst.* **9**:259-274

Slayter, R.O. 1967. Plant Water Relationships. Academic Press, New York pp.210-211

Snaydon, R.W., Fernando, D.N.S. and Sangakkara, R. 1989. The effects of Coconut Palms on Understorey, Proc. XVI Intl. Grassland Congres, 4-11 October 1989, Nice. Association Francaise pour la Production Fouragere, Centre National de Recherde Agronomique, Versailles, France pp.469-470

Southwood, T.R.E. 1988. Tactics, stratergies and templets. Oikos **52**:3-18

Stone, E.L. and Kalisz, P.J. 1991. On the maximum extent of tree roots. *For. Ecol. Manage.* **46**:59-102

Suresh, K.K. and Rai, R.S.V. 1987. Studies on the allelopathic effects of some agroforestry tree crops. *Int. Tree Crops J.* **4**:109-115

Sutton, R.F. 1980. Root system morphogenesis. *N. Z. J. For. Sci.* **10**:264-292

Thomas, J. 1996. Understorey productivity of Agri-silvicultural systems as affected by tree population density and fertilizer regimes. M.Sc.(For.) thesis, Kerala Agricultural University, Thrissur, Kerala, India pp.123-128

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

Tilman, D. 1982. Resource competition and community structure. Princeton University Press, USA pp.31-33

Tilman, D. 1987. On the meaning of competition and the mechanisms of competitive superiority. *Functional Ecology* **1**:304-315

Tilman, D. 1988. Plant strategies and the dynamics and structure of plant communities. Princeton University Press, Princeton, New Jersey, USA pp.75-79

Tilman, D. and Wedin, D. 1991. Plant traits and resource reduction for five grasses growing on a nitrogen gradient. *Ecology* **72**(2):685-700

Tomlinson, H., Traore, A. and Teklenaimanot, Z. 1998. An investigation of the root distribution of Parkia biglobosa in Berkina Faso, West Africa, using a logarithmic spiral trench. *For. Ecol. Manage.* **107**:173-182

Trenbath, B. 1976. Plant interactions in mixed crop communities. Multiple cropping, ASA Special Pub. No.27, American Society of Agronomy, Madison, Wisconsin p.129-170

Trenbath, B.R. and Harper, J.L. 1973. Neighbour effects in the genus Avence. I. Comparison of crop species. *J. appl. Ecol.* **10**:379-400

Trenbath, B.R. 1974. Biomass productivity in mixtures. *Adv. Agron.* **26**:117-210

Van Noordwijk, M. and Purnomosidhi, P. 1995. Root architecture in relation to tree-crop-soil interactions and shoot pruning in agroforestry. *Agrofor. Syst.* **30**:161-173

Vandameer, J. 1989. The ecology of Intercropping. Cambridge University Press. Cambridge. UK p.237

Varghese, P.T., Nair, P.K.R., Nelliat, E.V., Varma, R. and Gopalasundaram. 1979. Intercropping with tubercrops in coconut gardens. Nelliat, E.V. (ed.), PLACROSYM I. Proceedings of the Annual Symposium on Plantation Crops, CPCRI, Kasaragod, India pp.7-11

Vasu, K., Vardan, K.M., Velayudhan, K.T. and Tessy Thomas. 1994. Activity and distribution pattern of roots of *Gliricidia sepium. J. Nuclear Agric. Biol.* **23**:24-28

Vergara, N.T. and Nair, P.K.R. 1985. Agroforestry in south pacific region: an overview. Agrofor.Syst. **3**:363-379 .

Wahid, P.A. 2001. Radioisotope studies of root activity and root level interactions in tree-based production systems: a review. *Appl. Radiat. and Isot.* **54**:715-736

Wahid, P.A., Kamala Devi, C.B., Philip, G. and Pillai, N.G. 1975. Effect of discontinuation of NPK fertilization on the NPK nutrition of coconut. *J. Plant. Crops* **3**:58-60

Wahid, P.A., Devi, C.B.K. and Haridasan, M. 1977. A critical review of phosphate fertilization of coconut. *Philipp. J. Coconut Stud.* 2(4):1-8

Wahid, P.A., Kamalam, N.V. and Sankar, S.J. 1985. Determination of phosphorus-32 in wet digested plant leaves by Cerenkov counting. *Int. J. Appl. Rad. Isot.* **36**:323-324

Wahid, P.A., Kamalam, N.V., Ashokan, P.K. and Vidyadharan, K.K. 1989a. Root activity pattern of cashew (*Anacardium occidentale* L.) in laterite soil. *J. Plant. Crops* **17**:85-89

Wahid, P.A., Kamalam, N.V., Ashokan, P.K. and Vikraman Nair, R.V. 1989b. Root activity pattern of cocoa (*Theobroma cacaco*). *J. Nucl. Agric. Biol.* **18**:153-156

Walkey, A.J. and Black, I.A. 1934. Estimation of soil organic carbon by the chromic acid titration method. *Soil Sci.* **31**:29-38

Wattnabe, F.S. and Olsen, S.R. 1965. Test of an ascorbic acid method for determining phosphorus in water and NH_4HCO_3 extracts from soil. *Proc. Soil Sci. Soc. Am.* **29**:677-678

*Whittaker, R.H. 1975. Communities and ecosystems. MacMillan, New York, USA pp.18-22

Wilson, S.D. and Tilman, D. 1991. Components of plant competition along an experimental gradient of nitrogen availability. *Ecology*, 72(3):1050-1065

Wilson, S.D. and Tilman, D. 1993. Plant competition and resource availability in response to disturbance and fertilisation. *Ecology*, 74(2):599-611

* Originals not seen

Appendices

APPENDIX I

Weather parameters during the experimental period (May 2000 to August 2001) recorded by the Department of Agricultural Meterology, College of Horticulture, Vellanikkara, Thrissur

Sl. No.	Months	Temperature (^{0} C)		Rainfall (mm)
		Maximum	Minimum	
1	May 2000	35.5	24.4	117.2
2	June	32	22.8	602
3	July	31.2	21.9	354
4	August	31.8	22.6	518.8
5	September	32.6	23	198.1
6	October	33.4	22.7	262.2
7	November	34.4	23.1	41.3
8	December	33.2	22	11.2
9	January 2001	35.2	23.2	0.0
10	February	36.2	22.9	12.2
11	March	37	24	4.4
12	April	38.4	24.7	243.1
13	May	34.5	24.5	192.6
14	June	32.8	23.1	676.2
15	July	31	22.7	477.7
16	August	30.6	23.1	253.2
	Mean	33.74	23.17	264.28
	Total			3964.20

APPENDIX II

Abstracts of ANOVA tables for coconut yeild and foliar nutrient content of 22 years old coconut palms as influenced by multipurpose trees (eight years old)and planting geometry

Source	df	Mean square							
		Quinqu-enneal nut yield	Nut yield (2000-2001)	November 14th			November 29th		
				N	P	K	N	P	K
Species	2	69.44	442.17	0.0035	0.00076	0.085	0.0084	0.0006	0.0228
Planting geometry	1	98.00	1.39	0.1200	0.00023	0.0028	0.0024	0.0002	0.00003
Interaction	2	2810.12	236.05	0.049	0.00006	0.035	0.022	0.0006	0.1101
Control Vs Rest	1	0.75	380.64	0.014	0.00002	0.145	0.242	0.0002	0.1664
Error	12	2968.04	156.15	0.085	0.0006	0.073	0.064	0.0002	0.0306
Block effects	2	21932.06**	94.44	0.08	0.0024*	0.014	0.07	0.0014**	0.029

* - Significant at 5% level
** - Significant at 1% level

APPENDIX III

Abstracts of ANOVA tables for soil chemical properties in 22 years old coconut plantation as influenced by multipurpose trees (eight years old) and planting geometry

Source	df	Mean square				
		Organic carbon	Total N	Available P	Available K	Soil pH
Species	2	0.076**	0.00011	175.07*	387.38	0.025
Planting geometry	1	0.0053	0.0000001	37.38	408.63	0.00067
Interaction	2	0.018	0.0013	68.36	434.31	0.0086
Control Vs Rest	1	0.000007	0.00014	9.74	33.75	0.00006
Error	12	0.0127	0.000059	47.44	450.04	0.0118
Block effects	2	0.0112	0.00157**	1839.55**	2443.06*	0.327**

* - Significant at 5% level
** - Significant at 1% level

APPENDIX IV

Abstracts of ANOVA tables for growth characteristics of eight years old multipurpose trees at periodic intervals (September 1992 to August 2001)

Source	Df	Mean square															
		Spt. '92	Mar '93	Oct '93	Apl. 94	Nov. '94	May. '95	Oct. '95	Mar. '96	Jul. '96	Mar. '97	Sept. '97	Mar. '98	May. '00	Oct. '00	Mar. '01	Aug. '01
Age (months)		4	10	17	23	30	36	41	46	50	58	63	70	96	101	106	111
Height (m)																	
Species	2	0.77**	1.91**	0.570**	0.507*	0.2005	0.2736	0.8399	1.40	2.296**	2.731**	3.958**	3.463**	5.934**	6.825**	6.405**	6.873**
Planting geometry	1	0.000	0.0007	0.0307	0.086	0.2222	0.4355	0.4646	0.24	0.353	0.227	0.229	0.390	0.067	0.084	0.238	0.331
Interaction	2	0.0026	0.010	0.007	0.034	0.073	0.1366	0.214	0.309	0.343	0.333	0.382	0.446	1.288	1.127	1.328	1.479
Error	10	0.0032	0.0158	0.037	0.074	0.135	0.196	0.304	0.384	0.434	0.565	0.544	0.606	0.701	0.752	0.916	0.890

* - Significant at 5% level

** - Significant at 1% level

APPENDIX V

Abstracts of ANOVA tables for growth characteristics of eight years old multipurpose trees at periodic intervals (July 1996 to August 2001)

Source	Df	Mean square							
		Jul. '96	Mar. '97	Aug. '97	Mar. '98	May. '00	Oct. '00	Mar. '01	Aug. '01
Age (months)		50	58	63	70	96	101	106	111
Diameter at breast height (cm)									
Species	2	27.769**	27.122**	27.158**	28.379**	37.006**	37.951**	32.713**	35.348**
Planting geometry	1	0.009	0.000	0.000	0.002	0.005	0.077	0.001	0.198
Interaction	2	0.272	0.658	0.610	0.901	1.153	1.663	2.562	1.817
Error	10	0.789	0.892	1.163	1.459	2.144	2.25	2.150	2.149

** - Significant at 1% level

APPENDIX VI

Abstracts of ANOVA tables for ^{32}P activity in leaves of 22years old coconut palms as influenced by multipurpose tree species (eight years old) and planting geometry

Source	df	Mean square	
		15 DAA ^{32}P	30 DAA ^{32}P
Species	2	0.0318	0.0461
Planting geometry	1	0.295	0.227
Interaction	2	0.146	0.0022
Control Vs Rest	1	0.047	0.148
Error	12	0.290	0.139
Block effects	2	0.48	0.214

DAA - Days after application

APPENDIX VII

Nutrient content and ^{32}P uptake by *Vateria indica* (eight years old) as influenced by distance from the treated coconut palm

l. o.	P (%)			K (%)			N (%)			^{32}p (cpm)		
	Distance (m)	Sampling 1	Sampling 2	Distane (m)	Sampling 1	Sampling 2	Distance (m)	Sampling 1	Sampling 2	Distance (m)	Sampling 1	Sampling 2
1	2.85	0.091	0.087	2.85	0.3	0.625	2.85	1.47	1.26	2.85	4797.77	122.44
2	3.15	0.136	0.115	3.15	1.05	1.025	3.15	2.31	1.61	3.15	437.77	353.11
3	3.2	0.135	0.105	3.2	1.35	0.9	3.2	1.61	1.61	3.2	148	80.88
4	3.2	0.15	0.125	3.2	0.55	0.9	3.2	1.96	1.54	3.2	5017.77	3121.33
5	3.25	0.072	0.054	3.25	0.225	0.35	3.25	1.68	1.82	3.25	926.66	198.22
6	3.25	0.1	0.11	3.25	0.275	0.55	3.25	2.03	1.47	3.5	2371.33	122.4
7	3.5	0.083	0.091	3.5	0.45	0.58	3.5	1.19	1.61	3.6	4633.8	583.11
8	3.5	0.104	0.062	3.5	0.65	0.78	3.5	1.61	1.75	3.6	55.33	576.66
9	3.6	0.113	0.08	3.6	0.275	0.6	3.6	1.61	1.47	3.6	292.44	832.22
10	3.6	0.091	0.096	3.6	0.4	0.8	3.6	1.61	1.33	3.75	740	926.66
11	3.6	0.141	0.098	3.6	0.65	0.875	3.6	1.47	1.33	3.8	43.55	18.64
12	3.65	0.11	0.106	3.65	1.25	1.075	3.65	1.54	1.68	3.8	680	136
13	3.75	0.113	0.125	3.75	0.925	1.075	3.75	2.17	1.68	3.8	1044.22	1778
14	3.8	0.115	0.098	3.8	1.05	0.95	3.8	2.45	1.89	3.8	3664.66	498.22
15	3.8	0.113	0.098	3.8	1	0.97	3.8	1.82	1.54	3.9	267.11	0
16	3.8	0.117	0.081	3.8	0.875	0.6	3.8	1.68	1.82	3.95	239.55	484
17	3.8	0.102	0.061	3.8	0.275	0.5	3.8	1.33	1.4	3.95	195.55	35.11
18	3.9	0.169	0.106	3.9	0.575	0.77	3.9	1.54	1.75	4	3130.44	147.77
19	3.95	0.104	0.049	3.95	0.325	0.3	3.95	1.05	1.61	4	467.33	318.22
20	3.95	0.137	0.1	3.95	1.2	1.025	3.95	2.38	1.19	4	27.77	103.77
21	4	0.085	0.069	4	0.303	0.3	4	1.33	1.12	4.1	3542.22	1063.55
22	4	0.155	0.085	4	1.25	0.5	4	1.82	1.82	4.1	3531.11	129.33
23	4	0.115	0.076	4	0.55	0.65	4	2.17	2.1	4.1	1695.77	1402.66
24	4.1	0.067	0.06	4.1	0.475	0.6	4.1	1.68	1.33	4.1	133.55	113.55
25	4.1	0.076	0.082	4.1	0.25	0.58	4.1	1.26	1.54	4.1	62	27.77
26	4.1	0.121	0.077	4.1	0.7	0.83	4.1	1.61	1.54	4.15	204.88	30.22
27	4.1	0.102	0.087	4.1	0.425	0.85	4.1	1.47	1.54	4.2	69.33	25.55
28	4.1	0.136	0.115	4.1	1.2	0.83	4.1	1.96	1.26	4.2	57.33	654.66
29	4.1	0.115	0.085	4.1	1.3	0.9	4.1	1.82	1.75	4.2	1135.55	348.22
30	4.15	0.141	0.113	4.15	0.6	1.05	4.15	2.1	1.89	4.3	2278.88	572
31	4.2	0.1	0.116	4.2	1.25	1.15	4.2	1.47	1.61	4.3	20.66	20.88
32	4.2	0.171	0.147	4.2	0.625	0.85	4.2	1.26	1.54	4.4	2838.88	454.22
33	4.2	0.155	0.119	4.2	1.1	0.82	4.2	1.61	1.54	4.5	474	122.22
34	4.2	0.109	0.079	4.2	0.225	0.35	4.2	1.26	1.33	4.55	148	27.77
35	4.3	0.043	0.073	4.3	0.15	0.33	4.3	1.33	1.4	4.6	41.55	36.88
36	4.3	0.136	0.087	4.3	0.775	0.65	4.3	2.1	1.75	4.6	27.55	18.88
37	4.4	0.11	0.088	4.4	0.9	0.88	4.4	1.75	1.54	4.6	1191.77	311.33
38	4.4	0.078	0.05	4.4	0.55	0.55	4.4	1.47	1.75	4.65	113.33	80.88
39	4.5	0.165	0.12	4.5	0.875	0.9	4.5	1.05	1.19	4.65	124.88	2.44
40	4.5	0.169	0.091	4.5	0.8	0.47	4.5	1.61	1.47	4.75	3318	274.44
41	4.5	0.098	0.11	4.5	0.425	0.825	4.5	1.19	1.33	4.8	161.11	32.44
42	4.5	0.155	0.116	4.5	0.325	0.85	4.5	1.96	1.96	4.85	104	9.55
43	4.55	0.084	0.092	4.55	0.275	0.45	4.55	2.03	1.61	4.85	1256.22	219.11
44	4.6	0.108	0.105	4.6	1.1	0.975	4.6	1.89	1.26	4.9	1196.88	173.11
45	4.6	0.152	0.11	4.6	0.725	0.53	4.6	1.82	1.68	4.9	1316.22	553.55
46	4.6	0.165	0.122	4.6	1.3	0.97	4.6	1.89	1.75	4.9	32	48.44
47	4.65	0.124	0.115	4.65	1.075	1.1	4.65	1.68	1.61	4.9	2558	1026.44

Contd.

Appendix VII continued.

I. o.	P (%)			K (%)			N (%)			^{32}p (cpm)		
	Distance (m)	Sampling 1	Sampling 2	Distane (m)	Sampling 1	Sampling 2	Distance (m)	Sampling 1	Sampling 2	Distance (m)	Sampling 1	Sampling 2
48	4.65	0.117	0.129	4.65	0.5	1.02	4.65	1.61	1.47	5	5775.55	507.11
49	4.75	0.069	0.056	4.75	0.325	0.47	4.75	1.75	1.61	5	1704	661.55
50	4.8	0.104	0.095	4.8	1.025	0.85	4.8	1.75	1.68	5.15	108.22	25.55
51	4.85	0.072	0.054	4.85	0.95	0.27	4.85	2.03	2.17	5.2	51.1	34.66
52	4.85	0.155	0.072	4.85	1.175	1	4.85	1.26	1.4	5.3	3864.22	463.3
53	4.9	0.106	0.065	4.9	1.05	0.92	4.9	1.75	1.75	5.3	9.1	6.8
54	4.9	0.123	0.083	4.9	0.95	0.57	4.9	1.47	1.75	5.3	2758.88	532.44
55	4.9	0.126	0.099	4.9	0.575	0.72	4.9	1.4	1.4	5.3	170.44	2.44
56	4.9	0.114	0.107	4.9	0.775	1.12	4.9	1.4	1.54	5.3	96.66	25.55
57	5	0.059	0.071	5	0.225	0.63	5	1.96	1.33	5.4	96.4	0
58	5	0.093	0.062	5	0.325	0.65	5	1.54	1.45	5.5	5192.22	352.88
59	5.1	0.102	0.065	5.1	0.825	0.625	5.1	1.61	1.4	5.6	2239.11	1871.33
60	5.15	0.116	0.103	5.15	1.075	0.93	5.15	2.45	1.96	5.6	131.77	131.55
61	5.2	0.143	0.12	5.2	1.2	1.15	5.2	1.82	1.82	5.75	2494.88	571.77
62	5.3	0.085	0.06	5.3	0.275	0.33	5.3	1.75	1.4	5.8	80.44	18.44
63	5.3	0.163	0.12	5.3	0.55	0.95	5.3	1.33	1.26	5.8	110.44	2.44
64	5.3	0.131	0.089	5.3	0.625	0.7	5.3	1.26	1.4	5.9	104	83.55
65	5.3	0.065	0.041	5.3	0.3	0.65	5.3	1.19	1.26	6	2356.88	205.11
66	5.3	0.136	0.123	5.3	1	0.97	5.3	1.89	1.68			
67	5.3	0.189	0.103	5.3	0.825	0.75	5.3	1.89	1.89			
68	5.4	0.117	0.105	5.4	0.675	0.95	5.4	1.4	1.4			
69	5.5	0.069	0.061	5.5	0.5	0.47	5.5	1.33	1.47			
70	5.5	0.14	0.129	5.5	0.9	1	5.5	1.89	1.75			
71	5.6	0.069	0.041	5.6	0.275	0.625	5.6	1.26	1.33			
72	5.6	0.132	0.105	5.6	1.025	0.8	5.6	1.89	1.6			
73	5.7	0.117	0.077	5.7	1.2	1.025	5.7	1.89	1.47			
74	5.75	0.117	0.053	5.75	1.5	0.52	5.75	1.61	1.61			
75	5.8	0.115	0.101	5.8	1.05	1.075	5.8	2.52	1.33			
76	5.8	0.115	0.105	5.8	0.6	0.77	5.8	1.4	1.61			
77	5.9	0.136	0.098	5.9	0.95	0.83	5.9	2.52	2.1			
78	6	0.093	0.083	6	0.475	0.95	6	1.89	1.54			
79	6.1	0.141	0.061	6.1	1.05	0.35						

APPENDIX VIII

Nutrient content and ^{32}P uptake by *Ailanthus triphysa* (eight years old) as influenced by distance from the treated coconut palm

l. o.	P (%)			K (%)			N (%)			^{32}P (cpm)		
	Distance (m)	Sampling 1	Sampling 2	Distane (m)	Sampling 1	Sampling 2	Distance (m)	Sampling 1	Sampling 2	Distance (m)	Sampling 1	Sampling 2
1	2.8	0.152	0.143	2.8	1.125	1.15	2.8	1.89	1.89	3	209.55	444.88
2	3	0.085	0.081	3	0.525	0.97	3	1.82	2.1	3	46.22	25.33
3	3	0.13	0.116	3	1.25	0.95	3	1.75	1.68	3	30	2.88
4	3	0.111	0.096	3	1.3	1	3	1.47	1.96	3.3	32	62.22
5	3.1	0.104	0.105	3	0.45	0.9	3.1	2.24	1.75	3.3	59.55	7.11
6	3.2	0.108	0.095	3.1	0.575	0.75	3.2	1.68	2.1	3.4	110.22	55.77
7	3.2	0.167	0.102	3.2	0.85	0.96	3.2	2.31	2.17	3.4	538.88	1069.77
8	3.3	0.152	0.094	3.2	0	0	3.3	1.4	1.54	3.45	87.77	57.77
9	3.3	0.119	0.109	3.3	1	0.625	3.3	1.68	2.45	3.5	20.44	0.44
10	3.4	0.093	0.09	3.3	0.55	1.05	3.4	1.68	2.1	3.6	648	80.66
11	3.4	0.119	0.115	3.4	0.65	0.86	3.4	1.96	2.17	3.6	585.11	76.22
12	3.45	0.115	0.103	3.4	1.3	1.15	3.45	2.03	2.03	3.8	274	250
13	3.5	0.11	0.092	3.45	0.725	0.9	3.5	1.96	2.1	3.8	25.11	32.44
14	3.5	0.128	0.119	3.5	0.825	0.7	3.5	2.24	1.61	3.95	15.77	83.11
15	3.6	0.117	0.112	3.5	1.125	1	3.6	2.1	1.96	3.95	80.44	0.44
16	3.6	0.137	0.106	3.6	1.05	1	3.6	2.17	2.17	3.95	36.44	6.88
17	3.6	0.115	0.098	3.6	1.55	1.025	3.6	2.17	2.17	4	75.77	30
18	3.7	0.138	0.084	3.6	0	0	3.7	1.68	1.75	4	149.55	78.44
19	3.75	0.139	0.119	3.7	0.9	0.93	3.75	2.31	2.24	4.1	89.55	6.88
20	3.8	0.109	0.08	3.75	1.55	1.1	3.8	2.24	2.38	4.15	825.11	193.77
21	3.8	0.129	0.122	3.8	0.95	1.038	3.8	1.89	2.1	4.2	41.33	2.44
22	3.8	0.133	0.107	3.8	1.025	1.16	3.8	1.61	1.75	4.2	0	7.11
23	3.9	0.169	0.153	3.8	0.7	0.85	3.9	1.75	1.47	4.25	267.33	71.55
24	3.95	0.115	0.094	3.9	0.925	1.075	3.95	1.4	1.26	4.3	596.88	9.3
25	3.95	0.141	0.115	3.95	0.9	0.95	3.95	1.89	1.4	4.3	20.4	41.55
26	3.95	0.119	0.098	3.95	0.45	0.75	3.95	1.54	1.68	4.3	8.88	7.33
27	3.95	0.152	0.115	3.95	1.075	0	3.95	2.1	1.54	4.5	112.66	120
28	4	0.119	0.103	3.95	0.875	1.025	3.95	2.24	2.17	4.5	73.33	20.88
29	4	0.112	0.098	3.95	0.65	0.625	4	1.54	1.82	4.5	22.66	18.44
30	4	0.112	0.094	3.95	0.7	0.9	4	2.52	1.33	4.5	71.33	12
31	4.1	0.13	0.092	4	0.925	0.085	4	1.61	1.68	4.5	30	2.88
32	4.1	0.145	0.096	4	1.125	0	4	1.61	1.68	4.55	250.88	62.44
33	4.15	0.133	0.113	4	0.65	1.15	4.1	1.96	2.24	4.65	22.66	18.88
34	4.15	0.117	0.114	4	0.975	0.95	4.1	2.03	2.1	4.65	66.88	103.77
35	4.2	0.108	0.087	4.1	1.275	0.875	4.15	2.03	1.54	4.7	13.77	103.77
36	4.2	0.123	0.113	4.1	1.3	1	4.15	2.52	2.24	4.7	53.11	101.55
37	4.2	0.132	0.116	4.15	1.15	0.975	4.2	1.61	1.54	4.7	0	2.66
38	4.25	0.107	0.102	4.15	0.7	0.6	4.2	1.82	1.68	4.8	111.11	136.22
39	4.3	0.1	0.129	4.2	1.225	0.83	4.2	1.96	1.89	4.8	41.55	350.66
40	4.3	0.112	0.096	4.2	1.125	1.2	4.25	2.38	2.24	4.8	726	23.11
41	4.3	0.108	0.102	4.2	1.2	1.15	4.3	2.1	1.68	4.8	191.77	66.88
42	4.3	0.133	0.11	4.25	0.75	1.2	4.3	1.82	2.03	4.8	209.55	73.77
43	4.5	0.115	0.101	4.3	1.325	1.075	4.3	2.17	2.1	4.8	57.77	6.88
44	4.5	0.097	0.088	4.3	0.9	1.1	4.3	1.68	1.75	4.9	6.88	25.66
45	4.5	0.119	0.084	4.3	0.825	1.075	4.5	2.1	1.96	5	1196.66	456.44
46	4.5	0.13	0.103	4.3	0.425	0.75	4.5	1.75	1.75	5	43.55	110.66

Contd.

Appendix VIII continued

l. o.	P (%)			K (%)			N (%)			^{32}p (cpm)		
	Distance (m)	Sampling 1	Sampling 2	Distane (m)	Sampling 1	Sampling 2	Distance (m)	Sampling 1	Sampling 2	Distance (m)	Sampling 1	Sampling 2
47	4.5	0.138	0.112	4.5	0.625	1.15	4.5	1.75	1.75	5	75.77	30
48	4.5	0.156	0.13	4.5	0.6	1.05	4.5	2.17	2.17	5	62.44	14
49	4.5	0.15	0.11	4.5	0.525	0.875	4.5	2.38	2.17	5.1	25.33	27.77
50	4.55	0.095	0.083	4.5	1.2	1.01	4.5	1.82	1.89	5.2	38.88	4.66
51	4.6	0.1	0.106	4.5	1.45	1.1	4.5	1.68	1.89	5.25	27.77	14
52	4.6	0.11	0.092	4.5	0.825	0.97	4.55	2.03	1.96	5.3	32	16.22
53	4.65	0.141	0.102	4.5	0.725	0.97	4.6	1.54	1.75	5.4	432.4	215.33
54	4.65	0.114	0.1	4.55	0.675	1.15	4.65	2.38	1.68	5.5	64.22	16.22
55	4.7	0.143	0.102	4.6	0	0	4.65	1.26	1.89	5.5	112.66	9.3
56	4.7	0.136	0.073	4.6	0.825	0.7	4.7	1.54	1.19	5.5	48.22	18.66
57	4.7	0.143	0.104	4.65	1.12	0.73	4.7	1.75	1.75	5.6	8.88	6.88
58	4.7	0.119	0.1	4.65	1.125	0.75	4.7	1.75	1.68	5.7	27.33	48.44
59	4.8	0.107	0.1	4.7	1.15	0.97	4.7	1.82	1.96	5.8	25.11	2.44
60	4.8	0.102	0.096	4.7	0.725	1.075	4.8	1.96	1.89	5.95	108.66	80.88
61	4.8	0.124	0.096	4.7	1.05	1.1	4.8	1.96	1.89	6.1	78	53.11
62	4.8	0.1	0.084	4.7	0.4	0.65	4.8	1.47	1.68	6.1	75.77	7.11
63	4.8	0.124	0.061	4.8	0.8	1.11	4.8	2.1	1.4	6.1	36.88	25.55
64	4.8	0.121	0.094	4.8	0.65	0.95	4.8	1.96	2.24			
65	4.8	0.145	0.089	4.8	1.1	0.84	4.8	1.47	1.68			
66	4.9	0.122	0.112	4.8	0.425	0.65	4.8	1.96	1.4			
67	5	0.11	0.103	4.8	0.95	1.125	4.9	1.89	1.96			
68	5	0.141	0.119	4.8	0.9	0.87	5	1.75	1.89			
69	5	0.117	0.118	4.8	0.5	0.67	5	2.1	1.54			
70	5	0.108	0.096	4.8	1.25	0.95	5	1.61	2.17			
71	5	0.117	0.083	4.9	0.85	1.03	5	2.66	1.47			
72	5.1	0.14	0.112	5	0.95	1.025	5	1.4	1.89			
73	5.2	0.119	0.103	5	1.225	0.72	5.1	1.61	2.03			
74	5.25	0.115	0.094	5	0.6	0.75	5.2	1.89	1.26			
75	5.3	0.112	0.073	5	1.1	0.85	5.25	1.75	1.75			
76	5.3	0.139	0.125	5	0.425	0.57	5.3	1.89	2.1			
77	5.4	0.115	0.11	5.1	0.625	0.85	5.3	1.54	2.24			
78	5.4	0.112	0.094	5.2	0.975	0.85	5.4	2.03	2.45			
79	5.5	0.112	0.092	5.25	1.075	0.62	5.4	1.75	1.75			
80	5.5	0.11	0.077	5.3	0.575	0.9	5.5	2.45	2.1			
81	5.5	0.124	0.132	5.3	0.9	0.9	5.5	1.54	2.17			
82	5.5	0.104	0.099	5.4	0.75	1.15	5.5	2.1	1.75			
83	5.6	0.102	0.099	5.4	0.875	0.65	5.5	1.68	1.75			
84	5.6	0.139	0.096	5.5	0.9	1.05	5.6	2.1	2.24			
85	5.6	0.143	0.086	5.5	0.9	0.73	5.6	1.47	1.47			
86	5.7	0.156	0.107	5.5	1.15	0.93	5.6	1.54	1.82			
87	5.8	0.126	0.091	5.5	0.625	0.98	5.7	1.54	1.54			
88	5.8	0.145	0.115	5.6	0.5	0.8	5.8	1.61	1.54			
89	5.9	0.106	0.119	5.6	1.1	1.05	5.8	1.61	1.68			
90	5.95	0.097	0.096	5.6	0.575	0.75	5.9	1.54	1.89			
91	6.1	0.135	0.091	5.7	0.6	0.65	5.95	1.89	2.1			
92	6.1	0.119	0.086	5.8	0.55	0.92	6.1	1.26	1.4			
93	6.1	0.109	0.102	5.8	0.65	0.82	6.1	1.61	1.75			
94				5.9	0.9	1	6.1	1.68	1.61			
95				5.95	0.7	0.97						
96				6.1	1.175	0.7						
97				6.1	0.8	1.125						
98				6.1	0.95	0.85						

APPENDIX IX

Nutrient content and ^{32}P uptake by *Grevillea robusta* (eight years old) as influenced by distance from the treated coconut palm

l. o.	P (%)			K (%)			N (%)			^{32}p (cpm)		
	Distance (m)	Sampling 1	Sampling 2	Distane (m)	Sampling 1	Sampling 2	Distance (m)	Sampling 1	Sampling 2	Distance (m)	Sampling 1	Sampling 2
1	3.1	0.089	0.057	3.1	1	1.07	3.1	1.89	1.54	3.55	113.33	4.66
2	3.1	0.152	0.133	3.1	1.3	1.28	3.1	1.96	1.61	3.6	138	108.44
3	3.35	0.123	0.112	3.35	0.9	1.37	3.35	2.03	2.1	3.6	245.11	260.44
4	3.5	0.117	0.095	3.5	1.375	1.1	3.5	1.96	2.17	3.8	82.66	7.11
5	3.55	0.113	0.071	3.55	0.925	1	3.55	1.54	1.33	4	82.66	11.55
6	3.6	0.069	0.049	3.6	0.625	1.12	3.6	2.03	1.4	4.15	94.22	27.7
7	3.6	0.156	0.079	3.6	1.1	1.1	3.6	1.82	2.03	4.2	94.22	143.11
8	3.65	0.129	0.108	3.65	1.1	1.15	3.65	2.1	2.03	4.25	254.44	353.33
9	3.8	0.167	0.115	3.8	1.07	1.21	3.8	1.68	1.75	4.3	4.22	4.88
10	4	0.133	0.059	4	1.1	1	4	2.24	1.61	4.35	52.66	4.66
11	4	0.138	0.1	4	0.95	1.17	4	1.75	2.17	4.35	27.33	32.44
12	4.1	0.143	0.098	4.1	0.925	1.1	4.1	1.68	1.75	4.4	240.44	230.66
13	4.15	0.139	0.13	4.15	1.475	1.1	4.15	2.24	1.47	4.45	389.55	412.66
14	4.2	0.117	0.113	4.2	1.25	1.15	4.2	2.24	1.4	4.5	251.11	147.77
15	4.2	0.077	0.101	4.2	1.325	1.11	4.2	2.03	1.68	4.5	13.55	9.33
16	4.25	0.115	0.056	4.25	1.05	1.15	4.25	1.47	1.26	4.55	99.33	163.77
17	4.3	0.136	0.106	4.3	1.05	1.11	4.3	1.61	1.75	4.55	117.33	20.88
18	4.3	0.135	0.103	4.3	1.125	1.18	4.3	1.89	1.89	4.7	34.22	13.77
19	4.3	0.117	0.109	4.3	1.1	1.06	4.3	2.17	2.1	4.85	59.55	23.11
20	4.35	0.106	0.092	4.35	1.625	1.5	4.35	2.38	1.89	4.9	59.55	53.11
21	4.35	0.163	0.073	4.35	1.275	1.1	4.35	1.96	1.75	4.9	41.55	16.22
22	4.35	0.1	0.066	4.35	1.425	1.3	4.35	1.54	1.68	5.1	154.88	18.66
23	4.4	0.151	0.137	4.4	1.125	1.16	4.4	2.45	1.96	5.2	119.55	20.88
24	4.45	0.147	0.084	4.45	0.775	1.21	4.45	2.45	2.17	5.55	18.22	23.33
25	4.5	0.108	0.098	4.5	1.2	1.25	4.5	1.82	1.75	5.6	48.22	14
26	4.5	0.122	0.103	4.5	0.625	1.27	4.5	1.54	1.82	5.7	32.22	34.66
27	4.5	0.115	0.086	4.5	1.125	1.07	4.5	1.4	1.61	5.7	280.88	145.33
28	4.5	0.152	0.127	4.5	1.05	1.15	4.5	1.75	1.89	6.1	99.33	20.88
29	4.55	0.082	0.094	4.55	1.2	1.1	4.55	1.96	1.68	6.5	98.88	48.44
30	4.55	0.112	0.088	4.55	1.25	1.18	4.55	2.24	2.17			
31	4.6	0.152	0.115	4.6	1.05	1.275	4.6	1.68	1.75			
32	4.7	0.102	0.099	4.7	0.5	1.15	4.7	1.61	1.68			
33	4.85	0.167	0.061	4.85	1.55	1.2	4.85	1.54	2.1			
34	4.9	0.134	0.08	4.9	1.45	1.27	4.9	2.24	1.68			
35	4.9	0.112	0.088	4.9	1.1	1.075	4.9	1.68	1.89			
36	4.9	0.156	0.138	4.9	1.175	1.18	4.9	2.17	1.75			
37	5.1	0.115	0.061	5.1	1.475	1.28	5.1	1.96	1.54			
38	5.1	0.155	0.116	5.1	1.125	1.2	5.1	1.47	1.61			
39	5.2	0.117	0.077	5.2	1.3	1.11	5.2	1.82	1.68			
40	5.2	0.113	0.1	5.2	1.15	1.11	5.2	1.96	1.68			
41	5.5	0.118	0.096	5.5	1.15	1.18	5.5	2.17	1.96			
42	5.55	0.121	0.094	5.55	1.125	1.3	5.55	2.1	1.68			
43	5.6	0.072	0.067	5.6	1.25	1.26	5.6	2.03	2.03			
44	5.6	0.133	0.079	5.6	0.875	1.08	5.6	1.33	1.4			
45	5.7	0.163	0.155	5.7	1.41	1.225	5.7	1.4	2.17			
46	5.7	0.14	0.057	5.7	1.25	1.17	5.7	2.24	2.1			
47	5.9	0.118	0.072	5.9	1.6	1.23	5.9	2.38	1.82			
48	6.1	0.113	0.083	6.1	0.95	1.02	6.1	1.68	1.75			
49	6.5	0.102	0.119	6.5	0.55	1.12	6.5	1.75	2.1			

APPENDIX X

Abstracts of MANOVA for total of all diameter roots of eight years old *Vateria indica*

A. Tests of Between-Subjects effects and tests of significance for T_1 using UNIQUE sums of square

Source	DF	Mean square	Sig. of F
Size	2	300979.26	0.000
Depth	4	65025.93	0.038
Size by depth	8	6373.70	0.966
Within + Residual	30	22380.74	

B. Tests involving DISTANCE Within-Subject effect

Mauchly sphericity test, W	0.23682
Chi-square approx.	40.47728 with 14DF
Significance	0.000
Green house – Geisser Epsilon	0.75347
Huynh – Feldt Epsilon	1.0000
Lower – bound Epsilon	0.2000

C. Multivariate tests of significance for different effects

Tests name	Value	Approx. F	Hypoth. DF	Error DF	Sig. of F
Distance					
Pillais	0.93410	73.70273♦	5.0	26.00	0.000
Hotellings	14.17360	73.70273♦	5.0	26.00	0.000
Wilks	0.06590	73.70273♦	5.0	26.00	0.000
Roys	0.93410				
Size by distance					
Pillais	0.80724	3.65461	10.00	54.00	0.001
Hotellings	1.56947	3.92366	10.00	50.00	0.001
Wilks	0.33416	3.79556♦	10.00	52.00	0.001
Roys	0.55029				
Depth by distance					
Pillais	0.81273	1.47897	20.00	116.00	0.102
Hotellings	1.47491	1.80676	20.00	98.00	0.030
Wilks	0.34474	1.65055	20.00	87.18	0.059
Roys	0.53596				
Size by depth by distance					
Pillais	0.83171	0.74825	40.00	150.00	0.857
Hotellings	1.15817	0.70649	40.00	122.00	0.896
Wilks	0.37762	0.72678	40.00	116.13	0.875
Roys	0.37174				

D. Tests involving "Distance" Within – Subject effect and Averaged tests of significance for distance using UNIQUE sums of squares

Source	DF	Mean square	Sig. of F
Distance	5	555508.15	0.000
Size by distance	10	29057.48	0.000
Depth by distance	20	12305.93	0.039
Size by depth by distance	40	4843.04	0.930
Within + Residual	150	7234.07	

♦ F statistics are exact

APPENDIX XV

Abstracts of MANOVA for <2.5mm diameter roots of eight years old *Ailanthus triphysa*

A. Tests of Between-Subjects effects and tests of significance for T_1 using UNIQUE sums of square

Source	DF	Mean square	Sig. of F
Size	2	423296.91	0.000
Depth	5	273220.25	0.000
Size by depth	10	19622.10	0.780
Within + Residual	36	31220.99	

B. Tests involving DISTANCE Within-Subject effect

Mauchly sphericity test, W	0.00007
Chi-square approx.	307.42695 with 65 DF
Significance	0.000
Green house – Geisser Epsilon	0.42520
Huynh – Feldt Epsilon	0.72722
Lower – bound Epsilon	0.09091

C. Multivariate tests of significance for different effects

Tests name	Value	Approx. F	Hypoth. DF	Error DF	Sig. of F
Distance					
Pillais	0.91198	24.48837♦	11.00	26.00	0.000
Hotellings	10.36046	24.48837♦	11.00	26.00	0.000
Wilks	0.08802	24.48837♦	11.00	26.00	0.000
Roys	0.91198				
Size by distance					
Pillais	1.13467	3.21857	22.00	54.00	0.000
Hotellings	2.64105	3.00119	22.00	50.00	0.001
Wilks	0.18645	3.11029♦	22.00	52.00	0.000
Roys	0.59466				
Depth by distance					
Pillais	2.19956	2.14209	55.00	150.00	0.000
Hotellings	7.59657	3.37012	55.00	122.00	0.000
Wilks	0.02677	2.67291	55.00	123.94	0.000
Roys	0.83345				
Size by depth by distance					
Pillais	2.42226	1.01708	110.00	350.00	0.446
Hotellings	5.26762	1.15888	110.00	242.00	0.175
Wilks	0.03246	1.09815	110.00	207.92	0.281
Roys	0.65440				

D. Tests involving "Distance" Within – Subject effect and Averaged tests of significance for distance using UNIQUE sums of squares

Source	DF	Mean square	Sig. of F
Distance	11	188363.41	0.000
Size by distance	22	9111.73	0.000
Depth by distance	55	18425.36	0.000
Size by depth by distance	110	2653.08	0.908
Within + Residual	396	3278.23	

♦ F statistics are exact

APPENDIX X

Abstracts of MANOVA for total of all diameter roots of eight years old *Vateria indica*

A. Tests of Between-Subjects effects and tests of significance for T_1 using UNIQUE sums of square

Source	DF	Mean square	Sig. of F
Size	2	300979.26	0.000
Depth	4	65025.93	0.038
Size by depth	8	6373.70	0.966
Within + Residual	30	22380.74	

B. Tests involving DISTANCE Within-Subject effect

Mauchly sphericity test, W	0.23682
Chi-square approx.	40.47728 with 14DF
Significance	0.000
Green house – Geisser Epsilon	0.75347
Huynh – Feldt Epsilon	1.0000
Lower – bound Epsilon	0.2000

C. Multivariate tests of significance for different effects

Tests name	Value	Approx. F	Hypoth. DF	Error DF	Sig. of F
Distance					
Pillais	0.93410	73.70273♦	5.0	26.00	0.000
Hotellings	14.17360	73.70273♦	5.0	26.00	0.000
Wilks	0.06590	73.70273♦	5.0	26.00	0.000
Roys	0.93410				
Size by distance					
Pillais	0.80724	3.65461	10.00	54.00	0.001
Hotellings	1.56947	3.92366	10.00	50.00	0.001
Wilks	0.33416	3.79556♦	10.00	52.00	0.001
Roys	0.55029				
Depth by distance					
Pillais	0.81273	1.47897	20.00	116.00	0.102
Hotellings	1.47491	1.80676	20.00	98.00	0.030
Wilks	0.34474	1.65055	20.00	87.18	0.059
Roys	0.53596				
Size by depth by distance					
Pillais	0.83171	0.74825	40.00	150.00	0.857
Hotellings	1.15817	0.70649	40.00	122.00	0.896
Wilks	0.37762	0.72678	40.00	116.13	0.875
Roys	0.37174				

D. Tests involving "Distance" Within – Subject effect and Averaged tests of significance for distance using UNIQUE sums of squares

Source	DF	Mean square	Sig. of F
Distance	5	555508.15	0.000
Size by distance	10	29057.48	0.000
Depth by distance	20	12305.93	0.039
Size by depth by distance	40	4843.04	0.930
Within + Residual	150	7234.07	

♦ F statistics are exact

APPENDIX XI

Abstracts of MANOVA for <2.5mm diameter roots of eight years old *Vateria indica*

A. Tests of Between-Subjects effects and tests of significance for T_1 using UNIQUE sums of square

Source	DF	Mean square	Sig. of F
Size	2	103761.48	0.004
Depth	4	17001.48	0.381
Size by depth	8	2744.81	0.993
Within + Residual	30	15651.85	

B. Tests involving DISTANCE Within-Subject effect

Mauchly sphericity test, W	0.24755
Chi-square approx.	39.23217 with 14 DF
Significance	0.000
Green house – Geisser Epsilon	0.72324
Huynh – Feldt Epsilon	1.0000
Lower – bound Epsilon	0.2000

C. Multivariate tests of significance for different effects

Tests name	Value	Approx. F	Hypoth. DF	Error DF	Sig. of F
Distance					
Pillais	0.91841	58.53646♦	5.0	26.00	0.000
Hotellings	11.25701	58.53646♦	5.0	26.00	0.000
Wilks	0.08159	58.53646♦	5.0	26.00	0.000
Roys	0.91841				
Size by distance					
Pillais	0.79132	3.53536	10.00	54.00	0.001
Hotellings	1.43398	3.58495	10.00	50.00	0.001
Wilks	0.35198	3.56489♦	10.00	52.00	0.001
Roys	0.51077				
Depth by distance					
Pillais	0.68989	1.20883	20.00	116.00	0.260
Hotellings	1.08681	1.33134	20.00	98.00	0.178
Wilks	0.42655	1.27681	20.00	87.18	0.217
Roys	0.44778				
Size by depth by distance					
Pillais	0.77452	0.68736	40.00	150.00	0.916
Hotellings	1.05602	0.64417	40.00	122.00	0.944
Wilks	0.40729	0.66435	40.00	116.13	0.930
Roys	0.35403				

D. Tests involving "Distance" Within – Subject effect and Averaged tests of significance for distance using UNIQUE sums of squares

Source	DF	Mean square	Sig. of F
Distance	5	206568.59	0.000
Size by distance	10	15834.37	0.000
Depth by distance	20	4097.48	0.333
Size by depth by distance	40	2675.48	0.874
Within + Residual	150	3651.85	

♦ F statistics are exact

APPENDIX XII

Abstracts of MANOVA for 2.5 - 5mm diameter roots of eight years old *Vateria indica*

A. Tests of Between-Subjects effects and tests of significance for T_1 using UNIQUE sums of square

Source	DF	Mean square	Sig. of F
Size	2	25120.00	0.000
Depth	4	6566.67	0.001
Size by depth	8	947.78	0.519
Within + Residual	30	1037.04	

B. Tests involving DISTANCE Within-Subject effect

Mauchly sphericity test, W	0.03175
Chi-square approx.	96.93840 with 14 DF
Significance	0.000
Green house – Geisser Epsilon	0.52644
Huynh – Feldt Epsilon	0.85100
Lower – bound Epsilon	0.2000

C. Multivariate tests of significance for different effects

Tests name	Value	Approx. F	Hypoth. DF	Error DF	Sig. of F
Distance					
Pillais	0.93275	72.11989♦	5.0	26.00	0.000
Hotellings	13.86921	72. 11989♦	5.0	26.00	0.000
Wilks	0.06725	72.11989♦	5.0	26.00	0.000
Roys	0.93275				
Size by distance					
Pillais	0.74255	3.18878	10.00	54.00	0.003
Hotellings	2.13399	5.33498	10.00	50.00	0.000
Wilks	0.30417	4.22849♦	10.00	52.00	0.000
Roys	0.67314				
Depth by distance					
Pillais	0.84985	1.56472	20.00	116.00	0.073
Hotellings	1.28991	1.58014	20.00	98.00	0.073
Wilks	0.35633	1.59092	20.00	87.18	0.073
Roys	0.44759				
Size by depth by distance					
Pillais	1.03994	0.98477	40.00	150.00	0.505
Hotellings	1.66933	1.01829	40.00	122.00	0.455
Wilks	0.27341	1.00591	40.00	116.13	0.474
Roys	0.48099				

D. Tests involving "Distance" Within – Subject effect and Averaged tests of significance for distance using UNIQUE sums of squares

Source	DF	Mean square	Sig. of F
Distance	5	28991.11	0.000
Size by distance	10	1601.78	0.048
Depth by distance	20	1331.11	0.063
Size by depth by distance	40	416.22	0.994
Within + Residual	150	839.70	

♦ F statistics are exact

APPENDIX XIII

Abstracts of MANOVA for >5mm diameter roots of eight years old *Vateria indica*

A. Tests of Between-Subjects effects and tests of significance for T_1 using UNIQUE sums of square

Source	DF	Mean square	Sig. of F
Size	2	6108.15	0.003
Depth	4	1976.30	0.083
Size by depth	8	289.63	0.945
Within + Residual	30	863.70	

B. Tests involving DISTANCE Within-Subject effect

Mauchly sphericity test, W	0.00539
Chi-square approx.	146.78843 with 14DF
Significance	0.000
Green house – Geisser Epsilon	0.42248
Huynh – Feldt Epsilon	0.66738
Lower – bound Epsilon	0.2000

C. Multivariate tests of significance for different effects

Tests name	Value	Approx. F	Hypoth. DF	Error DF	Sig. of F
Distance					
Pillais	0.74190	14.94687◆	5.0	26.00	0.000
Hotellings	2.87440	14.94687◆	5.0	26.00	0.000
Wilks	0.25810	14.94687◆	5.0	26.00	0.000
Roys	0.74190				
Size by distance					
Pillais	0.49275	1.76538	10.00	54.00	0.090
Hotellings	0.91847	2.29618	10.00	50.00	0.026
Wilks	0.51645	2.03584◆	10.00	52.00	0.048
Roys	0.47331				
Depth by distance					
Pillais	0.59370	1.01091	20.00	116.00	0.455
Hotellings	0.80135	0.98166	20.00	98.00	0.491
Wilks	0.50395	1.00046	20.00	87.18	0.470
Roys	0.33215				
Size by depth by distance					
Pillais	0.80011	0.71440	40.00	150.00	0.892
Hotellings	1.25808	0.76743	40.00	122.00	0.831
Wilks	0.37185	0.73963	40.00	116.13	0.862
Roys	0.44632				

D. Tests involving "Distance" Within – Subject effect and Averaged tests of significance for distance using UNIQUE sums of squares

Source	DF	Mean square	Sig. of F
Distance	5	17332.15	0.000
Size by distance	10	787.26	0.299
Depth by distance	20	644.74	0.492
Size by depth by distance	40	355.41	0.988
Within + Residual	150	659.26	

◆ F statistics are exact

APPENDIX XIV

Abstracts of MANOVA for total of all diameter roots of eight years old *Ailanthus triphysa*

A. Tests of Between-Subjects effects and tests of significance for T_1 using UNIQUE sums of square

Source	DF	Mean square	Sig. of F
Size	2	718846.30	0.000
Depth	5	512136.30	0.000
Size by depth	10	30520.37	0.758
Within + Residual	36	46683.95	

B. Tests involving DISTANCE Within-Subject effect

Mauchly sphericity test, W	0.00011
Chi-square approx.	292.42966 with 65 DF
Significance	0.000
Green house – Geisser Epsilon	0.42828
Huynh – Feldt Epsilon	0.73333
Lower – bound Epsilon	0.09091

C. Multivariate tests of significance for different effects

Tests name	Value	Approx. F	Hypoth. DF	Error DF	Sig. of F
Distance					
Pillais	0.94740	42.57155◆	11.00	26.00	0.000
Hotellings	18.01104	42.57155◆	11.00	26.00	0.000
Wilks	0.05260	42.57155◆	11.00	26.00	0.000
Roys	0.94740				
Size by distance					
Pillais	1.19639	3.65428	22.00	54.00	0.000
Hotellings	3.03494	3.44880	22.00	50.00	0.000
Wilks	0.15961	3.55275◆	22.00	52.00	0.000
Roys	0.64109				
Depth by distance					
Pillais	2.05002	1.89526	55.00	150.00	0.001
Hotellings	9.88091	4.38353	55.00	122.00	0.000
Wilks	0.02545	2.72724	55.00	123.94	0.000
Roys	0.88767				
Size by depth by distance					
Pillais	2.24447	0.92082	110.00	350.00	0.692
Hotellings	4.53015	0.99663	110.00	242.00	0.500
Wilks	0.04733	0.95133	110.00	207.92	0.611
Roys	0.68267				

D. Tests involving "Distance" Within – Subject effect and Averaged tests of significance for distance using UNIQUE sums of squares

Source	DF	Mean square	Sig. of F
Distance	11	373040.40	0.000
Size by distance	22	16391.75	0.000
Depth by distance	55	33939.93	0.000
Size by depth by distance	110	3952.69	0.876
Within + Residual	396	4750.62	

◆ F statistics are exact

APPENDIX XV

Abstracts of MANOVA for <2.5mm diameter roots of eight years old *Ailanthus triphysa*

A. Tests of Between-Subjects effects and tests of significance for T_1 using UNIQUE sums of square

Source	DF	Mean square	Sig. of F
Size	2	423296.91	0.000
Depth	5	273220.25	0.000
Size by depth	10	19622.10	0.780
Within + Residual	36	31220.99	

B. Tests involving DISTANCE Within-Subject effect

Mauchly sphericity test, W	0.00007
Chi-square approx.	307.42695 with 65 DF
Significance	0.000
Green house – Geisser Epsilon	0.42520
Huynh – Feldt Epsilon	0.72722
Lower – bound Epsilon	0.09091

C. Multivariate tests of significance for different effects

Tests name	Value	Approx. F	Hypoth. DF	Error DF	Sig. of F
Distance					
Pillais	0.91198	24.48837♦	11.00	26.00	0.000
Hotellings	10.36046	24.48837♦	11.00	26.00	0.000
Wilks	0.08802	24.48837♦	11.00	26.00	0.000
Roys	0.91198				
Size by distance					
Pillais	1.13467	3.21857	22.00	54.00	0.000
Hotellings	2.64105	3.00119	22.00	50.00	0.001
Wilks	0.18645	3.11029♦	22.00	52.00	0.000
Roys	0.59466				
Depth by distance					
Pillais	2.19956	2.14209	55.00	150.00	0.000
Hotellings	7.59657	3.37012	55.00	122.00	0.000
Wilks	0.02677	2.67291	55.00	123.94	0.000
Roys	0.83345				
Size by depth by distance					
Pillais	2.42226	1.01708	110.00	350.00	0.446
Hotellings	5.26762	1.15888	110.00	242.00	0.175
Wilks	0.03246	1.09815	110.00	207.92	0.281
Roys	0.65440				

D. Tests involving "Distance" Within – Subject effect and Averaged tests of significance for distance using UNIQUE sums of squares

Source	DF	Mean square	Sig. of F
Distance	11	188363.41	0.000
Size by distance	22	9111.73	0.000
Depth by distance	55	18425.36	0.000
Size by depth by distance	110	2653.08	0.908
Within + Residual	396	3278.23	

♦ F statistics are exact

APPENDIX XVI

Abstracts of MANOVA for 2.5 –5mm diameter roots of eight years old *Ailanthus triphysa*

A. Tests of Between-Subjects effects and tests of significance for T_1 using UNIQUE sums of square

Source	DF	Mean square	Sig. of F
Size	2	9558.02	0.003
Depth	5	22619.88	0.000
Size by depth	10	951.36	0.734
Within + Residual	36	1396.30	

B. Tests involving DISTANCE Within-Subject effect

Mauchly sphericity test, W	0.00063
Chi-square approx.	236.86555 with 65 DF
Significance	0.000
Green house – Geisser Epsilon	0.52572
Huynh – Feldt Epsilon	0.93348
Lower – bound Epsilon	0.09091

C. Multivariate tests of significance for different effects

Tests name	Value	Approx. F	Hypoth. DF	Error DF	Sig. of F
Distance					
Pillais	.95946	55.94197♦	11.00	26.00	0.000
Hotellings	23.66776	55.94197♦	11.00	26.00	0.000
Wilks	0.04054	55.94197♦	11.00	26.00	0.000
Roys	0.95946				
Size by distance					
Pillais	1.11917	3.11872	22.00	54.00	0.000
Hotellings	2.60321	2.95819	22.00	50.00	0.001
Wilks	0.19135	3.03974♦	22.00	52.00	0.001
Roys	0.61071				
Depth by distance					
Pillais	1.95438	1.75009	55.00	150.00	0.004
Hotellings	10.23184	4.53921	55.00	122.00	0.000
Wilks	0.02575	2.71429	55.00	123.94	0.000
Roys	0.89032				
Size by depth by distance					
Pillais	2.48294	1.05098	110.00	350.00	0.363
Hotellings	6.92692	1.52392	110.00	242.00	0.004
Wilks	0.02252	1.24775	110.00	207.92	0.087
Roys	0.79187				

D. Tests involving "Distance" Within – Subject effect and Averaged tests of significance for distance using UNIQUE sums of squares

Source	DF	Mean square	Sig. of F
Distance	11	16447.76	0.000
Size by distance	22	1238.83	0.000
Depth by distance	55	1436.85	0.000
Size by depth by distance	110	390.55	0.648
Within + Residual	396	415.82	

♦ F statistics are exact

APPENDIX XVII

Abstracts of MANOVA for >5mm diameter roots of eight years old *Ailanthus triphysa*

A. Tests of Between-Subjects effects and tests of significance for T_1 using UNIQUE sums of square

Source	DF	Mean square	Sig. of F
Size	2	13274.07	0.000
Depth	5	2383.33	0.001
Size by depth	10	614.07	0.190
Within + Residual	36	417.28	

B. Tests involving DISTANCE Within-Subject effect

Mauchly sphericity test, W	0.00069
Chi-square approx.	233.69312 with 65 DF
Significance	0.000
Green house – Geisser Epsilon	0.50316
Huynh – Feldt Epsilon	0.88590
Lower – bound Epsilon	0.09091

C. Multivariate tests of significance for different effects

Tests name	Value	Approx. F	Hypoth. DF	Error DF	Sig. of F
Distance					
Pillais	0.93005	31.42497♦	11.00	26.00	0.000
Hotellings	13.29518	31.42497♦	11.00	26.00	0.000
Wilks	0.06995	31.42497♦	11.00	26.00	0.000
Roys	0.93005				
Size by distance					
Pillais	1.15219	3.335380	22.00	54.00	0.000
Hotellings	5.49311	6.24217	22.00	50.00	0.000
Wilks	0.11314	4.66326♦	22.00	52.00	0.000
Roys	0.83407				
Depth by distance					
Pillais	2.04520	1.88772	55.00	150.00	0.001
Hotellings	11.06253	4.90774	55.00	122.00	0.000
Wilks	0.2303	2.83558	55.00	123.94	0.000
Roys	0.90143				
Size by depth by distance					
Pillais	2.63596	1.13893	110.00	350.00	0.190
Hotellings	12.17191	2.67782	110.00	242.00	0.000
Wilks	0.01033	1.59227	110.00	207.92	0.002
Roys	0.90037				

D. Tests involving "Distance" Within – Subject effect and Averaged tests of significance for distance using UNIQUE sums of squares

Source	DF	Mean square	Sig. of F
Distance	11	2530.81	0.000
Size by distance	22	243.77	0.120
Depth by distance	55	430.20	0.000
Size by depth by distance	110	186.60	0.352
Within + Residual	396	176.88	

♦ F statistics are exact

APPENDIX XVIII

Abstracts of MANOVA for total of all diameter roots of eight years old *Grevillea robusta*

. Tests of Between-Subjects effects and tests of significance for T_1 using UNIQUE sums of square

Source	DF	Mean square	Sig. of F
Size	2	96143.70	0.000
Depth	4	137601.48	0.000
Size by depth	8	6332.59	0.660
Within + Residual	30	8614.81	

B. Tests involving DISTANCE Within-Subject effect

Mauchly sphericity test, W	0.01735
Chi-square approx.	113.92586 with 14 DF
Significance	0.000
Green house – Geisser Epsilon	0.48768
Huynh – Feldt Epsilon	0.78172
Lower – bound Epsilon	0.2000

C. Multivariate tests of significance for different effects

Tests name	Value	Approx. F	Hypoth. DF	Error DF	Sig. of F
Distance					
Pillais	0.85234	30.01685♦	5.0	26.00	0.000
Hotellings	5.77247	30.01685♦	5.0	26.00	0.000
Wilks	0.14766	30.01685♦	5.0	26.00	0.000
Roys					
Size by distance					
Pillais	0.40134	1.35565	10.00	54.00	0.226
Hotellings	0.51733	1.29334	10.00	50.00	0.260
Wilks	0.63506	1.32522♦	10.00	52.00	0.242
Roys	0.26287				
Depth by distance					
Pillais	0.87406	1.62177	20.00	116.00	0.059
Hotellings	1.45734	1.78524	20.00	98.00	0.033
Wilks	0.33005	1.72995	20.00	87.18	0.043
Roys	0.48730				
Size by depth by distance					
Pillais	0.79813	0.71230	40.00	150.00	0.894
Hotellings	1.34651	0.82137	40.00	122.00	0.759
Wilks	0.36316	0.75946	40.00	116.13	0.839
Roys	0.50315				

D. Tests involving "Distance" Within – Subject effect and Averaged tests of significance for distance using UNIQUE sums of squares

Source	DF	Mean square	Sig. of F
Distance	5	371504.59	0.000
Size by distance	10	4252.15	0.550
Depth by distance	20	16620.15	0.000
Size by depth by distance	40	2569.93	0.989
Within + Residual	150	4812.15	

♦ F statistics are exact

APPENDIX XIX

Abstracts of MANOVA for < 2.5mm diameter roots of eight years old *Grevillea robusta*

A. Tests of Between-Subjects effects and tests of significance for T_1 using UNIQUE sums of square

Source	DF	Mean square	Sig. of F
Size	2	59228.15	0.000
Depth	4	51374.07	0.000
Size by depth	8	4909.63	0.261
Within + Residual	30	3651.85	

B. Tests involving DISTANCE Within-Subject effect

Mauchly sphericity test, W	0.03202
Chi-square approx.	96.70549 with 14 DF
Significance	0.000
Green house – Geisser Epsilon	0.49107
Huynh – Feldt Epsilon	0.78774
Lower – bound Epsilon	0.2000

C. Multivariate tests of significance for different effects

Tests name	Value	Approx. F	Hypoth. DF	Error DF	Sig. of F
Distance					
Pillais	0.85832	31.50159♦	5.0	26.00	0.000
Hotellings	6.05800	31.50159♦	5.0	26.00	0.000
Wilks	0.14168	31.50159♦	5.0	26.00	0.000
Roys	0.85832				
Size by distance					
Pillais	0.61148	2.37804	10.00	54.00	0.020
Hotellings	0.98936	2.47341	10.00	50.00	0.017
Wilks	0.46449	2.42985♦	10.00	52.00	0.019
Roys	0.43807				
Depth by distance					
Pillais	0.88295	1.64295	20.00	116.00	0.054
Hotellings	1.45005	1.77631	20.00	98.00	0.034
Wilks	0.32930	1.73413	20.00	87.18	0.043
Roys	0.48796				
Size by depth by distance					
Pillais	0.88952	0.81151	40.00	150.00	0.777
Hotellings	1.68882	1.03018	40.00	122.00	0.437
Wilks	0.30573	0.90698	40.00	116.13	0.629
Roys	0.56875				

D. Tests involving "Distance" Within – Subject effect and Averaged tests of significance for distance using UNIQUE sums of squares

Source	DF	Mean square	Sig. of F
Distance	5	141068.15	0.000
Size by distance	10	3265.48	0.176
Depth by distance	20	5845.19	0.001
Size by depth by distance	40	1864.74	0.777
Within + Residual	150	2297.19	

♦ F statistics are exact

APPENDIX XX

Abstracts of MANOVA for 2.5 - 5mm diameter roots of eight years old *Grevillea robusta*

A. Tests of Between-Subjects effects and tests of significance for T_1 using UNIQUE sums of square

Source	DF	Mean square	Sig. of F
Size	2	1444.44	0.289
Depth	4	9142.96	0.000
Size by depth	8	185.19	0.994
Within + Residual	30	1117.04	

B. Tests involving DISTANCE Within-Subject effect

Mauchly sphericity test, W	0.05483
Chi-square approx.	81.58635 with 14 DF
Significance	0.000
Green house – Geisser Epsilon	0.66665
Huynh – Feldt Epsilon	1.0000
Lower – bound Epsilon	0.2000

C. Multivariate tests of significance for different effects

Tests name	Value	Approx. F	Hypoth. DF	Error DF	Sig. of F
Distance					
Pillais	0.88431	39.74860◆	5.0	26.00	0.000
Hotellings	7.64396	39.74860◆	5.0	26.00	0.000
Wilks	0.11569	39.74860◆	5.0	26.00	0.000
Roys	0.88431				
Size by distance					
Pillais	0.34852	1.13958	10.00	54.00	0.351
Hotellings	0.48709	1.21773	10.00	50.00	0.303
Wilks	0.66402	1.8135◆	10.00	52.00	0.325
Roys	0.30778				
Depth by distance					
Pillais	0.83237	1.52410	20.00	116.00	0.086
Hotellings	1.54479	1.89237	20.00	98.00	0.021
Wilks	0.33249	1.71647	20.00	87.18	0.046
Roys	0.54800				
Size by depth by distance					
Pillais	0.83221	0.74879	40.00	150.00	0.857
Hotellings	1.29002	0.78691	40.00	122.00	0.806
Wilks	0.36136	0.76364	40.00	116.13	0.834
Roys	0.46606				

D. Tests involving "Distance" Within – Subject effect and Averaged tests of significance for distance using UNIQUE sums of squares

Source	DF	Mean square	Sig. of F
Distance	5	28973.33	0.000
Size by distance	10	644.44	0.242
Depth by distance	20	1378.52	0.000
Size by depth by distance	40	440.74	0.672
Within + Residual	150	500.15	

◆ F statistics are exact

APPENDIX XXI

Abstracts of MANOVA for >5mm diameter roots of eight years old *Grevillea robusta*

A. Tests of Between-Subjects effects and tests of significance for T_1 using UNIQUE sums of square

Source	DF	Mean square	Sig. of F
Size	2	1317.04	0.083
Depth	4	2531.11	0.003
Size by depth	8	457.78	0.500
Within + Residual	30	487.41	

B. Tests involving DISTANCE Within-Subject effect

Mauchly sphericity test, W	0.02339
Chi-square approx.	105.52938 with 14 DF
Significance	0.000
Green house – Geisser Epsilon	0.52159
Huynh – Feldt Epsilon	0.84227
Lower – bound Epsilon	0.2000

C. Multivariate tests of significance for different effects

Tests name	Value	Approx. F	Hypoth. DF	Error DF	Sig. of F
Distance					
Pillais	0.60991	8.13029♦	5.0	26.00	0.000
Hotellings	1.56352	8.13029♦	5.0	26.00	0.000
Wilks	0.39009	8.13029♦	5.0	26.00	0.000
Roys	0.60991				
Size by distance					
Pillais	0.34059	1.10835	10.00	54.00	0.373
Hotellings	0.42677	1.06692	10.00	50.00	0.405
Wilks	0.68379	1.08841♦	10.00	52.00	0.388
Roys	0.23823				
Depth by distance					
Pillais	0.68841	1.20570	20.00	116.00	0.262
Hotellings	1.17054	1.43391	20.00	98.00	0.125
Wilks	0.41444	1.32599	20.00	87.18	0.185
Roys	0.47924				
Size by depth by distance					
Pillais	1.14852	1.11826	40.00	150.00	0.310
Hotellings	1.73039	1.0554	40.00	122.00	0.400
Wilks	0.24889	1.09110	40.00	116.13	0.352
Roys	0.46059				

D. Tests involving "Distance" Within – Subject effect and Averaged tests of significance for distance using UNIQUE sums of squares

Source	DF	Mean square	Sig. of F
Distance	5	4645.93	0.000
Size by distance	10	264.59	0.621
Depth by distance	20	566.67	0.034
Size by depth by distance	40	365.33	0.313
Within + Residual	150	327.41	

♦ F statistics are exact

ROOT COMPETITION BETWEEN COCONUT PALMS AND INTERPLANTED MULTIPURPOSE TREES UNDER VARYING NUTRIENT MANAGEMENT REGIMES

By

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ABSTRACT OF THE THESIS

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ABSTRACT

Coconut based production systems in the tropics often aim at improved resource capture through incorporating several trees and field crops. However, competition between the system components are probable when multipurpose trees are systematically interplanted in the coconut plantations. Soil fertility regimes are presumably important in determining the magnitude of below ground competitive interactions. Hence a study was conducted to evaluate the influence of interplanted multipurpose trees on coconut productivity along a soil fertility gradient, to assess the performance of multipurpose trees and to determine the nature of below ground interactions between coconut palms and multipurpose trees, at Vellanikkara since 1992. Treatments included combinations of cocounut with any one of the three multipurpose trees namely, *Vateria indica, Ailanthus triphysa* and *Grevillea robusta*, following two planting geometries(randomised block design, replicated thrice). A soil fertility gradient, was super-imposed with high, medium and low fertility levels in 2000. ^{32}P soil injection technique was employed to characterize root interaction and logarithmic spiral trenching technique for evaluating root distribution pattern.

Results show that coconut yield was not adversely affected by multipurpose trees interplanting until the trees reached eight years of age. Vateria, ailanthus and grevillea showed marked variations in their growth rates. Initially vateria recorded higher height and radial growth albeit ailanthus registered higher growth rates subsequently.

Isotopic studies reveal that ^{32}P absorption by coconut palms was similar in both sole and mixed cropping situations along the fertility gradient; probably implying the non-interfering nature of multipurpose trees. ^{32}P absorption by vateria and ailanthus suggests that the absorption of radioactive phosphorus declined linearly with increasing distance ie. ^{32}P absorption by multipurpose trees also did not affect the ^{32}P uptake by coconut, suggesting that integrated land use systems involving multipurpose trees and coconut are ideally suited for improved resource capture and increased system productivity.

Excavation of multipurpose tree root systems showed that proximal locations recorded higher rooting intensities and that the rooting intensities decreased with increasing distance. Size of the trees showed discernible differences in respect of spatial root distribution pattern. Large sized trees showed higher root distribution compared to small and medium. The first 10cm soil layer recorded the highest rooting intensities. Ailanthus roots were distributed upto a maximum distance of 469 cm, vateria upto 163 cm and grevillea upto 227 cm. Implicit in this is the species-dependent variations in lateral root spread. In general, vateria and ailanthus have a well developed and ramified root systems. Grevillea, however, had a less spreading root systems. Selection of tree species with low root competitiveness and/or trees with complementary root interactions is of strategic importance in agroforestry.