ROOT DISTRIBUTION PATTERN OF BAMBOO [*Bambusa arundinacea* (Retz.) Roxb. Gamble] AND ASSOCIATED COMPETITIVE EFFECTS

By

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THESIS

Submitted in partial fulfilment of the requirement for the degree of

Master of Science in Forestry

Faculty of Agriculture
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COLLEGE OF FORESTRY
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DECLARATION

I hereby declare that this thesis entitled **"Root distribution pattern of bamboo [*Bambusa arundinacea* (Retz.) Roxb. Gamble] and associated competitive effects"** 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.

Place : *Vellanikkara*
Date : 5-6-1999

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Finally, I bow my head before THE ALMIGHTY

Divakara B.N.

B.N. DIVAKARA

DEDICATED

TO

MY LOVING PARENTS

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Introduction

INTRODUCTION

Bamboos are valuable gifts of nature to mankind. It provides the basic necessities of life such as food, fuel, shelter and clothing. More than 50 per cent of the annual bamboo production, however, is used by the paper and pulp industry in India (Varmah and Bahadur, 1980). Bamboos are also effective in preventing soil erosion and facilitate on-site nutrient conservation (Christanty *et al.* 1996, 1997).

Bamboos form an important component of many evergreen and deciduous forests of India. They occupy over 9.6 million ha with an annual yield of 3.23 million tonnes (Sharma, 1987). Bamboos occur almost ubiquitously in the country except in Kashmir and cover about 12.8 per cent area of the tropical moist-deciduous forests in northern and southern India and the deciduous and semi-evergreen forests in north-eastern India. Recolonisation of forests plantations by bamboo is also not an uncommon phenomenon in India. Teak plantations of the site quality II and III are invaded by *Bambusa arundinacea* (Retz.) Willd. or other bamboos (FAO, 1956). In Kerala state where teak is raised extensively, bamboo is one of the important components of several plantations (Chandrashekara, 1996).

Bamboos are important components of the traditional homegardens of Kerala too (Kumar, 1997). Elsewhere also bamboo based agroforestry systems are popular (Christanty *et al.* 1997). Homegardens are often perceived as a prominent source of rural bamboo in Kerala (Krishnankutty, 1990). He estimated the standing stock of bamboo in the homegardens of Kerala as 39 million culms and the net area of bamboo as 581 ha.

Bambusa arundinacea (Retz.) Willd. is the prominent bamboo species in the homegardens of Kerala. Other species, such as *B. vulgaris* Schrad. ex Wendl., non Nees. and *Dendrocalamus strictus* Nees. though found, are spotty in distribution. Kumar (1997) reported that bamboo abundance in the homegardens is a function of the size of the operational holdings. Fragmentation of the holdings accelerated the process of spontaneous destruction of rural bamboos. Overall rural bamboo is regarded as a diminishing resource .

In many traditional land use systems, bamboos occur primarly as scattered trees or on farm boundaries. In managed land use systems also bamboos are generally planted on farm boundaries, presumably to offset the competitive influence. Farmers, however, apprehend severe competition for site resources between bamboos and other components in mixed species systems. Information available is, however, scarce in this respect. In mixed species system, roots of different species frequently intermingle and often this overlap can be extensive (Clements *et al.* 1929). Bamboo being a fast growing plant is expected to consume substantial quantities of nutrients. Furthermore, if soil resources are limited and neighbouring plant species have active root system in the same location of the soil profile, one species may be more effective in acquiring these scarce resources than the other. In general, tree root systems can potentially outcompete the field crops grown in association with them.

The partitioning and spatial distribution of the root system affect its ability to acquire water and nutrients. Generally, as width, depth and branching of root systems increase, plant's competitive ability increases. This is particularly true for bamboos which possess profusely growing surface roots. Some farmers, therefore, practice trenching to spatially isolate bamboo roots from the rest of the crops. Although there is increasing information of root system biomass and root production in various ecosystems, there is paucity of information on rooting intensity and root competition in tropical agroforestry systems involving bamboos. Hence the present experiment was designed with the main objectives of:

1. Characterising the root distribution pattern of boundary planted bamboos and
2. To evaluate the extent of root competition between bamboo and the associated trees in mixed species planting systems.

Review of Literature

REVIEW OF LITERATURE

2.1. Importance of Bamboo

Bamboos are giant, woody, tree-like grasses. They have a long history as an exceptionally versatile and widely used resource, linked with mankind ever since the beginning of civilization. It is variously known as the "poor man's multi-purpose timber", the "cradle to bier companion of man" (Hocking, 1993; John and Nadagauda, 1995) and as "green gold" of the forest (Maheshwari and Satpathy, 1990). It is a prominent renewable resource that yields considerable biomass over short rotations. "Bamboos are all things to some men and some things to all men" (Marden, 1980). It is a very important forest produce and plays a vital role in the socio-economics of rural population. The uses of bamboo are many and vary from place to place depending on local preferences and availability (Das, 1990).

Bamboo is used in nearly every aspect of daily life. Its importance is better felt and understood in areas where it abounds or where timber and other traditional construction materials are not readily available or expensive. It supports many major industries such as housing, construction, handicrafts and furniture making, fishing, banana cultivation and food production (PCARRD, 1979). It is also used for making musical instruments, for ornamental purpose and as a landscape material. More importantly, it is used in the pulp and paper industries, where it is consumed at the rate of about 4.9 million tonnes out of 9.5 million tonnes production in India (Varmah and Bahadur, 1980).

Apart from its commercial uses, bamboo is very effective in preventing soil erosion (Kamondo and Haq, 1990). It binds the earth against raging floods and the shocks of earth-quakes (Luis Marden, 1980). Added to this, the slow decomposition of its silica-rich litter and the extremely high biomass of fine roots helps to recover much of the nutrients leached deeper into the soil profile. The importance of bamboo is reflected in the Indonesian saying that "without bamboo, the land dies" (Christanty *et al.* 1996,1997). Under sound management, bamboos combine productivity with soil conservation and field-bund stabilization (Hocking, 1993).

2.2. Species diversity, distribution and abundance of bamboo

Bamboos are an unique group of monocotyledonous, fast growing, perennial giant, arborescent grasses belonging to the tribe Bambuseae of the family Poaceae (Gramineae). Over 75 genera and 1250 species of bamboos are reported to occur in the world (Sharma, 1987). Eighty percent of the world bamboo resource is distributed mainly in the south Asian tropical region (Kigomo, 1990). About 130 species belonging to 24 genera of bamboos have been reported from India (Sharma, 1987), out of these 20 are indigenous and 4 are of exotic origin.

Bamboos occur as natural vegetation in the tropical, sub-tropical and temperate regions, but are found in great abundance in the tropical Asia. In India, it has a wide distribution. Bamboos from an understorey in several forest types. The tropical moist-deciduous forests of northern and southern India and the deciduous and semi-evergreen forests of north-eastern India are the natural habitats of bamboos (Appasamy and Ganapathi, 1992). The total forest area covered by bamboos in the country is about 9.6 million hectares (Sharma, 1987), this is about 12.8 per cent of the total forest area of the country.

In Kerala, bamboos are found distributed right from the sea coast to the high ranges, *Bambusa arundinacea* (Retz.) Willd., *Dendrocalamus strictus* Nees., *Oxytenanthera* sp. *Ochalandra travancorica* (Bedd.) Benth ex Gamble. *O. scriptoria* (Dennst.) Fischer and *O. ebracteata* Raizada and Chatterji, have been found associated with different forest types in the state (Varmah and Bahadur, 1980). Among these, *Bambusa arundinaceae, Dendrocalamus strictus* and *Ochlandra* species are economically important and commercially exploited bamboos in Kerala (Mohanan, 1994).

In general, bamboos, because of their varied uses and fast growth, forms a species suitable for Agroforestry, plantation forestry and social forestry (John and Nadagauda, 1995). In Kerala homegardening forms a pre-dominant land use activity and bamboo is a important component of the homegardening system in many parts of the state (Kumar, 1997, Kumar *et al.* 1994). The total area occupied by bamboo in the homesteads of Kerala is estimated to be about 581 ha with 39 million culms (Krishnankutty, 1990).

2.3. Bamboo biomass production

Biomass production and allocation to various parts is a decisive factor that reflects the success of an organism in an environment (Gadgil and Solbrig, 1972). Measurements of the amount and distribution of biomass and nutrients are important in understanding the structure and function of the ecosystem (Grove and Malajczuk, 1985). Relative allocation of various fraction to total biomass varied markedly among the species.

2.3.1. Biomass accumulation in different organs

The most important component in respect of total biomass accumulation for all species is the bole/culms while foliage represents the least biomass yield. Bamboo clump biomass production and its relative allocation to various component was evaluated in talun - kebun (fallow cropping) rotation cycle by Christanty *et al* (1996) using *Gigantochloa* species. The results revealed that the above ground biomass of each bamboo component increased with increased field age from 0.4 Mg ha^{-1} at 16 months to 2.7, 9.2 and 34.4 Mg ha^{-1} at the ages of 24, 36 and 72 months respectively in case of culm biomass, 0.1 Mg ha^{-1} at 16 months to 6 Mg ha^{-1} at 72 months in case of branch biomass, 0.1 Mg ha^{-1} at 16 months to 2.6 Mg ha^{-1} and 4.7 Mg ha^{-1} at 36 and 72 months respectively in case of foliage biomass. The ratio of branches to foliage biomass was approximately 1.0 except at 72 months when it rose to about 1.3.

The biomass of live mother rhizomes however, decreased with time (8.4 Mg ha^{-1} at 16 months and 0 Mg ha^{-1} at 72 months). In contrast, biomass of live new rhizomes increased with increasing field age (0.2 Mg ha^{-1} at 16 month and 10.5 Mg ha^{-1} at 72 months).

They also found that above ground biomass accounted for 6 per cent, 34 per cent and 50 per cent of total bamboo biomass at 16, 24, 36 months. Conversely, the proportion of the total biomass contributed by below ground components decreased with increasing age. It accounted for about 94 per cent of total biomass at 16 months, but represented only 41 per cent at 72 months.

Biomass productivity in *Bambusa arundinacea* aged 4,5 and 6 years were studied by Shanmughavel and Francies (1996) and found that the standing biomass increased with age, as expected. Culms accumulated a higher proportion of the biomass than the other parts of the bamboo (biomass in leaves, branches and culm were 1.9, 27.2 and 92.8 Mg ha^{-1} respectively at age 4 years and 4.0, 39.9 and 242.7 Mg ha^{-1} at 6 years).

2.3.2. Species differences in biomass production

In a comparative study on biomass production of two bamboo species, Chinte (1965), found that, in a 3 to 4 year old plantation *Bambusa vulgaris* recorded 7 Mg ha^{-1} while *Gigantochloa aspera* registered a value of 1 Mg ha^{-1}. Othman (1992), evaluated the above ground biomass of *Gigantochloa scortechinii* in natural stands and three year old plantations. He found that biomass production was 71.9 Mg ha^{-1} in a plantation and 36.2 Mg ha^{-1} in natural stands. Young (1991), examined dominant understory bamboo (*Chusquea* spp) at timberline in north-central Peru and found an above ground biomass yield of 22 Mg ha^{-1}, below -ground biomass yield of 7 Mg ha^{-1} and an average culm density of 26 culms/ha.

Also, in a study on biomass production of *Gigantochloa spp.* by Christanty *et al.* (1996), the mass of the live rhizomes almost doubled (from 5-8 to 10.5 Mg ha^{-1}) during the fallow period (36-72 months). Coarse root biomass increased from 0 Mg ha^{-1} at 16 months to 2.1 Mg ha^{-1} at 72 months. Total fine root biomass in the mature bamboo field (72 months) was approximately 18.9 Mg ha^{-1}. However, information relating to biomass accumulation in bamboo roots is very scarce, although there is an increasing volume of published information in this respect relating to other species.

2.4. Ecological requirements of bamboo

Babusa arundinacea grows well on acidic non-calcareous soils of varying texture formed mainly from granitic gneisses and basalt. It prefers humid condition but tolerates water logging to some extent (Khader Hussain, 1980). In general, it is found on soils rich in aluminium, manganese and potassium (Yadav *et al.*, 1963). Bamboo forest occurs best in localities where the soil is deep and loamy in texture with less humus or humified matter, with a topography of middle to lower slopes of the hills and also in valleys where drainage is good (Khan, 1960).

Bamboo being an extremely fast growing species, can be expected to consume large quantities of nutrients. Studies have shown that the supply of nutrients considerably increased growth and biomass production of *Bambusa* spp. (Shi *et al.* 1987).Chandrashekara (1996), assessed the contribution of bamboo to the vegetation structure, nutrient cycling pattern in 15 to 20 year old teak plantations in the Kariem-muriem forest range, Kerala. It indicated that the role played by *Bambusa arundinaceae* in conservation of potassium (easily leachable element). Lower accumulation of calcium in biomass and higher fractional annual turnover rate of calcium suggested bamboo adaptability to calcium-poor soils.

Artificial fertilization increases the growth rate and yield of bamboo. Fertilizer trials conducted by Patil and Patil (1990) on *Dendrocalamus strictus* (Roxb.) Nees. indicated that the total dry matter production increased from 4 Mg ha^{-1} in control to 12.5 Mg ha^{-1} with an application of 100 + 50 + 50 kg NPK/ha per year. Suzuki and Narita (1975) reported that the number of sprouts from the fertilized plots was 1.7 to 1.9 times that of the control. Also fertilizer experiments conducted on *Thyrsostachys siamensis*, *Dendrocalamus asper*, *Bambusa* spp. and *D. strictus* in three-year-old plantation at Dong-lam in Khonkaen by Suwannapinuut and Thaiutsa (1990) showed that the use of 15-15-15 NPK fertilizer at 100 kg ha^{-1} is sufficient to increase the yield.

2.5. Bamboos on farmlands

Bamboos are grown in homegardens and farmlands under mixed species system in south and south east Asia (Tejwani, 1994). Since bamboos are vigorous, fast growing and dense, they cannot be combined with arable crops with ease. Bamboos are, therefore confined largely to the field margins (Hocking, 1993). Also, farmers are not willing to sacrifice large farm areas for raising bamboos since subsistence crops are far more important to them. Hence, in the peninsular India cultivation of bamboo as a sole crop is seen only in industrial plantations.

However, intercropping of bamboo and cash crops is commonly practiced by farmers in Thailand (Thammincha, 1985). Farmers in Sikkim and Manipur grow bamboo in agricultural fields all along the irrigation channels and stream banks to meet the fodder needs of their live stock (Venugopal, 1986).

Effect of intercropping bamboo (*Dendrocalamus strictus* Nees.) with soyabean (*Glycine max* L. Merrill) was evaluated in Coimbatore by Seshadri (1995). He found that intercropping of bamboo during the first six years is technically feasible and economically viable. The period of intercropping can however, be extended further if wider spacing of bamboo is used and under judicious manipulations of bamboo canopy.

Patil and Patil, (1982) evaluated suitable companion crops that can be grown along with bamboo. It is found that the growth and dry matter production of bamboo is not adversely affected by planting trees like *Sesbania grandiflora, Macroptillium atropurpureum, Leucaena leucocephala, Lotononis bainessi* and *Casuarina equisetifolia* as intercrops. Performance of bamboo with horticulture crops (mango, cashewnut, jack fruit and kokum and rubber) was evaluated by Wang and Rajput (1991) in Konkan. They showed that, bamboo is the most profitable among all crops. Cashew and mango ranked next to it. Venkatesan (1980) reported that sandal is found growing well with bamboos.

Growing space requirements of bamboo in conjunction with agricultural crops was studied by Sheikh (1983) at the Pakistan Forest Institute, Peshawar and found that there was not much difference in diameter of the bamboos but the number of culms per clumps was much more in the widest spacing i.e. 6 × 6m and almost double than that of the 2 × 2m and 3 × 3m spacing. Mathauda (1959), evaluated the silviculture and management of *B. arundinacea* and found that initial spacing is governed by the size of bamboo and the quality of soil. Wider spacing is needed in the case of large bamboos and on better quality of soil. However, when bamboo is grown with agriculture crops, 6 × 6 m to 9 × 9 m spacing is considered optimal.

However, farmers often apprehend competition for site resources and are generally reluctant to grow bamboo on their farm fields (Kumar, 1998). Therefore, it is essential to have a thorough understanding of the technical, social, economic and biophysical constraints of bamboo based farming systems.

2.6. Competitive interactions involving bamboos on farmlands

Competition for native and applied resources among component crops is an important factor that limits productivity of agroforestry systems (George *et al.* 1996). However, studies on bamboo root distribution pattern and root level interactions with the associated crops is seldom found in the literature.

Root competition for nutrients is a complex combination of soil supply and plant uptake mechanisms (Gillespie, 1989). Vandenbeldt *et al.* (1990) reported that soil nutrition and competition for soil water is dependent on root distribution pattern too. Plants with deep root system generally decreases competition, where as shorter thick roots quickly deplete adjacent nutrient pools, promoting steep and extensive nutrient gradients (Gillespie, 1989). Ong *et al.* (1991) found that tree roots can exploit water and nutrients below the shallow roots of field crops.

Above ground competition (i.e. for light) and below ground competition (i.e. for water and nutrients) may both be important under boundary plantings, as was demonstrated in a study in Uganda that used a root mesh to prevent lateral root spread. When trees of four species were 3.5 year old, crop yields adjacent to trees without root mesh were 20 per cent to 55 per cent of yield in the tree-less open area (Okorio *et al.* 1994). When root mesh was installed to 0.5 m depth and 0.5 m away from trees, yields increased by 152 per cent adjacent to *Maesopsis eminii*, 57 per cent adjacent to *Markhamia lutea* and 16 per cent adjacent to *Casuarina cunninghamiania*.

Root studies also revealed lack of spatial complementary 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). Competition of trees for aboveground factor can be managed to some extent by pruning, maintaining the appropriate density and sequential thinning. However, the scope for management of below ground competition is limited to the manipulating of root densities through species or cultivar selection for known soil nutrient deficiencies (Gillespie, 1989; Rao *et al.*, 1998) and by regulating spacing (Gillespie, 1989).

Further, 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 culture involving widely spaced crops have been very scanty (Ashokan *et al.* 1988). Therefore a better understanding of the interactions is necessary for a elucidating the scientific under pinnings of traditional as well as evolving land use systems.

2.7. Bamboo root distribution pattern

Information on the distribution of active roots is a pre-requisite for formulating a rational method for fertilizer application (Wahid *et al.* 1989 a). Also it is important in understanding the extent of soil space explored by component species in polyculture in view of the competition/complementary root level interactions taking place among them (Willey, 1979).

A study conducted on *Bambusa tulda* to ascertain the distribution of the roots in the soil by White and Childers (1945) showed that, the roots were seen at a distance of more than 17 feet from the clump. Most of the roots (83 per cent) were present in the upperfoot of soil which is the area, where root serve best in controlling soil erosion. The percentage of roots at lower layer were, 1 to 2 foot depth (12 per cent), 2 to 3 foot depth (4 per cent) and 3 to 4 foot depth (1 per cent).

As agroforestry land use systems are relatively complex, and bamboos are generally characterised by large clump size, a thorough understanding of root distribution pattern is essential for selection of species (to be grown as component crops). However, the information on bamboo root distribution is scanty. Studies relating to root distribution pattern of bamboo is scarce owing to methodological problems.

The excavation method probably gives a clear picture of the entire root system of a plant as it exists naturally. It gives the length, size, shape, colour, distribution of each individual root, also it gives the inter-relationship between competing root systems of other plants (Coker, 1959; Kolesnikov, 1971). It is usually practiced for woody trees and shrubs than for annual crops (Bohm, 1979). However, the excavation methods are laborious and time consuming. Also it is incapable of characterising the functional roots (physiologically active fine roots).

Logarithmic trenching has been used to characterise the root distribution pattern of trees in relation to their diameter and crown spread (Huguet 1973). Tomlinson *et al.* (1998) also employed this technique for investigating the root distribution pattern *Parkia biglobosa* (Jacq.) Benth. They found that tree roots extended upto 10 m from the trunk, there by exploiting an area twice that of the crown.

Methods involving radioactive isotopes have gained significance in ecological root research considering the limitations of excavation approach. ^{32}P is a most commonly used isotope because of its short half-life (14.3 days). It is also mobile in plants to become rather uniformly distributed in root system in a short time and is relatively in-expensive (Bohm, 1979).However, tracer methods do have some limitations, as it can not be used in stony, crevices and cracks and also the data obtained is not easy to relate with those from another (Page and Gerwitz, 1974). Nonetheless, it is used as it gives information on uptake of nutrients from different soil layers and provides root information with out separating from soil.

Studies conducted by Wahid *et al.* (1989 a,b) in cocoa and cashew using ^{32}P reveals that, the cashew is a surface feeder with 80 per cent of roots are confined to the top 15 cm of soil layer and 72 per cent of roots activity was found within the radial distance of 2 m from the tree. In case of cocoa, 85 per cent of the feeder roots were found within the area of radius 150 cm around the tree. Also, Jamaludheen *et al.* (1997) employed this technique to characterise the root distribution of wild Jack in eight-and-a-half year old age and found that roots are concentrated upto 75 cm distance and to 30 cm depth.

Overall, information on bamboo root distribution and associated competitive effects are scarce. However, such details are probably necessary to improve the traditional land use practices involving bamboos and/or for classifying new agroforestry system.

Materials and Methods

MATERIALS AND METHODS

3.1. Location

The study was conducted at the Instructional farm, College of Forestry, Kerala Agricultural University, Vellanikkara, Thrissur district, Kerala (10° 13'N latitude and 76° 31'E longitude and at an elevation of 22.25 m above sea level), during the period from June 1997 to May 1998.

3.1.1. Climate

Vellanikkara experiences a warm humid climate, having a mean annual rainfall of 2824 mm (mean corresponding to the twelve-year period from 1985-1997), most of which is received during the south-west monsoon (June to August). The mean maximum temperature ranges from 28.6°C (July) to 36.5°C (April) and mean minimum temperature varies from 21.8°C (July) to 25.6°C (April). The total rainfall received during study period was 3247.3 mm (Fig.1, Appendix I).

3.1.2. Soil

The soil of the experimental site is a well drained lateritic loam, having a pH:5.74 ± 0.004, total N:0.13 ± 0.004%, available P:14.10 ± 0.586 mg g^{-1}, available K:44.17 ± 0.680 mg g^{-1} and organic C: 1.28 ± 0.087%.

3.2. Field Experiment

The field experiment was conducted in a bamboo [*Bambusa arundinacea* (Retz.) Willd.] stand established on field boundaries in the Panchavadi block of the KAU estate.

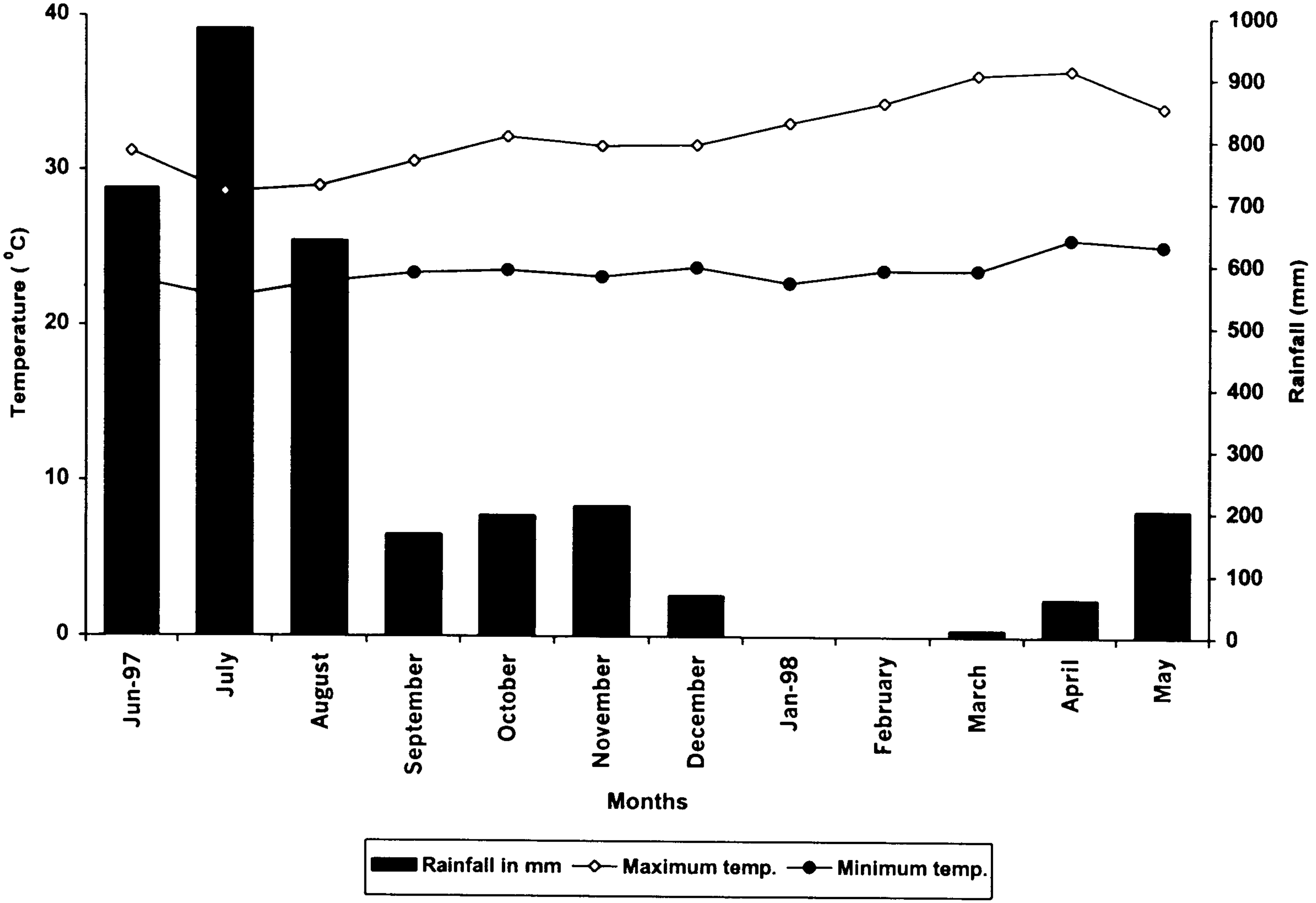


Fig. 1 Weather parameters at Vellanikkara for the experimental period

3.2.1. Stand Description

Bamboo clumps were established in 1985, as part of a commercial planting programme (over a linear distance of about 0.5 km). There are about 40 clumps bordering teak (*Tectona grandis* Linn. f.) stand with a mean spacing of about 21 m between clumps (range 7.6 to 64.2 m) and about 25 clumps on the boundaries of the adjacent vateria (*Vateria indica* Linn.) stand at mean spacing of 11 m distance (range 3.5 to 22.2 m). The clump size is with a variable mean diameter of 2 m (range 0.43 to 3.0 m), mean height of 12.5 m (range 5.4 to 19.2 m) and mean number of 40 culms per clump (range 5 to 98).

Teak was established in this area by planting one year old teak seedlings at 2 × 2 m spacing during June, 1985. Intermediate treatments such as weeding and pruning of lower branches were carried out at irregular intervals. Stand height and diameter at breast height (DBH) ranged from 3.5 m to 18 m (mean 10.2 m) and 4.0 cm to 28.0 cm (mean 11.2 m) respectively.

Vateria was planted at this site in July 1991 as part of an experimental programme. Although there were four spacing treatments in this experiment, the *Vateria* strip neighbouring bamboo clumps followed 3 × 1 m spacing. Fertilizers were applied at the rate of 50:25:25 kg of N, P_2O_5 and K_2O ha^{-1} $year^{-1}$ in this strip. Mean height and DBH were 4.2 m (range 1.7 to 8.2 m) and 8.4 cm (range 2.0 to 18.0 cm) respectively.

3.3. Evaluation of root competition using ^{32}P soil injection method

To asses the nature of root competition experienced by different tree components grown in association with bamboo, radiotracer technique involving ^{32}P

PLATE 1 General views of bamboo clump in experiment area

soil injection was employed. Two binary associations: teak (*Tectona grandis* Linn.f.) - bamboo and *Vateria* (*Vateria indica* Linn.) - bamboo were selected for this purpose.

3.3.1. Selection of experimental units

Lateral distances from the base of the bamboo clump to the nearest *Vateria* and/or teak were measured all along the boundary line. Eighteen experimental units were then selected taking into consideration factors such as uniformity in size of bamboo clumps/other tree components and distance between the two tree components of the binary mixture. A minimum distance of 10 m was maintained between two experimental units. Wherever two experimental units did not conform to this minimum distance (four cases), they were separated by 70 cm deep and 10 m long trenches to ensure minimum interference to adjacent units. Selected experimental units were broadly grouped into three lateral distance classes (viz. <2.5 m, 2.5 to 3.5 m and >3.5 m or <3 m, 3 to 4.5 m and >4.5 m respectively for teak – bamboo and *Vateria* – bamboo combination).

DBH of teak in the experimental units ranged from 6 to 27.3 cm (mean 13.5 cm) and height from 5.85 to 16.85 m (mean 11.4 m). The respective figures for *Vateria* experimental units were 2.7 to 12.7 cm (mean 6.7 cm) and 3.2 to 6.75 m (mean 5.51 m). As regards to neighbouring trees, DBH fell in the range 4 to 28 cm (mean 15.5 cm) and height 3.5 to 17.5 m (mean 10.5 m) for teak and DBH 2 to 14.6 cm (mean 8.4 cm) and height 1.7 to 7.75 m (mean 4.8 m) for *Vateria.*

For soil application of ^{32}P, eight equally spaced holes were dug to either 25 cm or 50 cm at a radial distance of 50 cm from trunk of the selected teak/*Vateria*

PLATE 2 Experimental units for ^{32}P application showing the access tubes

a) Teak – bamboo combination

b) *Vateria* – bamboo combination

tree using a soil auger of 2 cm diameter. PVC access tubes protruding 10 cm above the soil surface were inserted into the holes. The open end of each tube was covered with a plastic cap to prevent entry of rain water.

^{32}P solution at a carrier level of 1000 mg L^{-1} P (IAEA, 1975) was dispensed into the access tube at the rate of 2 mL per hole during north-east monsoon on November 4, 1997 using a device fabricated for the purpose (Wahid *et al.*, 1988). The total radioactivity applied per plant was 116.92 MBq (3.16 mCi).

After dispensing, the access tube was washed down with a jet of about 15 mL water to clean the residual activity remaining in the tube. The carrier in the ^{32}P solution was used to minimise the chances of soil fixation of the radioisotope (IAEA, 1975).

3.3.2. Leaf sampling and radioassay

Newly formed, young leaves of treated plants, neighbouring plants of the same species and the associated bamboo clumps were sampled separately for radioassay. Sampling was done thrice at 15, 31 and 45 days after application of ^{32}P. The leaf samples were air-dried for one day and oven dried at 75°C and radioassayed for ^{32}P content at the Radio-tracer Laboratory, Kerala Agricultural University, Vellanikkara. The method consisted of wet digestion of one gram of plant sample using diacid mixture (HNO_3 and $HClO_4$ in 2:1 ratio) and the digest was transferred to a counting vial. The final volume of the content in the vial was madeup to 20 mL. The vials were counted in a liquid scintillation counter (Wallac 1409 Pharmacia, Finland) by Cerenkov counting technique (IAEA, 1975). During the course of experiment, the counting efficiency remained constant at 32 per cent and

PLATE 3 One of the small clumps selected for characterising root distribution

hence the count rates were not converted to dpm but were expressed as cpm values. Prior to statistical analysis the cpm values were corrected for back ground as well as for decay and subjected $\log_{10}(x+1)$ transformation and analysed.

3.4. Characterizing root distribution using modified logarithmic spiral trenching method

Logarithmic spiral trenches suggested by Huguet (1973) were used to characterise the root systems. Eighteen bamboo clumps were randomly selected considering their clump diameter and distance between adjacent bamboo clumps. Minimum distance between two selected bamboo clumps was maintained at 5 m apart. Based on clump diameter they were classified as small (1.0 to 2.5 m diameter range), medium (2.5 to 4.0 m) and large (4.0 to 5.5 m). Each category having six clumps. Crown radius of each selected clump was measured by projecting the crown edges to the ground. The distance between each crown edges were summed and mean crown radius (r) calculated. Crown radius ranged from 5.4 to 12.03 m (mean 8.6 m).

Root systems of the selected clumps were partially excavated using a modified logarithmic spiral trench technique based on the ratio between crown radius and diameter of clump (r/d). The dimensions of each trench was determined using the following formulae.

$$X = 0.75 \times d \longrightarrow (1)$$

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

$$Z = Xe^{y\theta} \longrightarrow (3)$$

PLATE 4 & 5 Two views of modified logarithmic spiral trench as dug around the bamboo clumps

Where, d = clump diameter in m

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

X = the distance of the starting point of the spiral from the trunk in m.

Y = natural logarithm of the ratio of crown radius to diameter of clump divided by $\pi/2$

Z = the distance of any point on the spiral from the clump base in m

The starting point for the internal face of each trench (A) was obtained by calculating 'X' from a north facing point on the trunk, the origin (O), with the spiral curving in a clockwise direction due south, thus sampling a 135° sector of the root system. θ was taken as 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 get the seven co-ordinates of the internal trench OA, OB, OC, OD, OE, OF and OG as shown in the Fig. 2. The co-ordinates of the external trench was obtained by increasing the length of the co-ordinates from 0 to 10 m from the internal trench by 60 cm to give OA', OB', OC', OD', OE', OF', and OG'.

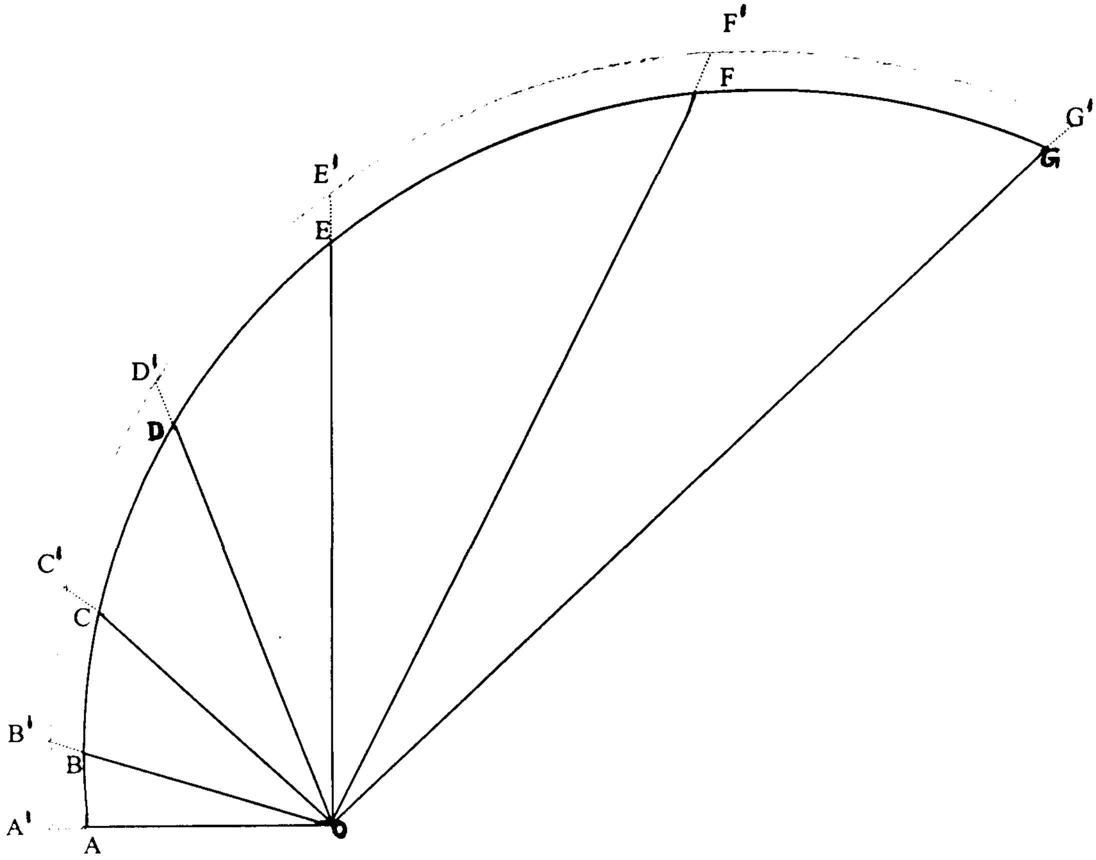


Fig. 2: Diagram to show the coordinates of the modified logarithmic spiral trench

PLATE 6 A closer view of the trench

Outlines of internal and external spirals was marked with a string before digging. The trench was then excavated to a width of 60 cm, between the internal and external spirals and to a depth of 60 cm taking care that the sides of the trench remained vertical. The number of severed roots exposed on both sides of the trench was assessed by placing a 50 cm × 50 cm quadrat against the vertical sides of the internal and external faces of the trench. The quadrats were positioned along the spiral trench at increments of 1 m from 0 to 10 m from the trunk.

Actual distance of each quadrat from the centre point of the clump and the distance of each quadrat from starting point on the vertical sides of internal and external faces were also recorded. Number of roots (<2 mm and 2-5 mm diameter size) in 10 cm depth intervals (for each 50 × 50 cm quadrat) were recorded.

All the roots at different depths in each quadrat at different intervals were converted into number of roots m^{-2}; the rooting intensity according to Bohm (1979).

3.5. Statistical analysis

The data on ^{32}P activity in the leaves of treated teak and treated *Vateria* trees were analysed following the two factor Analysis of Variance technique for Completely Randomized Design, using MSTAT (version 1.2) with lateral distance (3 levels) and depth of application (2 levels).

Data on ^{32}P activity in bamboo leaves were analysed using two factor Completely Randomized Design with covariance analysis (MSTAT, version 1.2). Main effects and interactions due to lateral distance (3 levels) and depth of application (2 levels) using girth of bamboo clump as the co-variate were ascertained.

The ^{32}P activity in the leaves of treated teak/*Vateria* trees were regressed on distance of bamboo occurrence using the linear regression models with MSTAT (version 1.2). Similarly, ^{32}P uptake by bamboo clumps was regressed on lateral distance from treated trees.

Foliar ^{32}P activity of neighbouring trees in each plot was worked out as the sum of activities for all trees sampled in an experimental unit and were subjected to analysis with lateral distance (3 levels) and depth of application (2 levels) following Analysis of Variance technique using MSTAT (version 1.2) for Completely Randomized Design. Data on ^{32}P activity in neighbouring teak/*Vateria* leaves were regressed both on distance from treated tree and distance between treated tree and bamboo occurrence using linear regression model with MSTAT (version 1.2).

Root intensity data (number m^{-2}) were analysed for differences between clump sizes and lateral distances (1 m intervals along the trajectory of the logarithmic spiral trenchs) using ANOVA with repeated measures (MANOVA) employing the statistical package SSPS (Advanced statistics version 2.0). Hierarchical cluster analysis was performed as the multivariate tests for clump size by distance, clump size and distance effects were significant. Clustering was done using average linkage between groups (Everitt, 1974). The distance measure used was squared Euclidean distance.

Regression equations linking distance (independent variable) and root count as dependent variable were fitted following multiple regression analysis (MSTAT, version 1.2).

Results

RESULTS

4.1. Absorption of ^{32}P by different components in teak-bamboo combination

Leaf assay of the treated and surrounding plants in the binary mixture revealed that the applied ^{32}P was absorbed not only by the treated teak trees but also by surrounding trees of the same and other species. Leaf assay, however, can lead to misleading information in comparisons involving ^{32}P absorbed by different species and individuals of the same species having different size/biomass contents. Hence, only within species comparisons of ^{32}P activity expressed as cpm values were made. Furthermore, analysis of covariance with clump diameters as the co-variate was performed in respect of the evaluations involving bamboo clumps.

4.1.1. Absorption of ^{32}P by treated teak

Data on ^{32}P uptake by teak as a function of lateral distance of bamboo occurrence are presented in Fig.3 and Tables 1 and 2 (ANOVA in Appendix II). In general ^{32}P uptake by teak increased as lateral distance of bamboo occurrence increased when the tracer was applied in the surface horizons of the soil profile (25 cm depth). With deeper placement (50 cm) ^{32}P recovery by teak declined linearly with increasing distance of bamboo occurrence. Mean ^{32}P cpm (counts per minute g^{-1} dry weight) values were 20 to 25 per cent higher when ^{32}P placement depth was 25 cm compared to 50 cm.

At 25 cm depth of placement, cpm values were 1227.52, 748.47 and 760.12 at 4.5 m and at 1.5 m distance from bamboo occurrence cpm values were 97.91, 6.3 and 117.12 at 15, 31 and 45 days of observations respectively. Comparison of ^{32}P uptake at different time intervals did not show any characteristic patterns. ANOVA performed on the data-set by pooling distance into 1 m classes also yielded no statistically significant variations. Although the ^{32}P uptake pattern of teak was

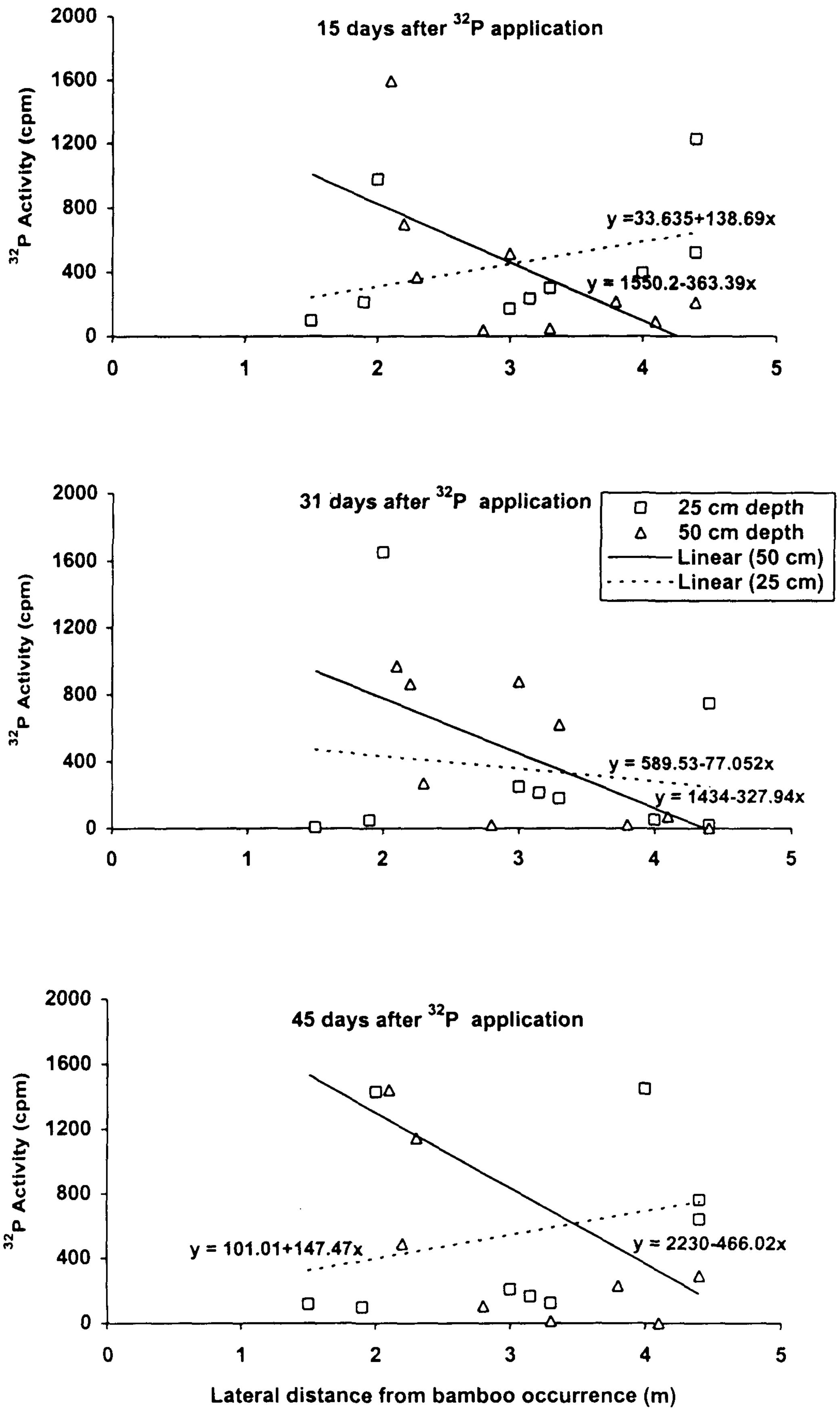


Fig. 3 Absorption of ^{32}P by treated teak as influenced by distance from bamboo clumps

Table 1 : ^{32}P absorbed (y) by treated teak trees (cpm g^{-1} dry leaves) as influenced by distance (x) from bamboo clumps

Days after isotope application	Depth of placement (cm)	Equation (Y = a + bx)	R^2	SEE	N	p
15	25	33.638 + 138.689 x	0.149	384.465	9	0.304
	50	1550.213 - 363.387 x	0.392	410.792	9	0.071
31	25	589.529 - 77.052 x	0.024	567.897	9	1.000
	50	1433.980 - 327.945 x	0.447	331.424	9	0.049
45	25	101.008 + 147.470 x	0.083	567.556	9	1.000
	50	2230.025 - 466.023 x	0.135	1069.812	9	0.330

cpm Count per minute
SEE Standard error of estimate
R^2 Coefficient of determination
n Number of observations
p Probability

Table 2: Absorption of 32p by teak at 15, 31and 45 days after application of ^{32}P to the soil

Lateral Distance of bamboo clumps (m)	15th day log (x+1) cpm g^{-1} dry weight		31st day log (x+1) cpm g^{-1} dry weight		45th day log (x+1) cpm g^{-1} dry weight	
	Mean	S.D ±	Mean	S.D ±	Mean	S.D ±
< 2.5	2.654 (450.8)	0.4474	2.347 (222.3)	0.9313	2.688 (487.5)	0.5348
2.5 - 3.5	2.174 (149.3)	0.4540	2.343 (220.3)	0.5636	2.213 (163.3)	0.7743
>3.5	2.503 (318.4)	0.3884	1.521 (33.2)	0.9340	2.279 (190.1)	1.1534
SEM ±	0.1565		0.3304		0.3317	
CD (0.05)	NS		NS		NS	
Depth of ^{32}P Placement (cm)						
25	2.533 (341.2)	0.3553	2.072 (118.0)	0.7562	2.522 (332.7)	0.4760
50	2.355 (226.5)	0.5428	2.069 (117.2)	1.0261	2.264 (183.7)	1.1047
SEM ±	0.1278		0.2698		0.2708	
CD (0.05)	NS		NS		NS	
Interaction						
SEM ±	0.2214		0.4673		0.4690	
CD (0.05)	NS		NS		NS	

Retransformed values given in paranthesis

cpm - count per minute
NS - Not Significant
SEM – Standard Error of Mean
CD - Critical Difference

distinctly different when the isotope was placed at different depths, both 25 cm and 50 cm depth were found to be statistically at par (Table 2). Interaction effect also was not significant.

4.1.2. Absorption of ^{32}P by neighbouring teak trees

^{32}P absorption by neighbouring teak trees declined as lateral distance with treated tree increased (Fig. 4). Both 25 cm and 50 cm deep placements exhibited a negative linear trend. The magnitude of reduction, however was greater when the tracer was placed at 25 cm depth. At this depth the cpm values at 5 m was 67, 86 and 10 per cent less than that at 1 m at 15, 31 and 45 days after application respectively. The corresponding figures at 50 cm depth were 82, 66 and 38 per cent at 15, 31 and 45 days after application respectively. Fitted equations, however, gave low R^2 values (Table 3). Two-way ANOVA with lateral distance of bamboo occurrence (grouped into 1 m class intervals) and depth of isotope application did not give statistically significant difference among the treatments (Table 5, Appendix III). Interaction effect also was not significant.

Teak trees adjacent to the treated trees registered progressively lower radioactivity levels with increasing lateral distance of bamboo occurrence (Fig 5), despite low R^2 values for fitted equations (Table 4). Having bamboo clumps at 1.5 m lateral distance from the treated teak tree resulted in 94, 95, 92 per cent reduction in the radio-activity absorbed compared to bamboo at 4.5 m distance (depth of application: 25 cm). Deeper placement of the radio-label, however, resulted in 26, 0 and 76 per cent less absorption at 15, 31 and 45 days after application. Differences in the sum of the radioactivities recorded by neighbourhood teak trees as a function of lateral distance of bamboo occurrence also were not significant (Table 5), presumably because of variations in the population of neighbouring plants (n:3-9).

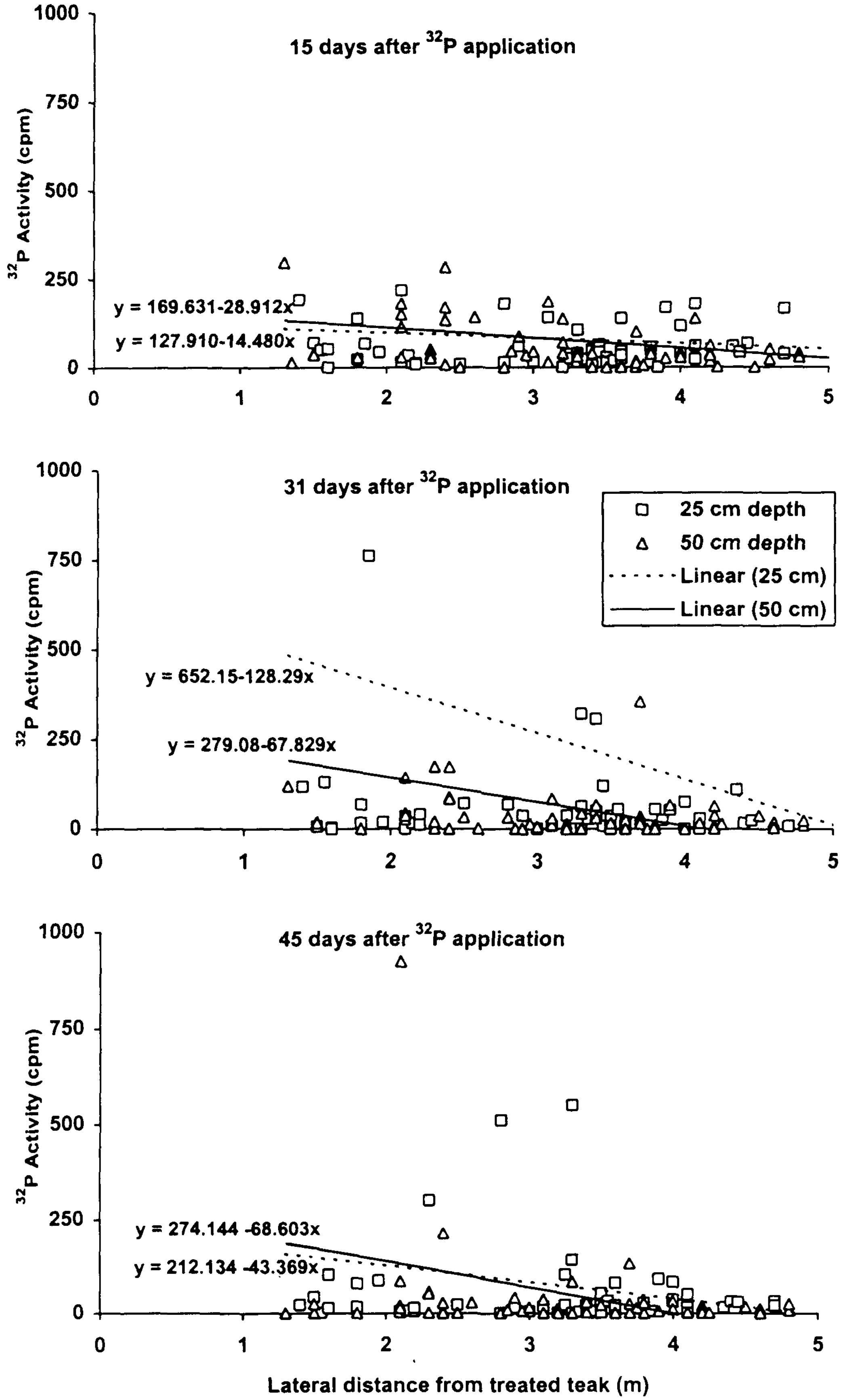


Fig. 4 Absorption of ^{32}P by neighboring teak at various distance from treated teak

Table 3 : ^{32}P absorbed (y) by neighbouring teak trees as (cpm g^{-1} dry leaves) influenced by distance (x) from the treated plants

Days after isotope application	Depth of application (cm)	Equation $Y = a + bx$	R^2	SEE	n	p
15	25	127.910 – 14.480x	0.01	154.608	55	1.000
	50	169.631 – 28.912x	0.03	160.761	57	0.223
31	25	652.148 – 128.294x	0.01	1143.940	55	1.000
	50	279.081 – 67.829x	0.10	192.731	57	0.019
45	25	212.134 – 43.369x	0.04	198.516	55	0.139
	50	274.144 – 68.603x	0.11	178.746	57	0.011

cpm Count per minute
SEE Standard error of estimate
R^2 Coefficient of determination
n Number of observations
p Probability

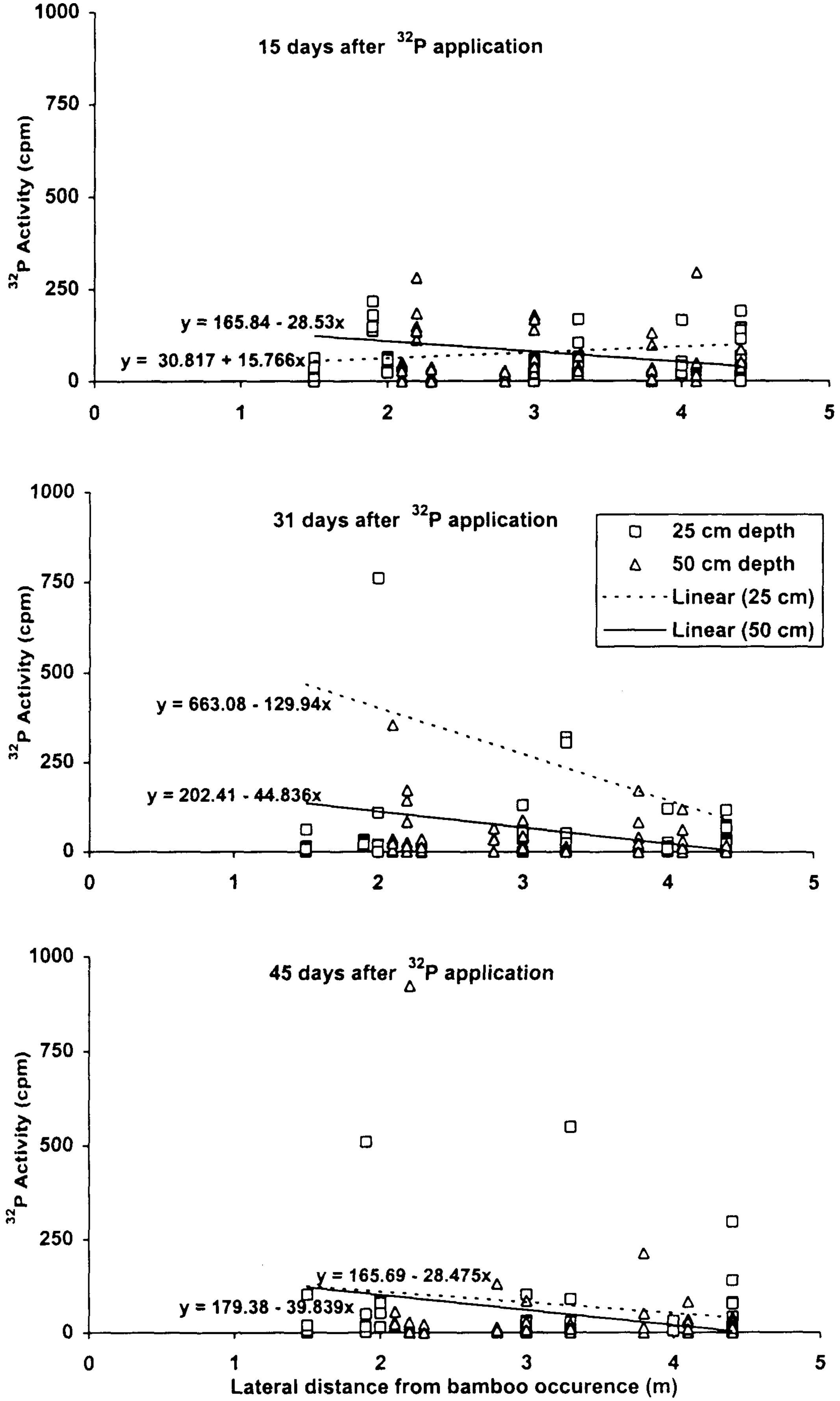


Fig. 5 Absorption of ^{32}P by neighboring teak as influenced by lateral distance between treated teak and bamboo occurrence

Table 4: ^{32}P absorbed (y) by neighbouring teak trees (cpm g^{-1} dry leaves) as influenced by distance (x) from treated teak to bamboo clump base

Days after isotope application	Depth of placement (cm)	Equation $y = a + bx$	R^2	SEE	n	p
15	25	30.817 + 15.766 x	0.01	154.253	55	1.000
	50	165.837 - 28.530 x	0.02	161.146	57	0.269
31	25	663.083 - 129.945 x	0.02	1141.544	55	1.000
	50	202.410 - 44.836 x	0.04	199.031	57	0.161
45	25	165.693 - 28.475 x	0.02	200.291	55	0.264
	50	179.337 - 39.839 x	0.03	186.587	57	0.184

cpm Count per minute
SEE Standard error of estimate
R^2 Coefficient of determination
n Number of observations
p Probability

Table 5: Absorption of ^{32}P by neighbouring teak at 15, 31 and 45 days after application of ^{32}P to the soil as influenced by lateral distance of bamboo occurrence

Lateral distance of bamboo occurrence (m)	15th day log (x+1) cpm g^{-1} dry weight		31st day log (x+1) cpm g^{-1} dry weight		45th day log (x+1) cpm g^{-1} dry weight	
	Mean	S.D ±	Mean	S.D ±	Mean	S.D ±
> 2.5	2.661 (458.1)	0.3943	2.897 (788.9)	0.6471	2.726 (532.1)	0.4502
2.5 - 3.5	2.406 (254.7)	0.3560	2.360 (229.1)	0.5020	2.269 (185.8)	0.4583
> 3.5	2.632 (428.6)	0.3425	2.430 (269.2)	0.6217	2.311 (204.6)	0.2889
SEM ±	0.1555		0.2352		0.1576	
CD (0.05)	NS		NS		NS	
Depth of ^{32}P Placement (cm)						
25	2.603 (400.9)	0.3206	2.798 (628.1)	0.5963	2.563 (365.6)	0.3820
50	2.529 (338.1)	0.4161	2.326 (211.8)	0.5550	2.307 (202.8)	0.4722
SEM ±	0.1270		0.1921		0.1287	
CD (0.05)	NS		NS		NS	
Interaction						
SEM ±	0.2199		0.3327		0.2229	
CD (0.05)	NS		NS		NS	

Foliar ^{32}P activity of neighbouring trees in each plot is worked out as the sum of activities for all trees sampled in an experimental unit (n ranges from 3 to 9)

Retransformed values given in paranthesis

cpm - Count per minute
NS - Not Significant
SEM – Standard Error of Mean
CD - Critical Difference

4.1.3. Absorption of ^{32}P by neighbourhood bamboo clumps

In general ^{32}P uptake by bamboos surrounding treated teak trees was inversely related to the lateral distance of bamboo occurrence (Fig 6, Tables 6 & 7 and Appendix IV). Shallow placement of the radio-isotope resulted in a modest reduction in the ^{32}P uptake of neighbourhood bamboos as the lateral distance of bamboo occurrence increased. Comparisons involving bamboo clumps at 1.5 m and 4.5 m showed that radioactivity absorbed by the bamboo clumps was 66, 43 and 55 per cent greater in the former, when the isotope was applied at 25 cm depth. Placement of the label at 25 cm depth resulted in greater ^{32}P uptake than deeper placement (Table 8).

4.2. Absorption of ^{32}P by different components in *Vateria*-bamboo combination

4.2.1. Absorption of ^{32}P by treated *Vateria* plants

Data on ^{32}P uptake by treated *Vateria* plants are shown in Fig 7 and Tables 9 and 10 (Appendix V). *Vateria* saplings absorbed more radioactivity when bamboo clumps were farther apart. There was an 86 per cent increase in radioactivity absorbed by *Vateria* when bamboos were at 6.3 m than at 1.3 m distance (15 days after application and 25 cm depth of placement). Depth of placement of the radio-label, however, altered the uptake pattern. Bamboo clumps at shorter distances consistently recorded higher cpm values when the isotope was applied at 50 cm depth.

As regards to the temporal pattern of ^{32}P uptake (Table 10), no clear cut trend was discernible. Treated plants registered highest cpm values of 15871.6 and 2631.78 at 6.3 m distance of bamboo occurrence at 15 and 45 days after application. At 31 days after application, there was a modest decrease in cpm values as lateral distance of bamboo clump occurrence increased (Fig. 7). However,

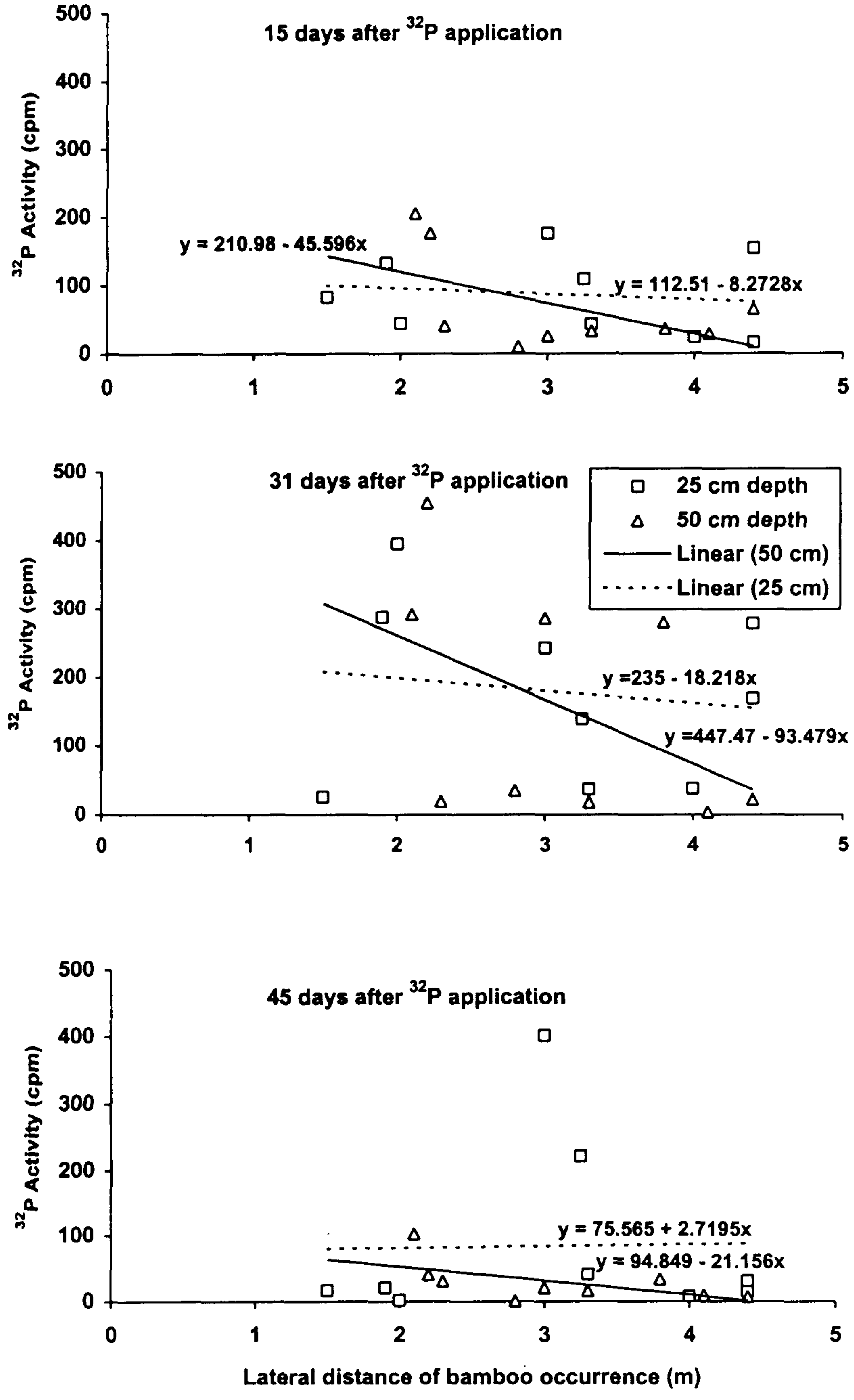


Fig. 6 Absorption of ^{32}P by neighbouring bamboo as influenced by distance from treated teak

Table 6: ^{32}P absorbed (y) by neighbouring bamboo (cpm g^{-1} dry leaves) as influenced by distance (x) from the treated teak tree and bamboo

Combination	Days after isotope application	Depth of placement (cm)	Equation $Y = a + bx$	R^2	SEE	n	p
Teak	15	25	112.517 – 8.273 x	0.02	62.114	9	1.000
		50	210.976 – 45.596 x	0.30	63.348	9	0.127
	31	25	234.998 – 18.218 x	0.02	138.451	9	1.000
		50	447.472 – 93.479 x	0.22	161.677	9	0.208
	45	25	75.565 + 2.720 x	0.00	146.403	9	1.000
		50	94.850 – 21.155 x	0.35	26.205	9	0.094

cpm Count per minute
SEE Standard error of estimate
R^2 Coefficient of determination
n Number of observations
p Probability

Table 7: ^{32}P recovered in the leaves of bamboo in teak-bamboo combination at 15, 31 and 45 days after application of ^{32}P as affected by lateral distance between the bamboo and the treated teak and depth of application

Lateral Distance of bamboo occurrence (m)	15th day log (x+1) cpm g^{-1} dry weight		31st day log (x+1) cpm g^{-1} dry weight		45th day log (x+1) cpm g^{-1} dry weight	
	Mean	S.D ±	Mean	S.D ±	Mean	S.D ±
< 2.5	1.982 (95.9)	0.3002	2.159 (144.2)	0.6253	1.378 (23.9)	0.5615
2.5 - 3.5	1.638 (43.5)	0.4462	1.873 (74.6)	0.5051	1.459 (28.8)	0.9286
> 3.5	1.602 (40.0)	0.3500	1.782 (60.5)	0.7218	1.156 (14.3)	0.2942
SEM ±	0.1438		0.2790		0.1915	
C.D (0.05)	NS		NS		NS	
^{32}P Placement Depth (cm)						
25	1.819 (65.9)	0.3702	2.083 (121.1)	0.4527	1.421 (26.46)	0.6970
50	1.662 (45.9)	0.4115	1.792 (61.9)	0.7251	1.240 (17.4)	0.5715
SEM ±	0.1174		0.2278		0.1563	
C.D (0.05)	NS		NS		NS	
Interaction						
SEM ±	0.2033		0.3945		0.2708	
C.D (0.05)	NS		NS		0.596	

Retransformed values given in paranthesis

cpm - count per minute
NS - Not Significant
SEM – Standard Error of Mean
CD - Critical Difference

Table 8: Combined effect of lateral distance from bamboo occurrence and depth of placement on foliage ^{32}P activity of bamboo ($\log_{10}(x+1)$ transformed values)

Depth of ^{32}P placement	Lateral distance of bamboo occurrence			Mean
	< 2.5 m	2.5 - 3.5 m	> 3.5 m	
25 cm	0.931 (8.5)	2.049 (111.9)	1.284 (19.2)	1.421 (26.46)
50 cm	1.824 (66.7)	0.868 (7.4)	1.029 (10.7)	1.240 (17.4)
Mean	1.378 (23.9)	1.459 (28.8)	1.157 (14.3)	

CD for interaction 0.596

Retransformed values in parenthesis

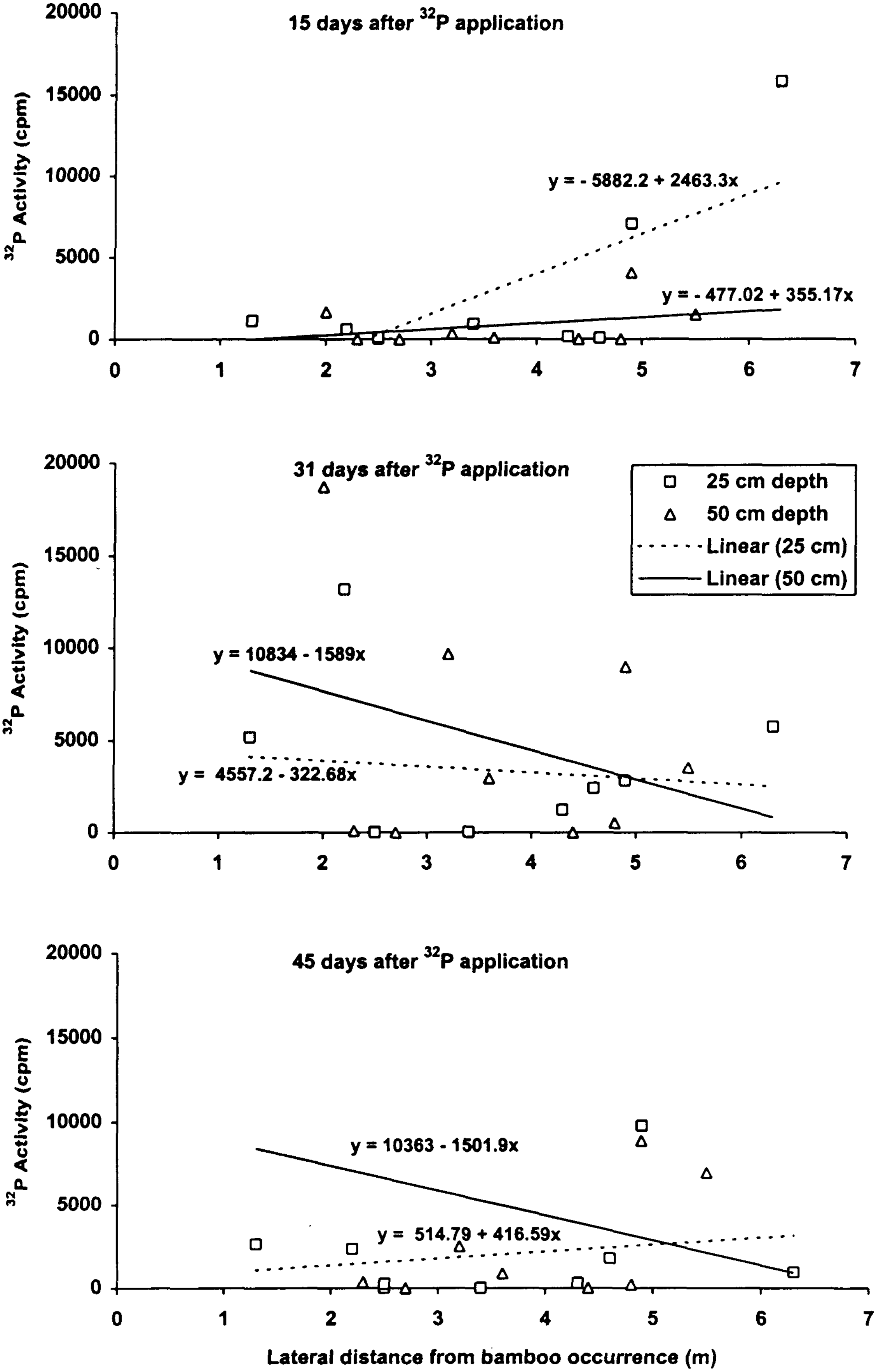


Fig. 7 Absorption of ^{32}P by treated *Vateria* as influenced by distances from bamboo clumps

Table 9 : ^{32}P absorbed (y) by treated *Vateria* trees (cpm g^{-1} dry leaves) as influenced by distance (x) from bamboo clumps

Days after isotope application	Depth of placement (cm)	Equation (Y = a + bx)	R^2	SEE	N	p
15	25	- 5882.210 + 2463.282 x	0.53	3913.538	9	0.026
	50	-477.016 + 355.170 x	0.11	1375.538	9	1.000
31	25	4557.243 – 322.685 x	0.02	4505.194	9	1.000
	50	10833.884 - 1588.964 x	0.10	6483.656	9	1.000
45	25	514.794 + 416.586 x	0.05	3210.460	9	1.000
	50	10362.993 - 1501.909 x	0.06	7986.596	9	1.000

cpm	Count per minute
SEE	Standard error of estimate
R^2	Coefficient of determination
n	Number of observations
p	Probability

Table 10: Absorption of ^{32}P by *Vateria* at 15, 31 and 45 days after application of ^{32}P to the soil

Lateral Distance of bamboo occurrence (m)	15th day alog (x+1) cpm g^{-1} dry weight		31st day log (x+1) cpm g^{-1} dry weight		45th day log (x+1) cpm g^{-1} dry weight	
	Mean	S.D ±	Mean	S.D ±	Mean	S.D ±
<3.0	1.624 (42.1)	1.2487	1.993 (98.4)	1.8873	2.107 (127.9)	1.7801
3.0 - 4.5	2.117 (130.9)	1.1173	2.616 (413.1)	1.5675	2.308 (203.2)	1.2345
>4.5	2.784 (608.1)	1.5827	3.468 (2937.7)	0.4261	3.384 (2421.0)	0.6702
SEM ±	0.5538		0.6545		0.5946	
C.D (0.05)	NS		NS		NS	
Depth of ^{32}P Placement (cm)						
25	2.655 (451.9)	1.0087	2.729 (535.8)	1.3898	2.559 (362.2)	1.2506
50	1.695 (49.5)	1.5142	2.656 (452.9)	1.6624	2.640 (436.5)	1.5339
SEM ±	0.4522		0.5344		0.4855	
C.D (0.05)	NS		NS		NS	
Interaction						
SEM ±	0.7832		0.9256		0.8408	
C.D (0.05)	NS		NS		NS	

Retransformed values given in paranthesis

cpm - count per minute
NS - Not Significant
SEM – Standard Error of Mean
CD - Critical Difference

with increasing distance the radioactivity recovered by treated *Vateria* declined dramatically when the label was placed at 50 cm at 31 and 45 days after application. Such a declining trend however, was not explicit at 15 days after application. Linear regression equations fitted linking ^{32}P activity with lateral distance of bamboo occurrence yielded R^2 values ranging from 2 to 53% (Table 9).

4.2.2. Absorption of ^{32}P by neighbouring *Vateria* plants

Vateria saplings adjacent to the treated trees showed an overall negative linear trend in ^{32}P uptake with increasing lateral distance between treated and neighbouring plants (Fig. 8, Table 11 and 13). R^2 values ranged from 1 to 11%. The magnitude of decrease in radio-label recovery with increasing distance from treated trees was highest at 31 days after application. At 25 cm depth of placement, ^{32}P absorption at 1 m lateral distance from treated plant was 94, 56 and 99 per cent greater compared to 5 m distance at 15, 31 and 45 days after application. The corresponding figures when label was placed at 50 cm depth were 88, 53 and 52 per cent.

^{32}P absorption by neighbouring *Vateria* plants followed a direct relationship with lateral distance between treated *Vateria* and bamboo occurrence except at 15 days after application (Fig. 9), although R^2 values for fitted equations were low (Table 12). There was a dramatic increase in absorption with increase in distance of bamboo occurrence at 31 and 45 days after application. Shallow placement of the radio-label (25 cm) at 6.3 m lateral distance from bamboo occurrence resulted in 20, 98 and 90% greater absorption compared to 1 m lateral distance at 15, 31 and 45 days of application respectively. At deeper placement, percentage increase in absorption was of the order of 0, 94 and 30 at 15, 31 & 45 days after application.

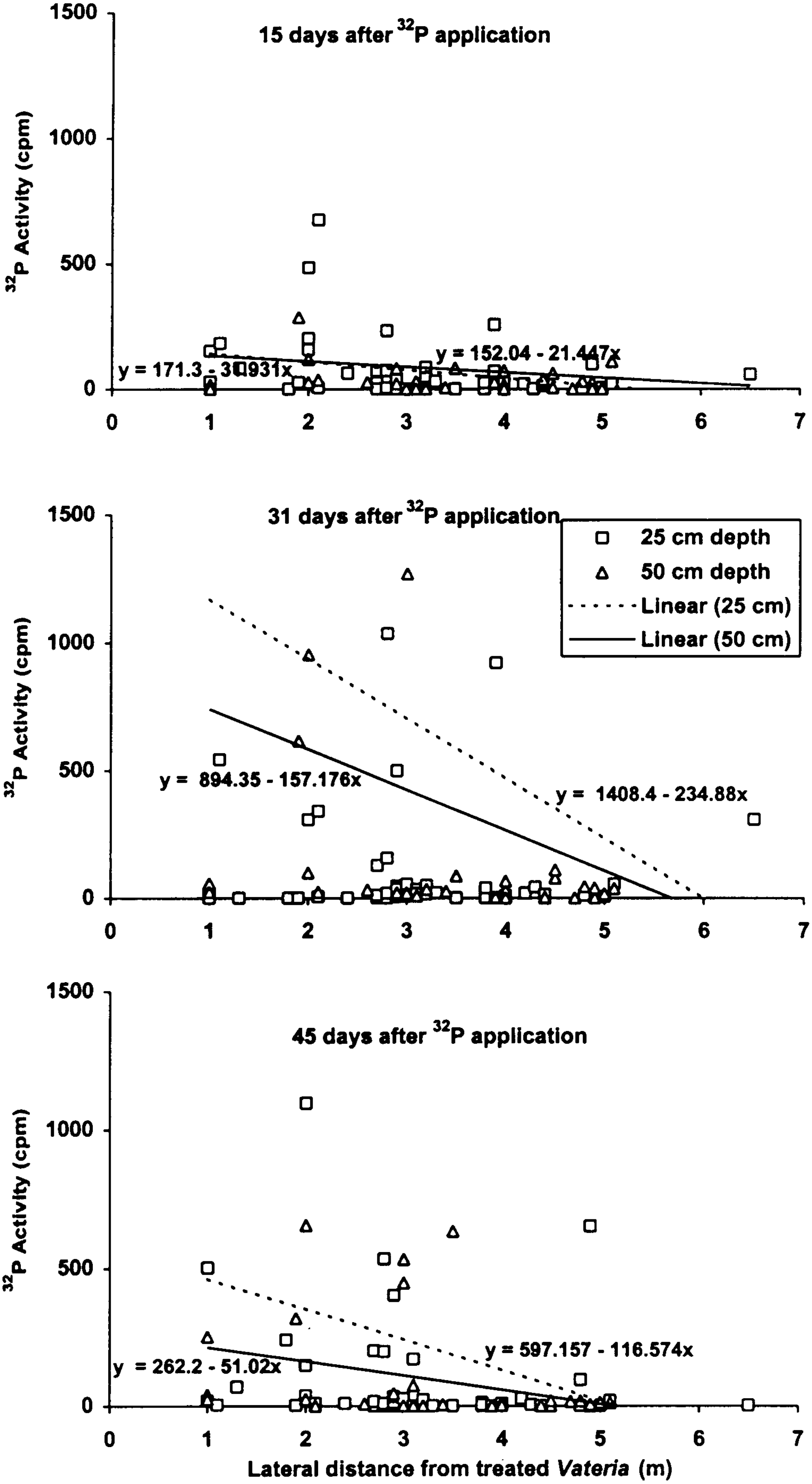


Fig. 8 Absorption of ^{32}P by neighbouring *Vateria* at various distances from the treated *Vateria*

Table 11 : ^{32}P absorbed (y) by neighbouring *Vateria* saplings (cpm g^{-1} dry leaves) as influenced by distance (x) from the treated plants

Days after isotope application	Depth of placement (cm)	Equation Y = a + bx	R^2	SEE	n	p
15	25	171.304 – 31.931 x	0.09	123.560	55	0.047
	50	152.038 – 21.447 x	0.01	281.940	57	1.000
31	25	1408.443 – 234.882 x	0.01	2627.052	55	1.000
	50	894.352 – 157.176 x	0.02	1550.508	57	1.000
45	25	597.157 – 116.574 x	0.04	664.527	55	0.172
	50	262.193 – 51.018 x	0.11	176.166	57	0.049

cpm	Count per minute
SEE	Standard error of estimate
R^2	Coefficient of determination
n	Number of observations
p	Probability

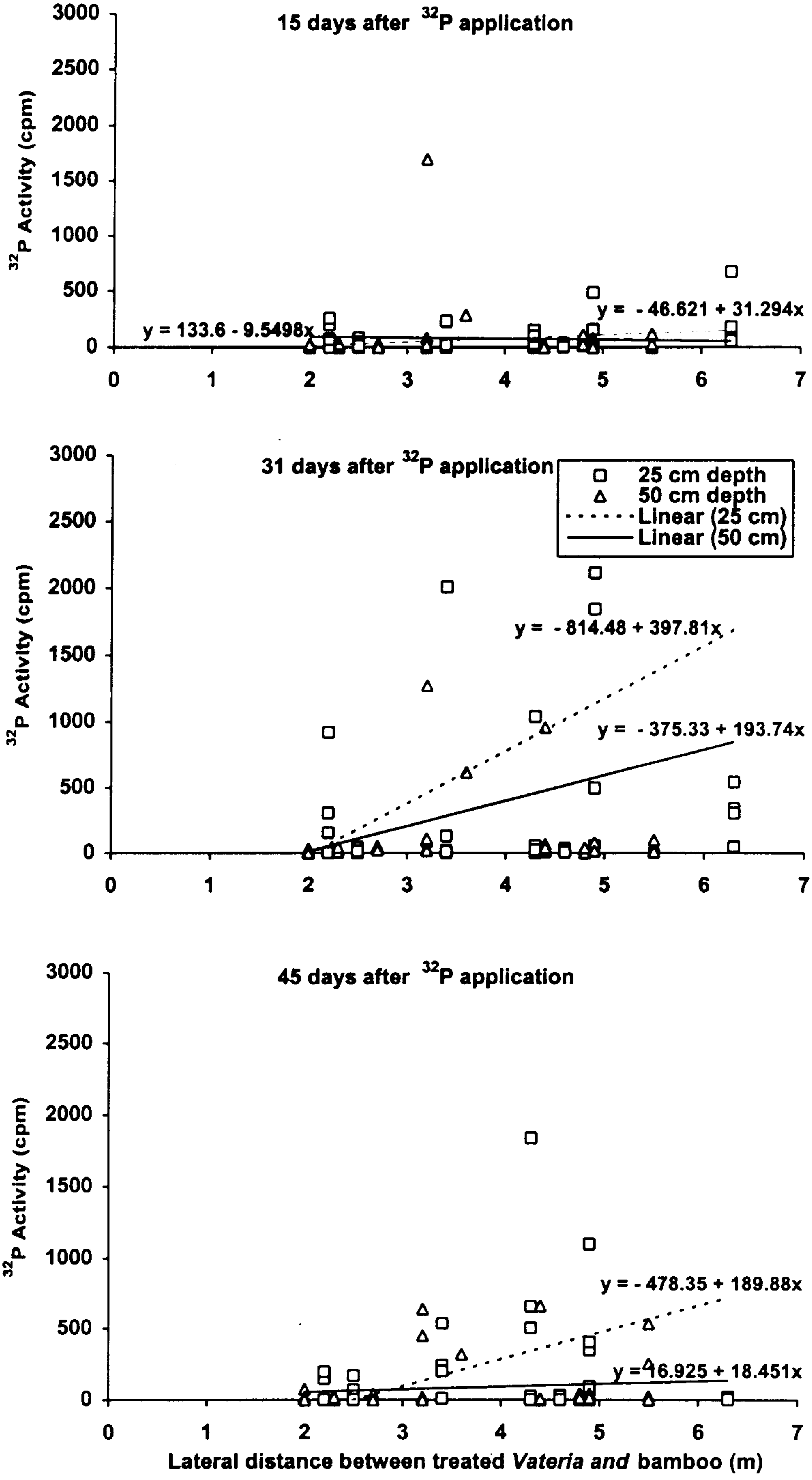


Fig. 9 Absorption of ^{32}P by neighbouring *Vateria* as influenced by lateral distance between treated *Vateria* and bamboo occurrence

Table 12: ^{32}P absorbed (y) by neighbouring *Vateria* saplings (cpm g^{-1} dry leaves) as influenced by distance (x) from treated *Vateria* to bamboo clump base

Days after isotope application	Depth of placement (cm)	Equation $y = a + bx$	R^2	SEE	n	p
15	25	$-46.621 + 31.294\,x$	0.09	123.023	47	0.037
	50	$133.603 - 9.550\,x$	0.01	282.847	37	1.000
31	25	$-814.479 + 397.811\,x$	0.04	2593.711	47	0.202
	50	$-375.326 + 193.741\,x$	0.03	1543.233	37	1.000
45	25	$-478.352 + 189.876\,x$	0.12	635.108	47	0.015
	50	$16.925 + 18.451\,x$	0.02	184.938	37	1.000

cpm Count per minute
SEE Standard error of estimate
R^2 Coefficient of determination
n Number of observations
p Probability

Table 13: Absorption of ^{32}P by neighbouring *Vateria* at 15, 31 and 45 days after application of ^{32}P to the soil as influenced by lateral distance of bamboo occurrence

Lateral distance of bamboo occurrence (m)	15th day log (x+1) cpm g^{-1} dry weight		31st day log (x+1) cpm g^{-1} dry weight		45th day log (x+1) cpm g^{-1} dry weight	
	Mean	S.D ±	Mean	S.D ±	Mean	S.D ±
< 3.0	2.020 (104.7)	0.4478	2.123 (132.7)	0.5283	2.002 (100.5)	0.3629
3.0 - 4.5	2.364 (231.2)	0.5917	3.113 (1297.2)	0.2383	2.953 (897.4)	0.2629
> 4.5	2.409 (256.5)	0.4515	2.874 (748.2)	1.1096	2.526 (335.7)	0.8489
SEM ±	0.2021		0.3160		0.2137	
CD (0.05)	NS		NS		0.4656	
Depth of ^{32}P Placement (cm)						
25	2.416 (260.6)	0.3955	2.885 (767.4)	0.8393	2.751 (563.6)	0.6566
50	2.112 (129.4)	0.5753	2.521 (331.9)	0.7754	2.236 (172.2)	0.5800
SEM ±	0.1650		0.2580		0.1745	
CD (0.05)	NS		NS		NS	
Interaction						
SEM ±	0.2858		0.4468		0.3022	
CD (0.05)	NS		NS		NS	

Foliar ^{32}P activity of neighbouring trees in each plot is worked out as the sum of activities for all trees sampled in an experimental unit (n ranges from 1 to 7)

Retransformed values given in paranthesis

cpm - count per minute
NS - Not Significant
SEM – Standard Error of Mean
CD - Critical Difference

Two-way ANOVA with lateral distance grouped into 1.5 m class intervals and depth of application as factors yielded no statistically significant variations except in respect of 45 days after isotope application (Table 13, Appendix VI). Both 25 cm and 50 cm depth of isotope placement essentially followed a similar trend in this respect.

4.2.3. Absorption of ^{32}P by neighbouring bamboo in *Vateria*-bamboo combination

Bamboo clumps adjacent to treated *Vateria* saplings showed a negative linear ^{32}P uptake pattern. Bamboo foliar ^{32}P activity declined with increasing lateral distance from treated plants (Fig. 10 and Tables 14 and 15). The fitted equations gave reasonably good R^2 values (Table 14). The cpm values at 2 m lateral distance of bamboo occurrence were 87.06, 39.29 and 43.56 at 15, 31 and 45 days after application respectively (depth of application: 25 cm) whereas at 5 m lateral distance the corresponding values were 33.94, 27.43 and 17.23. Respective figures for deeper placement of isotope at 2 m lateral distance was 28, 53, 55 and at 5 m lateral distance the cpm values were 30.54, 22.63 and 8.27 at 15, 31 and 45 days after application respectively. Neither depth of isotope placement nor time after isotope application seemed to influence this parameter.

Data on ^{32}P uptake as influenced by lateral distance of bamboo occurrence and depth of isotope application showed statistically significant variations only at 45 days after isotope application (Table 15, Appendix VII). Highest ^{32}P activity was recorded by the bamboo clumps in 1-3 m lateral distance compared to 4.5-6.0 m lateral distance at 45 days after application. Similarly deeper placement resulted in 32% higher ^{32}P recovery compared to shallow placement (25 cm) at 45 days after application.

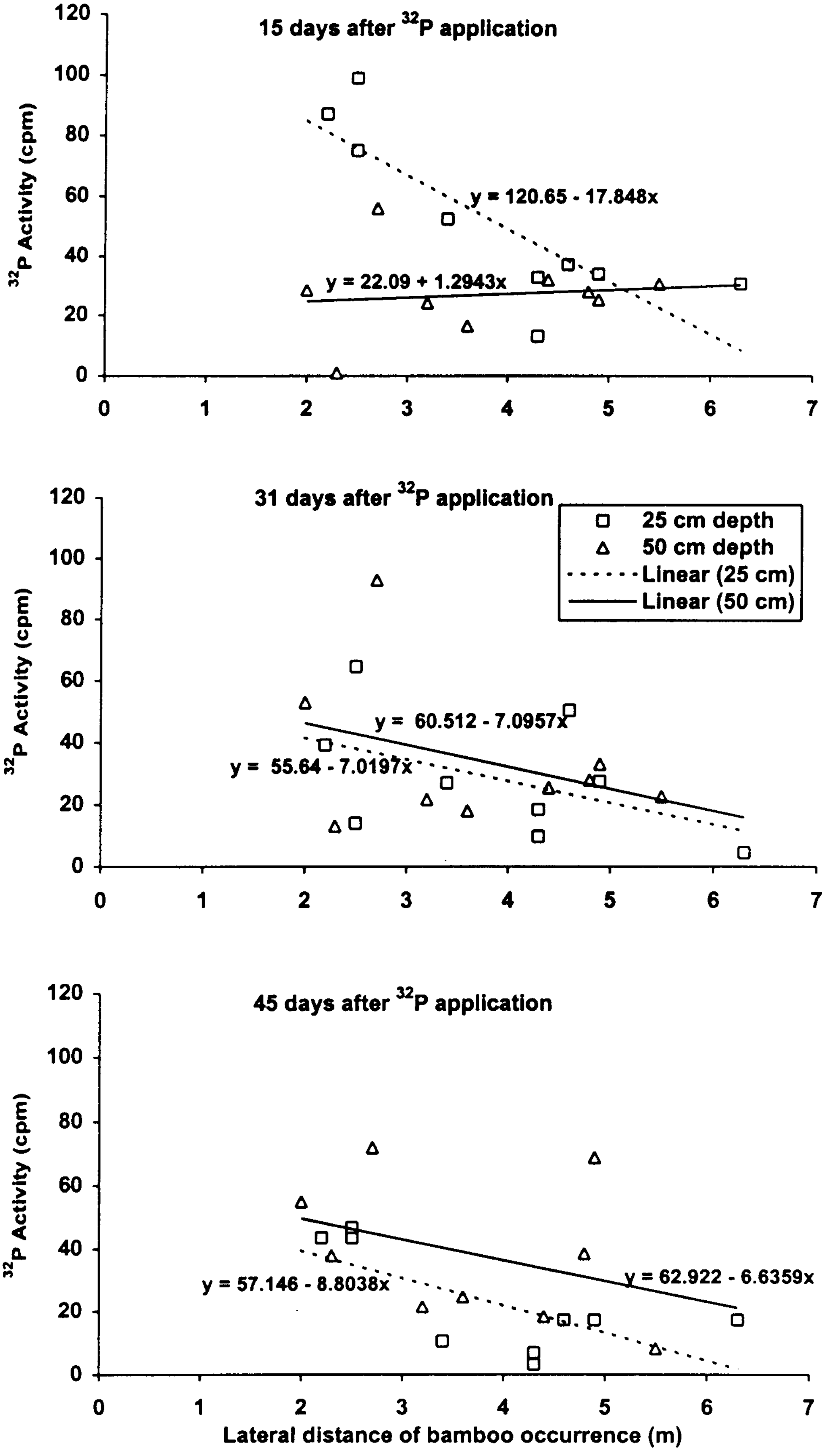


Fig. 10 Absorption of ^{32}P by neighbouring bamboo as influenced by distance from treated *Vateria* saplings

Table 14: ^{32}P absorbed (y) by neighbouring bamboo (cpm g^{-1} dry leaves) as influenced by distance (x) from the treated *Vateria* tree and bamboo

Combination	Days after isotope application	Depth of placement (cm)	Equation Y= a + bx	R^2	SEE	n	p
Vateria	15	25	120.654 - 17.848 x	0.68	17.732	9	0.006
		50	22.090 + 1.294 x	0.01	15.387	9	1.000
	31	25	55.640 - 7.020 x	0.23	18.594	9	0.192
		50	60.511 - 7.096 x	0.13	24.764	9	0.345
	45	25	57.146 - 8.804 x	0.49	13.004	9	0.036
		50	62.923 - 6.636 x	0.13	22.510	9	0.332

cpm	Count per minute
SEE	Standard error of estimate
R^2	Coefficient of determination
n	Number of observations
p	Probability

Table 15: ^{32}P recovered in the leaves of bamboo in *Vateria*-bamboo combination at 15, 31 and 45 days after application of ^{32}P to the soil as affected by lateral distance between the bamboo and the treated *Vateria* and depth of application

Lateral Distance of bamboo occurrence (m)	15th day log (x+1) cpm g-1 dry weight		31st day log (x+1) cpm g^{-1} dry weight		45th day log (x+1) cpm g^{-1} dry weight	
	Mean	S.D ±	Mean	S.D ±	Mean	S.D ±
< 3.0	1.361 (23.0)	0.7609	1.407 (25.5)	0.3531	1.745 (55.6)	0.0983
3.0 - 4.5	1.518 (33.0)	0.2198	1.397 (25.0)	0.1612	1.015 (10.4)	0.3406
> 4.5	1.520 (33.1)	0.0596	1.387 (24.4)	0.3641	1.328 (21.3)	0.4471
SEM ±	0.1628		0.1258		0.0949	
C.D (0.05)	NS		NS		0.3616	
Depth of ^{32}P Placement (cm) 25	1.653 (45.0)	0.2765	1.351 (22.4)	0.3680	1.219 (16.6)	0.3947
50	1.280 (19.1)	0.5046	1.443 (27.7)	0.2551	1.506 (32.1)	0.3055
SEM ±	0.1599		0.1027		0.0775	
C.D (0.05)	NS		NS		0.3616	
Interaction SEM ±	0.2302		0.1780		0.1634	
C.D (0.05)	NS		NS		0.3616	

Retransformed values given in paranthesis

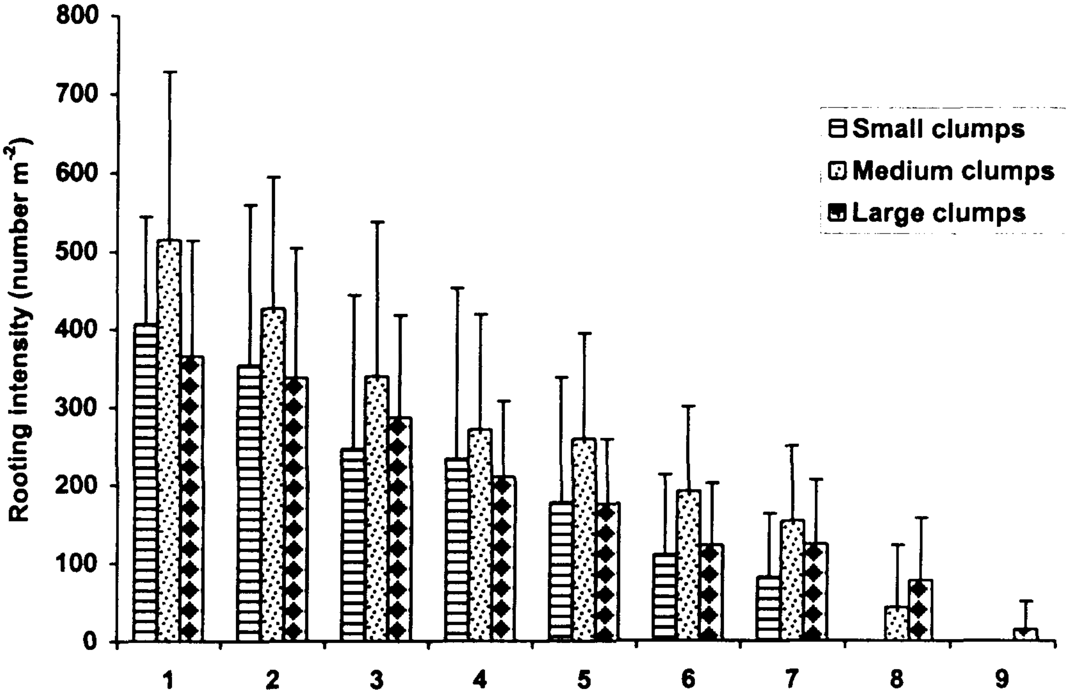
cpm - count per minute
NS - Not Significant
SEM – Standard Error of Mean
CD - Critical Difference

4.3. Spatial distribution of bamboo roots

Data on bamboo rooting intensity at different points along the logarithmic spiral trenches are presented in Figs. 11-17 and Tables 16-22. Locations close to the clump base recorded higher rooting intensities with the first quadrat recording the highest root counts. Mean rooting intensity (total) in the 1st quadrat was 478.7, 576.0 and 414.0 respectively for the small, medium and large clumps on the internal face of the trench (Table 18). The corresponding figures on external face of the trench were 414, 491.3 and 325.3 m^{-2} (Table 21). Distance to the first quadrat ranged from 0.9 to 4.1 m and 1.5 to 4.7 depending on the size of the clumps on the internal and external faces of the trenches.

On the whole, there was a linear decrease in rooting intensity with increasing distance. Farther quadrats recorded progressively lower rooting intensities. There were only less than 10%, 13% and 28% roots in small, medium and large clumps respectively at a distance >8 m lateral distance (co-ordinates) from base of the clump. Although both root diameter classes were similar in respect of lateral spread, number of roots in the less than 2 mm diameter class was substantially greater than 2-5 mm. The latter represented only 10% of the total roots.

Size of the bamboo clumps showed discernible differences in respect of spatial root distribution pattern. In general, medium size class clumps registered higher rooting intensities in quadrats 1-7 (Table 18 and 21) than small and large clumps. All root diameter classes followed an essentially similar trend in this respect. MANOVA indicated statistically significant variations between quadrats, clump sizes, depth and their interactions. Pillais trace, Hotelling's trace, Wilk's lambda and Roy's test were all highly significant (Appendix X, XIII). In the case of small clumps lateral spread of roots extended up to 7th or 8th quadrat (co-ordinate length corresponds to 7.7 to 8.9 m) depending on the internal or external face of the trench. Medium sized



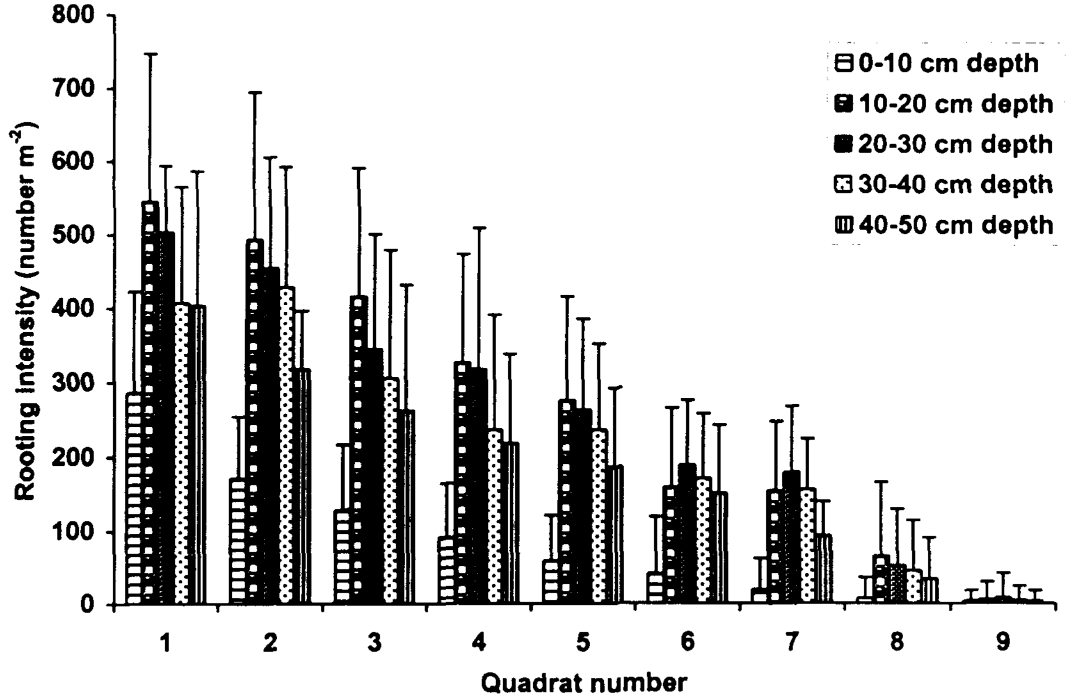


Fig.11 Bamboo rooting intensity (Number m^{-2}, <2 mm diameter roots) on internal face of the trench for different clump sizes and depth

Table 16: Bamboo rooting intensity (number m^{-2}, <2mm diameter) as influenced by clump size, distance and depth on the internal face of the trench

Clump size class	Quadrat number from the base of the clump*																	
	1		2		3		4		5		6		7		8		9	
	Rooting intensity (number m^{-2})																	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Small	406.7	137.60	354.0	205.45	246.7	197.32	233.3	219.86	177.3	161.18	110.0	102.62	81.3	81.36	0.0	0.0	0.0	0.0
Medium	515.3	212.61	426.7	167.85	340.0	198.13	271.3	147.69	259.3	135.29	191.3	109.0	153.3	96.47	42.7	79.61	0.0	0.0
Large	365.3	149.01	338.0	166.62	286.7	131.45	210.0	97.66	175.3	83.66	122.0	79.54	123.3	82.22	77.3	79.78	14.7	35.60
Depth class (cm)																		
0-10	286.7	135.47	171.1	83.52	127.8	89.48	91.1	72.67	58.9	61.92	40.0	78.22	18.9	42.55	6.7	28.28	3.33	14.14
10-20	545.5	201.38	493.3	201.41	415.6	175.10	326.7	146.49	275.6	140.01	157.8	106.91	153.3	94.06	64.4	100.48	5.56	23.57
20-30	503.3	90.29	454.4	151.20	344.4	156.36	317.8	190.84	263.3	121.61	187.8	87.08	177.8	89.68	51.1	77.38	7.8	33.00
30-40	406.7	158.23	427.8	163.94	305.6	173.52	236.7	153.89	236.7	114.84	170.0	87.65	154.4	69.56	44.4	69.47	4.4	18.86
40-50	403.3	182.95	317.8	78.18	262.2	169.13	218.9	119.11	185.6	106.01	150.0	92.86	92.2	46.60	33.3	56.98	3.3	14.14

* Quadrat number 1 was located at a distance of 0.75D from the base of the clump, where D = clump diameter. Subsequent quadrats were located at 1m intervals

Averaged tests of significance - MANOVA
Distance $P<0.001$
Clump size by distance $P<0.001$
Depth by distance $P<0.001$
Clump size by depth by distance $P<0.573$
SD - Standard deviation

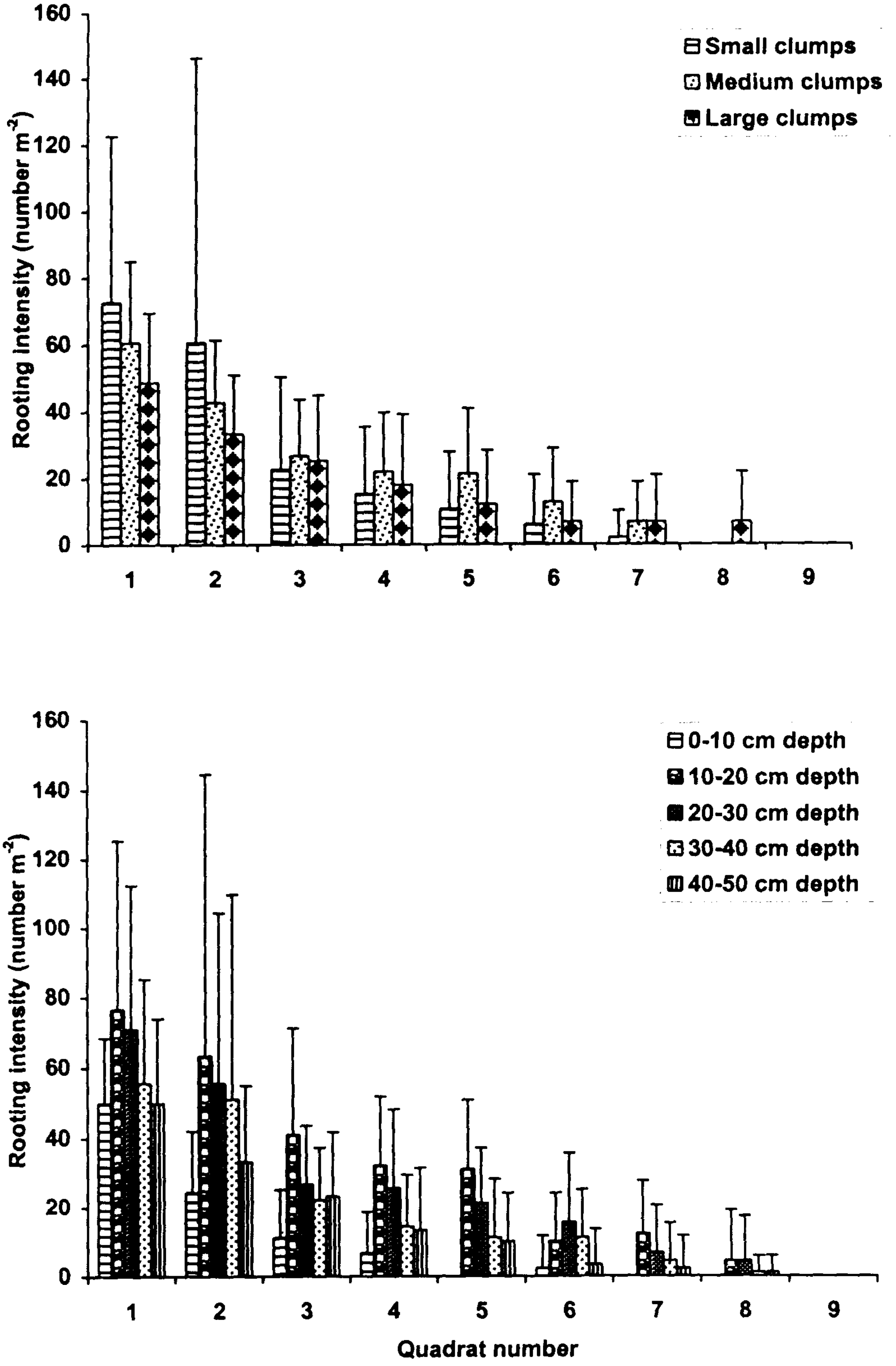


Fig.12 Bamboo rooting intensity (number m^{-2}, 2-5 mm diameter roots) on internal face of the trench for different clump sizes and depth

Table 17: Bamboo rooting intensity (number m^{-2}, 2-5 mm diameter) as influenced by clump size, distance and depth on the internal face of the trench

Clump size class	Quadrat number from the base of the clump*																	
	1		2		3		4		5		6		7		8		9	
	Rooting intensity (number m^{-2})																	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Small	72.7	49.96	60.7	85.58	22.7	27.66	15.3	20.13	10.7	17.21	6.0	14.99	2.0	8.05	0.0	0.0	0.0	0.0
Medium	60.7	24.34	42.7	18.74	26.7	16.88	22.0	17.69	21.3	19.61	12.7	16.17	6.7	12.13	0.0	0.0	0.0	0.0
Large	48.7	20.80	33.3	17.68	25.3	19.61	18.0	21.24	12.0	16.27	6.7	12.13	6.7	14.22	6.7	15.16	0.0	0.0
Depth class (cm)																		
0-10	50.0	18.47	24.4	17.56	11.1	14.10	6.7	11.88	0.0	0.0	2.2	9.43	0.0	0.0	0.0	0.0	0.0	0.0
10-20	76.7	48.63	63.3	81.24	41.1	30.27	32.2	19.57	31.1	19.67	10.0	14.14	12.2	15.55	4.4	14.64	0.0	0.0
20-30	71.1	41.29	55.6	48.78	26.7	16.80	25.6	22.55	21.1	16.05	15.6	20.07	6.7	13.72	4.4	12.94	0.0	0.0
30-40	55.6	29.55	51.1	58.70	22.2	15.17	14.4	15.04	11.1	17.11	11.1	14.10	4.4	10.97	1.1	4.71	0.0	0.0
40-50	50.0	24.01	33.3	21.69	23.2	18.47	13.3	18.15	10.0	14.14	3.3	10.29	2.2	9.43	1.1	4.71	0.0	0.0

* Quadrat number 1 was located at a distance of 0.75D from the base of the clump, where D = clump diameter. Subsequent quadrats were located at 1m intervals

Averaged tests of significance - MANOVA

Distance $P<0.001$

Clump size by distance $P<0.001$

Depth by distance $P<0.178$

Clump size by depth by distance $P<0.996$

SD - Standard deviation

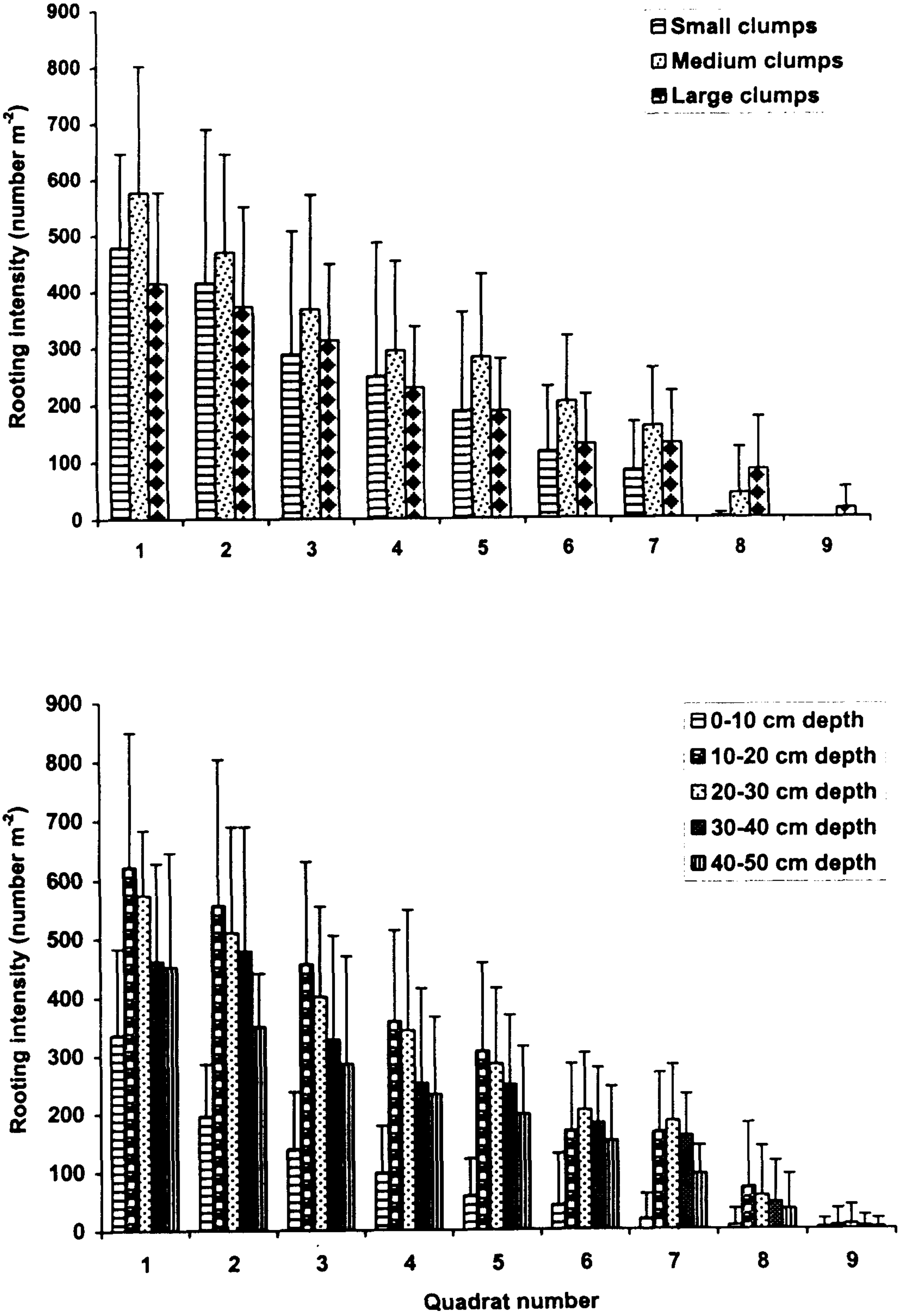


Fig.13 Bamboo rooting intensity (Number m^{-2}, total roots) on internal face of the trench for different clump sizes and depth

Table 18 : Bamboo rooting intensity (number m^{-2}, total roots) as influenced by clump size, distance and depth on the internal face of the trench

Clump size class	Quadrat number from the base of the clump*																	
	1		2		3		4		5		6		7		8		9	
	Rooting intensity (number m^{-2})																	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Small	478.7	167.00	414.7	274.12	287.3	219.50	248.7	237.03	188.0	173.13	116.0	113.55	83.3	84.05	2.0	6.10	0.0	0.0
Medium	576.0	225.50	469.3	175.44	366.7	204.86	293.3	159.51	281.3	148.09	202.7	114.80	160.0	101.44	42.7	79.61	0.0	0.0
Large	414.0	162.49	371.3	179.63	312.0	136.01	228.0	107.59	187.3	91.05	128.7	86.25	129.3	90.63	84.0	90.73	15.3	37.39
Depth class (cm)																		
0-10	336.7	145.56	195.6	90.11	138.9	98.09	97.8	79.67	58.9	61.92	42.2	86.74	17.8	42.78	6.7	28.28	3.3	14.14
10-20	622.2	226.68	556.7	246.89	456.7	173.71	358.9	154.23	306.7	150.76	167.8	115.02	165.6	101.94	71.1	110.02	6.7	28.28
20-30	574.4	109.29	510.0	179.57	401.1	153.31	343.3	204.57	284.4	129.90	203.3	98.76	184.4	96.91	56.7	84.09	7.8	33.00
30-40	462.2	166.05	478.9	210.71	327.8	176.79	251.1	163.09	247.8	120.81	181.1	95.66	158.9	71.45	45.6	69.89	4.4	18.86
40-50	452.2	193.56	351.1	90.29	285.6	183.92	232.2	133.93	196.7	117.27	151.1	92.60	94.4	47.92	34.4	58.93	3.3	14.14

* Quadrat number 1 was located at a distance of 0.75D from the base of the clump, where D = clump diameter. Subsequent quadrats were located at 1m intervals
Averaged tests of significance - MANOVA
Distance $P<0.001$
Clump size by distance $P<0.001$
Depth by distance $P<0.001$
Clump size by depth by distance $P<0.659$
SD - Standard deviation

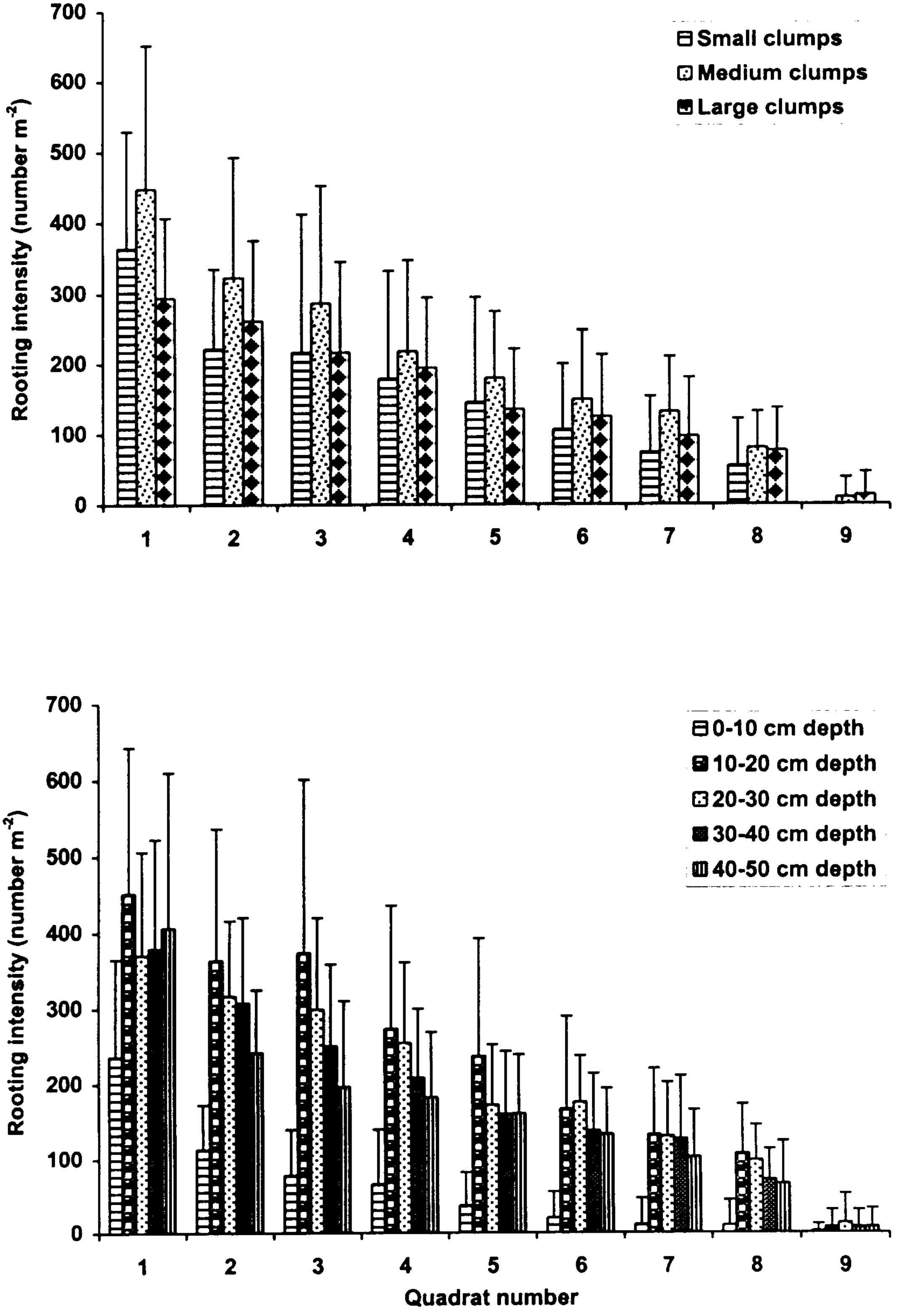


Fig. 14 Bamboo rooting intensity (Number m^{-2}, <2 mm diameter) on external face of the trench for different clump sizes and depth

Table 19 : Bamboo rooting intensity (number m^{-2}, <2 mm diameter) as influenced by clump size, distance and depth on the external face of the trench

Clump size class	Quadrat number from the base of the clump*																	
	1		2		3		4		5		6		7		8		9	
	Rooting intensity (number m^{-2})																	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Small	364.0	165.29	221.3	114.22	216.0	196.34	178.7	153.48	145.3	149.20	106.0	93.09	73.3	79.88	54.7	66.42	0.0	0.0
Medium	448.0	204.47	323.3	169.63	286.7	166.20	217.3	129.59	179.3	94.61	149.3	97.94	131.3	78.02	80.0	51.46	10.0	28.16
Large	294.0	113.16	261.3	113.74	216.0	129.12	194.0	100.23	135.3	85.29	124.7	87.52	96.7	83.06	76.0	60.44	13.3	32.52
Depth class (cm)																		
0-10	236.7	127.83	113.3	59.80	77.8	62.46	65.6	74.77	36.7	44.59	20.0	34.98	11.1	35.13	10.0	33.78	2.2	9.43
10-20	451.1	191.74	363.3	173.04	373.3	227.93	273.3	161.76	236.7	154.96	166.7	122.71	132.2	87.62	106.7	65.80	7.8	22.90
20-30	370.0	135.86	316.7	99.23	298.9	120.48	254.4	106.01	172.2	79.75	175.6	61.57	130.0	71.37	97.8	47.47	13.3	38.81
30-40	378.9	143.48	307.8	112.54	251.1	106.76	207.8	92.07	160.0	83.17	137.8	75.42	126.7	82.89	71.1	41.85	7.8	22.90
40-50	406.7	203.27	242.2	82.86	196.7	113.81	182.2	86.74	161.1	77.45	133.3	60.59	102.2	63.20	65.6	58.13	7.8	24.87

* Quadrat number 1 was located at a distance of 0.75D from the base of the clump, where D = clump diameter. Subsequent quadrats were located at 1m intervals

Averaged tests of significance - MANOVA
Distance $P<0.001$
Clump size by distance $P<0.001$
Depth by distance $P<0.001$
Clump size by depth by distance $P<0.983$
SD - Standard deviation

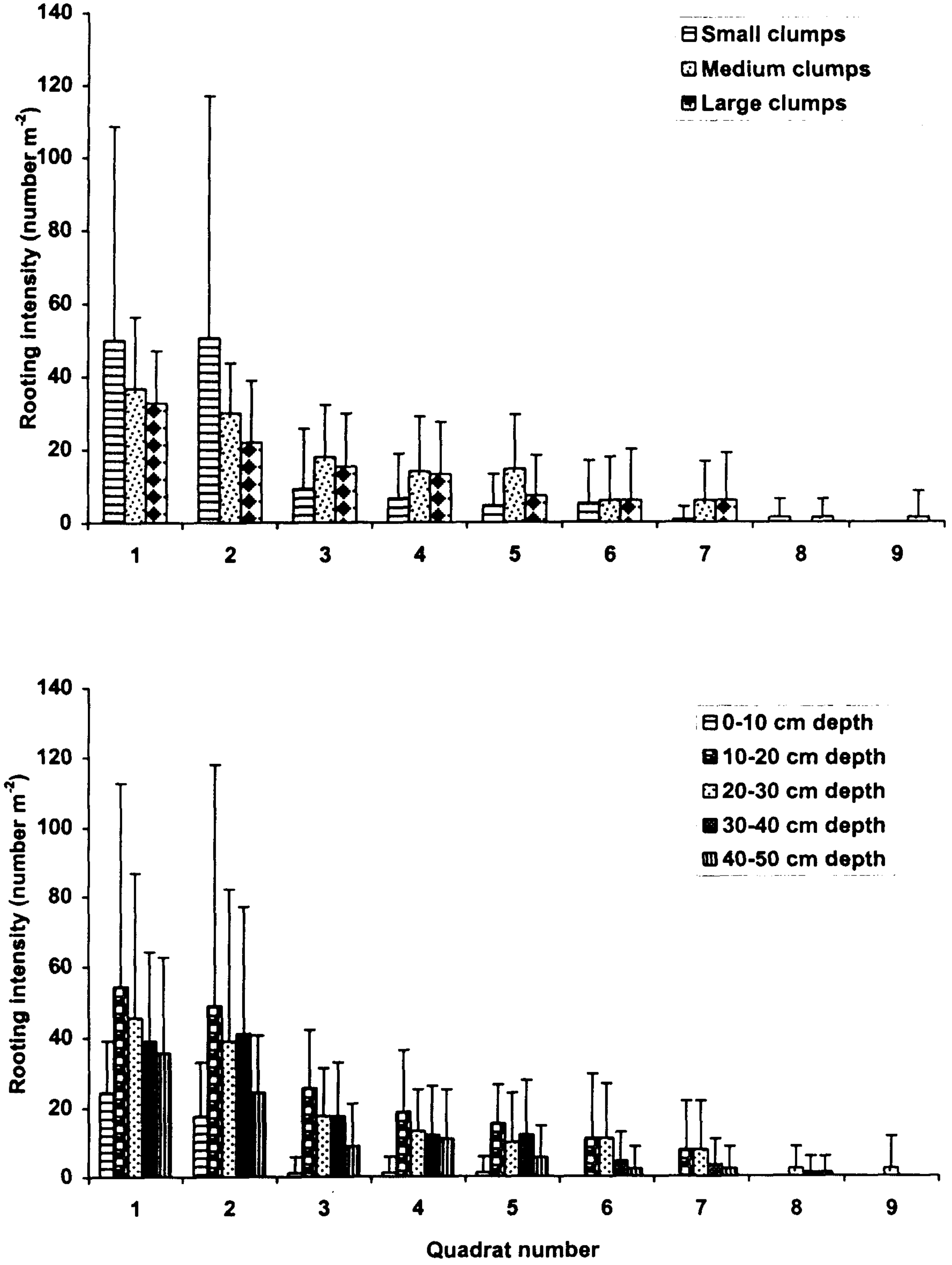


Fig.15 Bamboo rooting intensity (Number m^{-2}, 2-5 mm diameter roots) on external face of the trench for different clump sizes and depth

Table 20 : Bamboo rooting intensity (number m^{-2}, 2-5 mm diameter) as influenced by clump size, distance and depth on the external face of the trench

Clump size class	Quadrat number from the base of the clump*																	
	1		2		3		4		5		6		7		8		9	
	Rooting intensity (number m^{-2})																	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Small	50.0	58.66	50.7	66.38	9.3	16.39	6.7	12.13	4.7	8.60	5.3	11.67	0.7	3.65	1.3	5.07	0.0	0.0
Medium	36.7	19.71	30.0	13.65	18.0	14.24	14.0	14.99	14.7	14.79	6.0	11.92	6.0	10.70	0.0	0.0	0.0	0.0
Large	32.7	14.37	22.0	16.90	15.3	14.56	13.3	14.22	7.3	11.12	6.0	14.04	6.0	13.03	1.3	5.07	1.3	7.3
Depth class (cm)																		
0-10	24.4	14.64	17.8	15.17	1.1	4.71	1.1	4.71	1.1	4.71	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10-20	54.4	58.13	48.9	69.02	25.6	16.53	18.9	17.45	15.6	10.97	11.1	18.44	7.8	13.96	0.0	0.0	0.0	0.0
20-30	45.6	41.05	38.9	43.10	17.8	13.53	13.3	11.88	10.0	14.14	11.1	15.68	7.8	13.96	2.2	6.47	2.2	9.43
30-40	38.9	25.18	41.1	35.96	17.8	15.17	12.2	13.96	12.2	15.55	4.4	8.56	3.3	7.67	1.1	4.71	0.0	0.0
40-50	35.6	27.06	24.4	16.17	8.9	12.31	11.1	14.10	5.6	9.22	2.2	6.47	2.2	6.47	1.1	4.71	0.0	0.0

* Quadrat number 1 was located at a distance of 0.75D from the base of the clump, where D = clump diameter. Subsequent quadrats were located at 1m intervals

Averaged tests of significance - MANOVA
Distance $P<0.001$
Clump size by distance $P<0.001$
Depth by distance $P<0.332$
Clump size by depth by distance $P<0.987$
SD - Standard deviation

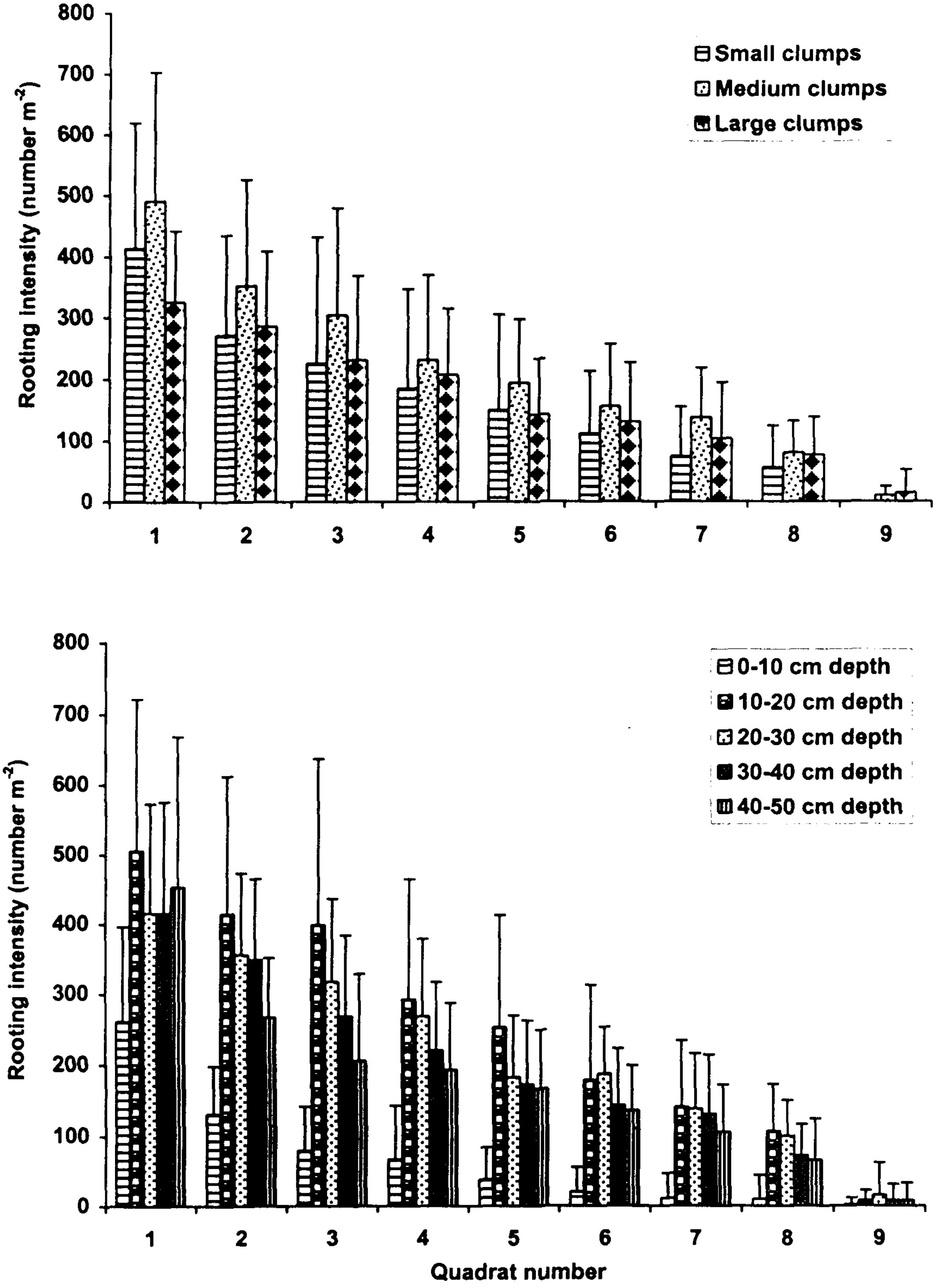


Fig.16 Bamboo rooting intensity (Number m^{-2}, total roots) on external face of the trench for different clump sizes and depth

Table 21 : Bamboo rooting intensity (number m^{-2},total roots) as influenced by clump size, distance and depth on the external face of the trench

Clump size class	Quadrat number from the base of the clump*																	
	1		2		3		4		5		6		7		8		9	
	Rooting intensity (number m^{-2})																	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Small	414.0	205.59	272.0	162.87	225.3	206.71	185.3	161.37	150.0	154.81	111.3	101.53	74.0	80.71	56.0	68.16	0.0	0.0
Medium	491.3	212.10	352.0	173.77	304.0	175.65	231.3	138.83	194.0	103.08	155.3	101.67	137.3	80.64	80.0	51.46	10.0	14.90
Large	325.3	116.73	286.0	123.31	231.0	137.93	207.3	107.32	142.7	90.32	130.7	96.24	103.3	90.83	76.7	61.49	14.7	37.48
Depth class (cm)																		
0-10	261.1	135.03	131.1	66.94	78.9	61.92	66.7	75.46	37.8	45.96	20.0	34.98	11.1	35.13	10.0	33.78	2.2	9.43
10-20	505.6	215.60	414.4	197.73	398.9	237.88	292.2	172.75	252.2	160.61	177.8	134.06	140.0	93.31	106.7	65.80	7.8	14.14
20-30	415.6	157.11	355.6	117.73	316.7	119.66	267.8	110.86	182.2	86.74	186.7	65.80	137.8	77.58	100.0	49.94	15.6	45.79
30-40	415.6	159.79	348.9	116.46	267.8	115.84	220.0	97.01	172.2	89.48	142.2	80.26	130.0	83.81	72.2	44.00	7.8	22.90
40-50	453.3	215.19	266.7	84.58	205.6	122.68	193.3	93.56	166.7	81.75	135.6	63.08	105.6	66.44	65.6	58.13	7.8	24.87

* Quadrat number 1 was located at a distance of 0.75D from the base of the clump, where D = clump diameter. Subsequent quadrats were located at 1m intervals
Averaged tests of significance - MANOVA
Distance $P<0.001$
Clump size by distance $P<0.001$
Depth by distance $P<0.001$
Clump size by depth by distance $P<0.985$
SD - Standard deviation

clumps had roots up to about 7.5 to 9.5 m, while large clumps extended their roots beyond 9.8 m. Rooting intensities for the small, medium and large lumps at 8.5, 9.5 and 9.5 m were 0, 80 and 88 m^{-2}. Although the medium sized clumps recorded higher rooting intensities up to 7.5 m, beyond this limit the large clumps recorded higher rooting intensities (Appendix XVI). The internal and external faces of the trench did not manifest any detectable differences in respect of rooting intensities.

Total rooting intensity up to 50 cm depth at different points along the logarithmic spiral trench was regressed on distance from the clump base (co-ordinates to the base of the clumps). The linear equation gave a satisfactory fit for all bamboo size classes and root diameter categories (Fig 17 and Table 22). R^2 values ranged from 0.31 to 0.69. Fig. 17 shows root distribution (depth-wise data combined) as influenced by distance from the clump base. The greatest number of roots was 789 m^{-2} of the profile wall at 2.8 m from the trunk (clump base). Regression equation linking distance from the base of the bamboo clump and rooting intensity for various size class categories of bamboo clumps and roots are presented in Table 22.

4.3.1. Depth-wise distribution of bamboo roots

There were significant differences in bamboo root distribution with depth (Appendix VIII-XIII). A comparison of the data on rooting intensity at different soil depths indicate that 10-20 cms registered the highest root counts with nearly 30% of total root counts. Overall it followed the order of 10-20 >20-30 >30-40 >40-50 >0-10. Although rooting intensity declined with lateral distance, all quadrats showed this general trend. Percentage of total roots at different depth intervals at 1 m away from the clumps was 13.8, 31.2, 25.6, 14.7 and 14.7 for 0-10, 10-20, 20-30, 30-40 and 40-50 cm horizons of the soil profile. Corresponding percentages at 10 m away from clumps were 0.0, 44.5, 33.3, 22.2 and 0.0% (Table 23).

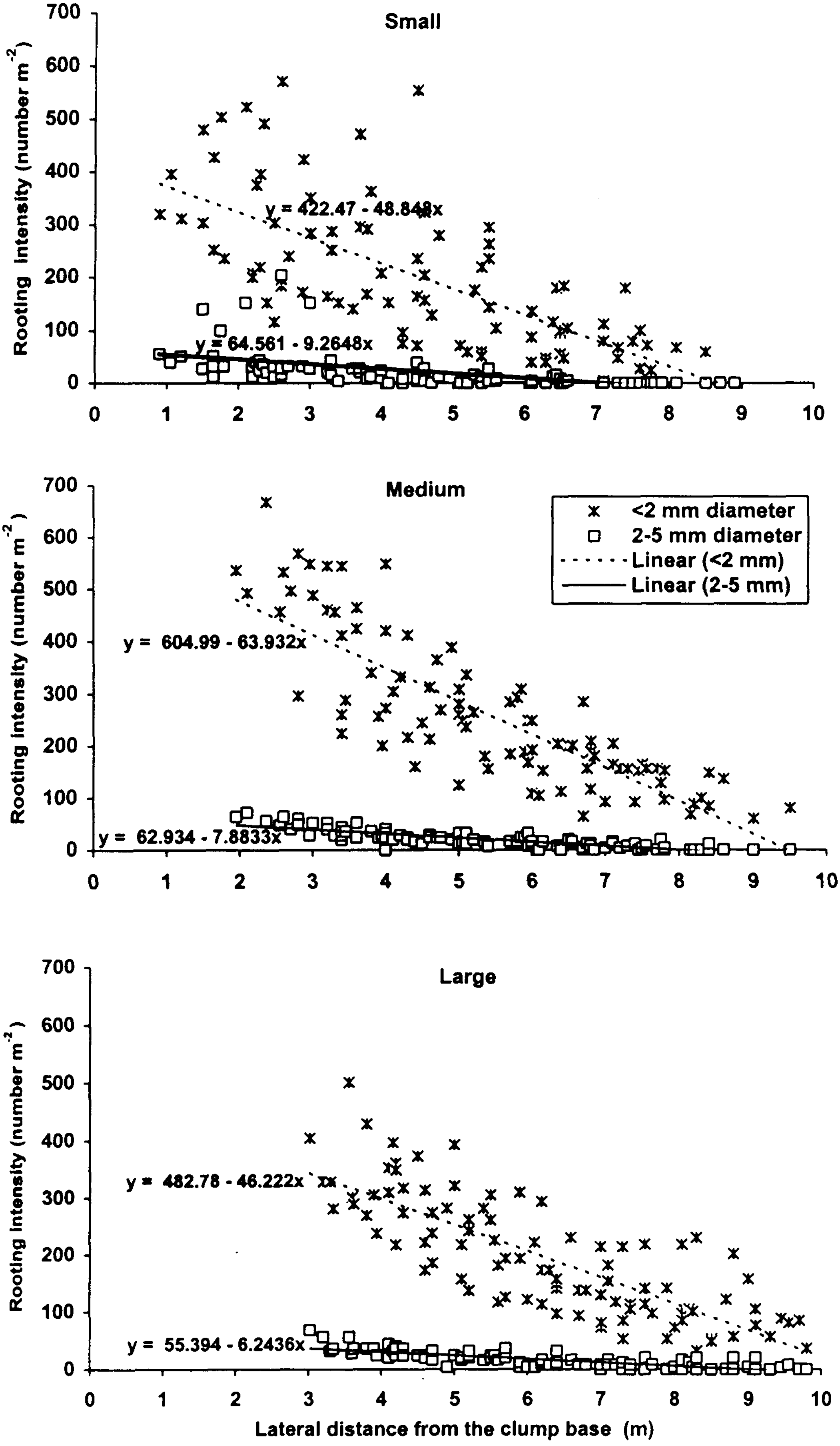


Fig.17 Bamboo rooting intensity as influenced by lateral distance for small, medium and large clumps

Table 22: Relationships between bamboo rooting intensity (number m^{-2}) and distance from the base of the clump

Clump size	Diameter classes	Equation $y = a + bx$	R^2	SEE	n	P
SMALL	< 2mm	$422.465 - 48.848\,x$	0.5256	98.496	93	<0.001
	2 - 5 mm	$64.561 - 9.265\,x$	0.3125	29.226	93	<0.001
MEDIUM	< 2mm	$604.988 - 63.932\,x$	0.6432	87.678	93	<0.001
	2 - 5 mm	$62.934 - 7.883\,x$	0.6972	9.568	93	<0.001
LARGE	< 2mm	$482.780 - 46.222\,x$	0.6336	63.401	97	<0.001
	2 - 5 mm	$55.394 - 6.244\,x$	0.6084	9.037	97	<0.001

x	Cardinal distance (m)
y	Rooting intensity
SEE	Standard error of estimate
R^2	Coefficient of determination
n	Number of observations
p	Probability

Table23: Percentage of roots at different depth intervals and lateral distance from base of the clump

Depth intervals (cm)	Lateral distance from the clump base (m)									
	1	2	3	4	5	6	7	8	9	10
0-10	13.8	19.3	7.5	8.6	8.6	10.0	0.0	0.0	0.0	0.0
10-20	31.2	30.7	29.8	29.3	33.4	34.0	16.7	21.0	26.7	44.5
20-30	25.6	22.1	24.5	25.0	28.2	24.0	45.8	42.2	40.0	33.3
30-40	14.7	14.3	23.3	21.6	17.3	10.0	16.7	21.0	20.0	22.2
40-50	14.7	13.6	14.9	15.5	12.3	22.0	20.8	15.9	13.3	0.0

Table 24: Cluster membership of cases using average linkage between groups

Cluster numbers	5 cluster solution	
	Clump size class	Depth interval (cm)
Internal face of the trench		
1	Small Small Medium Large	0-10 40-50 0-10 0-10
2	Small Small	10-20 20-30
3	Small Large Large	30-40 30-40 40-50
4	Medium Medium	10-20 20-30
5	Medium Medium Large Large	30-40 40-50 10-20 20-30
External face of the trench		
1	Small Medium Large	0-10 0-10 0-10
2	Small Medium Medium Medium	10-20 20-30 30-40 40-50
3	Small Small Large Large Large Large	20-30 30-40 10-20 20-30 30-40 40-50
4	Small	40-50
5	Medium	10-20

Hierarchical cluster analysis using average linkage between clump size-depth interval combinations showed that root counts formed five distinct clusters. Regardless of clump size classes, rooting intensity in the 0-10 cm soil depth formed one distinct group (Table 24). With respect to the rooting intensity on the internal face of the logarithmic spiral trenches 40-50 cm depth interval also formed part of this group, although it formed an exclusive category in the case of roots on the external face of the trench. Other main groupings included 10-20 and 20-30 cm depth intervals for the small clumps and 10-20 and 20-30 cm depth classes for the medium clumps. Surprisingly, 30-40 cm depth interval for the small clumps formed a more or less homogenous sub-set with 30-40 and 40-50 cm horizons in respect of large clumps. Rooting intensities in 30-40 at 40-50 cm profile zones for medium clumps and 10-20 and 20-30 cm for the large clumps were also similar in respect of rooting intensity.

Discussion

DISCUSSION

6.1. ^{32}P absorption by different components in binary mixtures

The results showed clearly that ^{32}P absorbed by teak or *Vateria* in binary mixtures involving bamboo is dependent on spatial distribution of the bamboo clumps (Tables 1, 9, 12 Fig. 3,7,9). There are distinct variations in this respect owing to depth of ^{32}P placement also. On the whole, absorption of ^{32}P applied in the surface horizons of the soil profile (25 cm depth) increased as spatial separation of bamboo increased from 1.5 to 4.5 m. With deeper placement of the label (50 cm), ^{32}P absorbed by the treated plants decreased as lateral distance from bamboos increased. However, this trend was less pronounced at 31 days after ^{32}P application.

Variations in ^{32}P absorption as a function of lateral distance of bamboo occurrence and depth of label placement can probably be explained by variations in rooting intensities of the components involved. Excavation studies have clearly shown that bamboo rooting intensities decreased linearly with distance from the clump (Fig. 17). A similar effect was discernible with respect to soil depth also.

The extent of ^{32}P recovery in the leaves of treated teak/*Vateria* plants indicates the presence of active roots in the corresponding rhizospheric positions. Many previous workers have reported a pronounced drop in root activity (on unit volume basis) with increasing soil depth and radial distance from the tree base (Jamaludheen *et al.*, 1997; Wahid *et al.*, 1989 a; George *et al.*, 1996). This in turn, signifies that most of the active roots responsible for water and nutrient uptake are concentrated near the base of the tree, in the top layer of the soil profile.

Overall, ^{32}P uptake by teak and *Vateria* in binary mixtures involving bamboo is a function of two co-varying factors viz. rooting intensities of teak/*Vateria* and the rooting intensity of bamboo. Close to the stem of the treated teak/*Vateria*/bamboo their respective root activity will be concentrated. However, bamboo rooting intensity declined linearly with increasing radial distance of its occurrence. As a result, in binary mixtures, uptake of ^{32}P applied at any specific point in the rhizosphere will be decided by the relative proportions of these two rooting systems. Schroth and Zech (1995) reported that in *Gliricidia* based hedgerow system the root length density of the hedgerows was too low to compete with crops for soil resources. However, the present results suggest that when bamboo hedgerows are present on the farm boundaries root competition may be substantial up to a distance of about 4-5 m.

Competition for below ground resources between trees have been seldom studied. However, some attempts were made to evaluate the competition for below ground resources between trees and field crops. Root competition in polyculture systems involving combinations of four tree species and four grass species was evaluated based on ^{32}P recovery by each species in mixed and sole crop situations by George *et al.* (1996). They found that, while grass species did not adversely affect the absorption of ^{32}P by trees, trees in general exerted either a complimentary/competitive influence depending on the nature of the tree species involved. Regarding trees, one species may have a competitive advantage over another for water and nutrients by (i) acquiring a greater proportion of available soil resources (ii) using water and nutrients more efficiently in producing biomass and/or (iii) allocating assimilate in ways that maximize survival and growth (Nambiar and Sands, 1993).

Root architecture is a cardinal determinant of below ground competition. Noordwijk and Purnomosidhi (1995) reported that desirable root architecture for trees differs between sequential and simultaneous agroforestry systems. In a sequential system, extensive root development may enhance nutrient capture and transfer to subsequent crops via organic pools. In simultaneous systems, tree root development in the crop root zone leads to competition for resources. In this context, the present experimental system is analogous to a simultaneous system, where extensive lateral spread of the component roots may enhance interspecific competition.

Not only interspecific competition (teak/*Vateria* Vs bamboo) is important in deciding the relative uptake of nutrients in mixed species systems, but also the intraspecific competition plays a cardinal role in deciding the magnitude of nutrient uptake. Data presented in Tables 3-5, 11-13 and Fig. 4-5, 8-9 shows that neighbouring teak and *Vateria* plants absorbed substantial portions of the isotope applied. Within species competition, however, may be a function of population density, stand age and/or stage of stand development. In commercial plantation forestry, tree species are chosen primarily for their capacity to achieve high growth rates over a wide range of sites and for the quality and value of their wood (Kumar *et al.,*1998).

Site factors and stage of stand development are important factors in deciding the magnitude of interspecific competition. On good sites, when resource availability is unlimited, competition may be lower. As regards to stand age/stage of stand development, competition may be low initially and may intensify later. It may increase as stand age increases and may peak at about crown closure (Long and Smith,1985). Regarding site-variations in the structure and distribution of plant roots, Klepper (1987) observed that the chemical and physical conditions of soil in the root zone are important. These factors may operate simultaneously and interactively to control root distribution.

On account of their profusely branching fibrous root systems bamboos are considered highly competitive. White and Childers (1945) ascertained the root distribution pattern of *Bambusa tulda* Roxb and found roots at a distance more than 17 feet from the clump with nearly 83% of the roots in the top 30 cm soil layer. Soil tillage may be used to destroy competing roots in the topsoil. Trenching around the bamboo clumps is routinely advocated as a method for reducing root density in the surface horizons of the soil profile. Deep placement of fertilizer may be recommended provided, the target species possess deep root system. However, if the target tree/crop root system are shallow, this approach may not be of much practical relevance.

6.2. Bamboo root distribution pattern

The data show that bamboo roots extend to a distance of at least 8 m (Fig. 11-17). Clump size appears to be a major determinant in this respect. Larger clumps obviously show greater lateral spread of roots. In an investigation of the root distribution of *Parkia biglobosa* (Jacq.) Benth. in Burkina Faso, Tomlinson *et al.* (1998) observed that lateral spread of tree roots is a function of the crown spread. They suggested that for trees with an average crown radius of 7 m, the area exploited by the root system is at least twice that of the crown. Although no such quantitative relationship could be evolved in the present study, clump size, probably a surrogate to crown diameter, seemed to be closely related to the area exploited by the root system.

Lateral spread of roots in boundary planted bamboo clumps in the present study irrespective of clump sizes, did not exceed beyond 10 m. Furthermore, isotope studies have clearly shown that most of the competitive effects are well within 5-6 m. Therefore, it can be concluded that root competition for below ground resource owing to boundary planted bamboos for woody perennial tree crops may be highest up to about 5-6 m. It shall be negligible beyond this limit. However, caution should be used in extrapolating the presented results as the site conditions and nature of associated tree/crop species need be taken into account when considering the lateral spread of roots.

Regarding the vertical distribution of roots, rooting intensity was highest in 10-20 cm soil horizon. A lower rooting intensity in the surface layers (0-10 cm) compared to lower depths observed in the present study is at variance with that reported by many previous workers. For instance, Jamaludheen *et al.* (1997) observed maximum root activity for *Artocarpus heterophyllus* in the top 30 cm as opposed to lower depth up to 90 cm.

Presumably bamboo roots are more or less evenly distributed in the soil profile up to 10-40 cm depth. Beyond 50 cm depth perhaps there may be drastic reduction in rooting intensity. Isotope studies have also shown that deep placement of the label resulted in relatively lower uptake by neighbouring bamboo clumps. Results of the hierarchial cluster analysis have shown that, overall 0-10 and 40-50 cm horizons and 10-40 cm depth zone formed distinctive categories. Implicit in this vertical distribution pattern of bamboo roots are capable of capturing the lower leaching nutrients and thus accomplish on-site nutrient conservation. Nutrient conserving processes are particularly relevant if crops are insufficiently developed or absent but mineralization rates of organic matter are high, as at the onset of rains (Schroth, 1985).

6.3. Implications for cropping in association with bamboo

In the humid tropical regions of peninsular India, numerous trees and field crops are often grown in association with *Bambusa arundinacea* and many other bamboos. Homegardening is a prominent example in this respect (Kumar, *et al.* 1994). Productivity of field crops grown in association with bamboo clumps has, however, generally been low, probably due to the shading effects and also the extensive lateral spread of bamboo roots. Results from isotope study, has indicated that competition by bamboo clumps may extend up to an area of at least 5-6 m radial distance from the clump base, for ten year old clumps on a lateritic site. After this, which magnitude of competition shall be negligible. However caution should be exercised in extrapolating the data to other sites and age classes as micro-site and tree age variations can alter root distribution pattern of trees quite substantially (IAEA, 1975).

Excavation studies also imply that, roots of bamboo clumps may be at least 8 m from base of the clumps and extend up to >10 m lateral distance. But, higher rooting intensities are seen in 5-6 m, lateral distance from clump base. With respect to the vertical distribution of roots, more roots are found in the 10-30 cm soil horizon. Thus, a considerable overlap between the bamboo roots and crop rooting zone in the 30 cm depth and 5-6 m lateral distance zone is possible.

Summary

SUMMARY

A field experiment to characterise root competition in bamboo based mixed species systems was conducted at Vellanikkara from June 1997 to May 1998. Treatments included application of ^{32}P at two depths in binary mixtures of teak-bamboo and *Vateria*-bamboo. Absorption of the radio-label by the treated and neighbouring plants was monitored at 15, 31 and 45 days after application. Root distribution pattern of boundary planted bamboo clumps were elucidated by partially excavating the root systems using a logarithmic spiral trenching method.

Salient results are as follows

(1). ^{32}P absorption by teak/*Vateria* increased as the lateral distance of bamboo occurrence increased.

(2). Deeper placement (50 cm) of ^{32}P showed higher recovery of the radio-label by teak/*Vateria*. But absorption of the isotope declined linearly with distance of bamboo occurrence.

(3). ^{32}P uptake by boundary-planted bamboos adjacent to treated teak/*Vateria* is inversely related to distance from the treated plants.

(4). Competition by bamboo clumps may extend up to an area of at least 5-6 m radial distance from the clump base for ten-year-old clumps on a lateritic site. Beyond six metres, the magnitude of competition may be negligible.

(5). Excavation studies indicated that bamboo rooting intensity was concentrated near the clump's base. There was a linear decrease in rooting intensity with distance.

(6). Root distribution pattern varied among bamboo clump sizes (small, medium and large). Medium sized clumps registered higher rooting intensities than small and large clumps up to quadrats 1-7. Large clumps recorded higher rooting intensities beyond this limit.

(7). Spatial distribution of bamboo roots may be upto least 8 m from base of the clumps and rarely extend beyond 10 m of lateral distance.

(8). Higher rooting intensities are seen upto 5-6 m lateral distance from clump base.

(9). Comparison of vertical distribution of roots at different depths of soil horizon has shown that, more roots are found in the 10-30 cm soil horizon with nearly 60% of total root counts.

(10). Radio-label recovered from different depths implies that physiologically active root are concentrated at 25 cm than at 50 cm depth. This may have important implications for fertilizer placement in mixed species systems.

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* Original not seen

Appendices

APPENDIX I

Weather parameters during the experimental period (June 1997 to May 1998) recorded from the Department of Agriculture Meteorology, College of Horticulture, Vellanikkara, Thrissur

Sl. No.	Months	Temperature (°C)		Rainfall (mm)
		Maximum	Minimum	
1	1997 June	31.2	23.0	720.5
2	July	28.6	21.8	979.2
3	August	29.0	22.8	636.8
4	September	30.6	23.4	164.0
5	October	32.2	23.6	194.7
6	November	31.6	23.2	209.7
7	December	31.7	23.8	66.7
8	1998 January	33.1	22.8	0
9	February	34.4	23.6	0
10	March	36.2	23.6	11
11	April	36.5	25.6	61.4
12	May	34.1	25.2	203.0
	Mean	32.4	23.5	270.60
	Total			3247.3

APPENDIX II

Abstract of ANOVA tables for radioactivity recovered from the leaves of teak as a function of lateral distance and depth and days after application of ^{32}P

Source	df	Mean square		
		Days after application of ^{32}P		
		15th	31st	45thday
Lateral distance (m)	2	0.362	1.355	0.398
Depth (cm)	1	0.142	0.000	0.300
Interaction	2	0.440	1.211	1.433
Error	12	0.147	0.655	0.660

APPENDIX III

Abstract of ANOVA tables for radioactivity recovered from the leaves of neighbouring teak as a function of lateral distance of bamboo occurrence and depth and days after application of ^{32}P

Source	df	Mean square		
		Days after application of ^{32}P		
		15th	31st	45th
Lateral distance (m)	2	0.117	0.512	0.383
Depth (cm)	1	0.025	1.000	0.295
Interaction	2	0.118	0.152	0.200
Error	12	0.145	0.332	0.149

APPENDIX IV

Abstracts of ANACOVA tables for radioactivity recovered from the leaves of bamboo in Teak bamboo combination as a function of lateral distance and depth and days after application of ^{32}P

Source	df	Mean square		
		Days after application of ^{32}P		
		15th	31st	45thday
Distance	2	0.249	0.223	0.145
Depth	1	0.109	0.374	0.145
Interaction	2	0.269	0.142	1.619*
Co-variate	1	0.003	0.030	0.351
Error	11	0.124	0.467	0.220

* Significant at 5% level

APPENDIX V

Abstracts of ANOVA tables for radioactivity recovered from the leaves of *Vateria* as a function of lateral distance and depth and days after application of ^{32}P

Source	df	Mean square		
		Days after application of ^{32}P		
		15th	31st	45thday
Lateral distance (m)	2	2.033	3.291	2.827
Depth (cm)	1	4.146	0.024	0.030
Interaction	2	0.169	0.074	0.113
Error	12	1.840	2.570	2.121

APPENDIX VI

Abstracts of ANOVA tables for radioactivity recovered from the leaves of neighbouring *Vateria* as a function of lateral distance of bamboo occurrence and depth and days after application of ^{32}P

Source	df	Mean square		
		Days after application of ^{32}P		
		15th	31st	45th
Lateral distance (m)	2	0.271	1.603	1.361*
Depth (cm)	1	0.416	0.596	1.190
Interaction	2	0.205	0.025	0.064
Error	12	0.245	0.599	0.274

* Significant at 5% level

APPENDIX VII

Abstracts of ANACOVA tables for radioactivity recovered from the leaves of bamboo in *Vateria*-bamboo combination as a function of lateral distance and depth and days after application of ^{32}P

Source	df	Mean square		
		Days after application of ^{32}P		
		15th	31st	45thday
Distance	2	0.030	0.000	0.462**
Depth	1	0.618	0.037	0.365*
Interaction	2	0.432	0.053	0.023
Co-variate	1	0.255	0.301	0.043
Error	11	0.159	0.095	0.054

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

APPENDIX-VIII

Abstracts of MANOVA of <2 mm diameter roots on internal face of the trench

A. Tests of Between-Subjects effects and tests of significance for T_1 (linear) using UNIQUE same of squares

Source	DF	Mean square	Sig. of F
Clump size	2	331699.26	0.001
Depth	4	850041.48	0.000
Clump size by Depth	8	20560.37	0.873
Within + Residual	75	43726.12	

B. Tests involving DISTANCE Within-Subject Effect

Mauchly sphericity test, W	0.02400
Chi-square approx.	269.00986 with 35DF
Significance	0.000
Greenhouse-Geisser Epsilon	0.55205
Huynh-Feldt Epsilon	0.70037
Lower-bound Epsilon	0.12500

C. Multivariate tests of significance for different effects

Test Name	Value	Approx. F	Hypoth. DF	Error DF	Sig. of F
Distance					
Pillais	0.93921	131.31938•	8.00	68.00	0.00
Hotellings	15.44934	131.31938•	8.00	68.00	0.00
Wilks	0.06079	131.31938•	8.00	68.00	0.00
Roys	0.93921				
Clump size by distance					
Pillais	0.75229	5.20037	16.00	138.00	0.00
Hotellings	1.20799	5.05845	16.00	134.00	0.00
Wilks	0.38894	5.12947•	16.00	136.00	0.00
Roys	0.39213				
Depth by distance					
Pillais	0.95023	2.76524	32.00	284.00	0.00
Hotellings	1.97002	4.09395	32.00	266.00	0.00
Wilks	0.26901	3.37279	32.00	252.37	0.00
Roys	0.60921				
Clump size by depth by distance					
Pillais	0.70662	0.90829	64.00	600.00	0.677
Hotellings	0.86689	0.89736	64.00	530.00	0.699
Wilks	0.45842	0.90206	64.00	398.71	0.687
Roys	0.26842				

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

Source	DF	Mean squares	Sig. of F
Distance	8	1863227.8	0.000
Clump size by distance	16	27882.59	0.000
Depth by distance	32	36567.59	0.000
Clump size by depth by distance	64	8392.31	0.573
Within + Residual	600	8769.90	

• 'F' statistic is exact

APPENDIX-IX

Abstracts of MANOVA of 2-5 mm diameter roots on internal face of the trench

A. Tests of Between-Subjects effects and tests of significance for T_1 (linear) using UNIQUE sums of squares

Source	DF	Mean square	Sig. of F
Clump size	2	1290.37	0.298
Depth	4	9877.78	0.000
Clump size by Depth	8	362.59	0.945
Within + Residual	75	1048.69	

B. Tests involving DISTANCE Within-Subject effect

Mauchly sphericity test, W	0.00084
Chi-square approx.	510.54763 with 35 DF
Significance	0.000
Greenhouse-Geisser Epsilon	0.28527
Huynh-Feldt Epsilon	0.34963
Lower-bound Epsilon	0.12500

C. Multivariate tests of significance for different effects

Test Name	Value	Approx./F	Hypoth. DF	Error DF	Sig. of F
Distance					
Pillais	0.85159	48.77432•	8.00	68.00	0.00
Hotellings	5.73816	48.77432•	8.00	68.00	0.00
Wilks	0.14841	48.77432•	8.00	68.00	0.00
Roys	0.85159				
Clump size by distance					
Pillais	0.40740	2.20634	16.00	138.00	0.007
Hotellings	0.52121	2.18258	16.00	134.00	0.008
Wilks	0.63168	2.19474•	16.00	136.00	0.008
Roys	0.25284				
Depth by distance					
Pillais	0.68410	1.83100	32.00	284.00	0.005
Hotellings	1.15309	2.39627	32.00	266.00	0.000
Wilks	0.41862	2.10042	32.00	252.37	0.001
Roys	0.47862				
Clump size by depth by distance					
Pillais	0.49841	0.62288	64.00	600.00	0.990
Hotellings	0.56062	0.58033	64.00	530.00	0.996
Wilks	0.58974	0.59728	64.00	398.71	0.994
Roys	0.16001				

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

Source	DF	Mean squares	Sig. of F
Distance	8	38620.00	0.000
Clump size by distance	16	1420.37	0.000
Depth by distance	32	643.61	0.178
Clump size by depth by distance	64	300.93	0.996
Within + Residual	600	521.36	

• 'F' statistic are exact

APPENDIX-X

Abstracts of MANOVA of total roots on internal face of the trench

A. Tests of Between-Subjects effects and tests of significance for T_1 (linear) using UNIQUE sums of squares

Source	DF	Mean square	Sig. of F
Clump size	2	335461.23	0.003
Depth	4	1051421.50	0.000
Clump size by depth	8	23682.22	0.882
Within + Residual	75	51775.90	

B. Tests involving DISTANCE Within-Subject effect

Mauchly sphericity test, W	0.01754
Chi-square approx.	291.61065 with 35 D.F
Significance	0.000
Greenhouse-Geisser Epsilon	0.53505
Huynh-Feldt Epsilon	0.67739
Lower-bound Epsilon	0.12500

C. Multivariate tests of significance for different effects

Test Name	Value	Approx. F	Hypoth. DF	Error DF	Sig. of F
Distance					
Pillais	0.93646	125.27983•	8.00	68.00	0.000
Hotellings	14.73880	125.27983•	8.00	68.00	0.000
Wilks	0.06354	125.27983•	8.00	68.00	0.000
Roys	0.93646				
Clump size by distance					
Pillais	0.72631	4.91831	16.00	138.00	0.000
Hotellings	1.14435	4.79195	16.00	134.00	0.000
Wilks	0.40507	4.85525•	16.00	136.00	0.000
Roys	0.38549				
Depth by distance					
Pillais	0.91639	2.63749	32.00	284.00	0.000
Hotellings	1.93316	4.01734	32.00	266.00	0.000
Wilks	0.27856	3.26671	32.00	252.37	0.000
Roys	0.60864				
Clump size by depth by distance					
Pillais	0.74139	0.95756	64.00	600.00	0.572
Hotellings	0.91927	0.95158	64.00	530.00	0.585
Wilks	0.43938	0.95468	64.00	398.71	0.578
Roys	0.28045				

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

Source	DF	Mean squares	Sig. of F
Distance	8	2422012.30	0.000
Clump size by distance	16	33777.90	0.000
Depth by distance	32	45543.93	0.000
Clump size by depth by distance	64	9880.14	0.659
Within + Residual	600	10775.46	

• F statistics are exact

APPENDIX-XI

Abstracts of MANOVA of <2 mm diameter roots on external face of the trench

A. Tests of Between-Subjects effects and tests of significance for T_1 (linear) using UNIQUE sums of squares

Source	DF	Mean square	Sig. of F
Clump size	2	217364.44	0.005
Depth	4	678694.32	0.000
Clump size by depth	8	30292.84	0.604
Within + Residual	75	37819.85	

B. Tests involving DISTANCE Within-Subject effect

Mauchly sphericity test, W	0.01346
Chi-square approx.	310.71757 with 35 D.F
Significance	0.000
Greenhouse-Geisser Epsilon	0.51445
Huynh-Feldt Epsilon	0.64966
Lower-bound Epsilon	0.12500

C. Multivariate tests of significance for different effects

Test Name	Value	Approx. F	Hypoth. DF	Error DF	Sig. of F
Distance					
Pillais	0.92211	100.63015•	8.00	68.00	0.000
Hotellings	11.83884	100.63015•	8.00	68.00	0.000
Wilks	0.07789	100.63015•	8.00	68.00	0.000
Roys	0.92211				
Clump size by distance					
Pillais	0.44321	2.45547	16.00	138.00	0.003
Hotellings	0.58316	2.44197	16.00	134.00	0.003
Wilks	0.60267	2.44911•	16.00	136.00	0.003
Roys	0.27844				
Depth by distance					
Pillais	0.94285	2.73711	32.00	284.00	0.000
Hotellings	1.76532	3.66856	32.00	266.00	0.000
Wilks	0.28722	3.17455	32.00	252.37	0.000
Roys	0.57123				
Clump size by depth by distance					
Pillais	0.64178	0.81769	64.00	600.00	0.842
Hotellings	0.76088	0.78763	64.00	530.00	0.882
Wilks	0.49782	0.80083	64.00	398.71	0.862
Roys	0.19970				

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

Source	DF	Mean squares	Sig. of F
Distance	8	1102695.60	0.000
Clumpsize by distance	16	20530.00	0.000
Depth by distance	32	23501.27	0.000
Clump size by depth by distance	64	4138.95	0.983
Within + Residual	600	6352.07	

• F statistic is exact

APPENDIX-XII

Abstracts of MANOVA of 2-5 mm diameter roots on external face of the trench

A. Tests of Between-Subjects effects and tests of significance for T_1 (linear) using UNIQUE sums of squares

Source	DF	Mean square	Sig. of F
Clump size	2	530.86	0.517
Depth	4	5602.96	0.000
Clump size by depth	8	194.44	0.981
Within + Residual	75	797.53	

B. Tests involving DISTANCE Within-Subject effect

Mauchly sphericity test, W	0.00008
Chi-square approx	681.00299
Significance	0.000
Greenhouse-Geisser Epsilon	0.22146
Huynh-Feldt Epsilon	0.26876
Lower-bound Epsilon	0.12500

C. Multivariate tests of significance for different effects

Test Name	Value	Approx. F	Hypoth. DF	Error DF	Sig. of F
Distance					
Pillais	0.74950	25.43201•	8.0	68.00	0.000
Hotellings	2.99200	25.43201•	8.0	68.00	0.000
Wilks	0.25050	25.43201•	8.0	68.00	0.000
Roys	0.74950				
Clump size by distance					
Pillais	0.40081	2.16172	16.00	138.00	0.009
Hotellings	0.53980	2.26041	16.00	134.00	0.006
Wilks	0.62965	2.21196•	16.00	136.00	0.007
Roys	0.29889				
Depth by distance					
Pillais	0.57172	1.48005	32.00	284.00	0.051
Hotellings	0.89740	1.86490	32.00	266.00	0.004
Wilks	0.49372	1.66343	32.00	252.37	0.017
Roys	0.42470				
Clump size by distance					
Pillais	0.82987	1.08506	64.00	600.00	0.311
Hotellings	1.05520	1.09230	64.00	530.00	0.300
Wilks	0.39401	1.09174	64.00	398.71	0.305
Roys	0.30963				

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

Source	DF	Mean squares	Sig. of F
Distance	8	18239.38	0.000
Clump size by distance	16	1339.75	0.000
Depth by distance	32	402.96	0.332
Clump size by depth by distance	64	235.28	0.987
Within+Residual	600	367.98	

• F statistics are exact

APPENDIX-XIII

Abstracts of MANOVA of total roots on external face of the trench

A. Tests of Between-Subjects effects and tests of significance for T_1 (linear) using UNIQUE sums of squares

Source	DF	Mean square	Sig. of F
Clump size	2	228089.38	0.009
Depth	4	802921.73	0.000
Clump size by depth	8	32175.80	0.679
Within + Residual	75	45136.99	

B. Tests involving DISTANCE Within-Subject effect

Mauchly sphericity test, W	0.01068
Chi-square approx.	327.37974 with 35 DF
Significance	0.000
Greenhouse-Geisser Epsilon	0.49345
Huynh-Feldt Epsilon	0.62152
Lower-bound Epsilon	0.12500

C. Multivariate tests of significance for different effects

Test Name	Value	Approx. F	Hypoth. DF	Error DF	Sig. of F
Distance					
Pillais	0.91144	87.47760•	8.00	68.00	0.00
Hotellings	10.29148	87.47760•	8.00	68.00	0.00
Wilks	0.08856	87.47760•	8.00	68.00	0.00
Roys	0.91144				
Clump size by distance					
Pillais	0.39135	2.09825	16.00	138.00	0.012
Hotellings	0.50193	2.10184	16.00	134.00	0.012
Wilks	0.64296	2.10048•	16.00	136.00	0.011
Roys	0.25874				
Depth by distance					
Pillais	0.92171	2.65737	32.00	284.00	0.00
Hotellings	1.64686	3.42239	32.00	266.00	0.00
Wilks	0.30231	3.02201	32.00	252.37	0.00
Roys	0.54846				
Clump size by depth by distance					
Pillais	0.63948	0.81450	64.00	600.00	0.847
Hotellings	0.75288	0.77934	64.00	530.00	0.892
Wilks	0.50027	0.79483	64.00	398.71	0.870
Roys	0.20440				

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

Source	DF	Mean squares	Sig. of F
Distance	8	1394022.7	0.000
Clump size by distance	16	22709.38	0.000
Depth by distance	32	29042.01	0.000
Clump size by depth by distance	64	4665.25	0.985
Within + Residual	600	7285.65	

• F statistic is exact

APPENDIX-XIV

^{32}P absorption by neighbouring teak (cpm g^{-1} dry leaves) at different lateral distance from bamboo occurrence

Depth of ^{32}P placement	Lateral Distance of bamboo occurrence	15 days after ^{32}P application	31 days after ^{32}P application	45 days after ^{32}P application
50.0	4.1	295.66	119.70	0.00
50.0	4.1	36.98	18.18	0.00
50.0	4.1	27.17	0.00	0.00
50.0	4.1	0.00	31.31	0.00
50.0	4.1	44.72	0.00	8.47
50.0	4.1	13.77	10.35	35.34
50.0	4.1	42.83	0.00	82.25
50.0	4.1	48.68	10.61	26.87
50.0	4.1	15.47	62.37	10.10
50.0	4.4	85.47	0.00	40.23
50.0	4.4	33.02	13.13	6.68
50.0	4.4	36.98	0.00	0.00
50.0	4.4	38.87	0.00	30.29
50.0	4.4	36.98	0.00	18.40
50.0	4.4	50.94	18.18	11.73
50.0	3.3	35.09	15.64	23.45
50.0	3.3	68.11	13.13	0.00
50.0	3.3	27.17	0.00	9.93
25.0	2.0	66.04	761.11	1319.87
25.0	2.0	42.83	18.18	85.67
25.0	2.0	27.17	20.96	52.12
25.0	2.0	23.40	18.18	78.83
25.0	2.0	58.86	0.00	15.15
25.0	2.0	58.30	109.34	15.15
25.0	4.4	189.66	117.17	21.83
25.0	4.4	1120.69	2540.40	297.23
25.0	4.4	139.52	7.83	16.78
25.0	4.4	144.83	36.36	1.63
25.0	4.4	136.60	5.30	20.19
25.0	4.4	36.98	75.51	80.62
25.0	4.4	114.85	0.00	35.18
25.0	1.9	136.60	15.66	16.78
25.0	1.9	215.92	33.84	1.60
25.0	1.9	177.72	8133.59	508.96
25.0	1.9	177.72	28.54	49.16
25.0	1.9	147.74	20.96	15.15
50.0	2.2	147.74	143.20	923.94
50.0	2.2	112.20	26.01	20.19
50.0	2.2	281.43	171.97	26.87
50.0	2.2	183.30	83.33	0.00
50.0	2.2	135.01	0.00	0.00
50.0	2.2	136.60	15.66	1.63
50.0	3.0	177.72	44.19	84.04
50.0	3.0	166.84	88.38	5.05

50.0	3.0	139.52	0.00	26.87
50.0	3.0	60.21	7.83	3.42
50.0	3.0	21.75	2.53	0.00
50.0	3.0	38.19	10.35	6.68
50.0	2.1	49.34	0.00	55.37
50.0	2.1	43.76	5.05	15.15
50.0	2.1	38.19	28.79	28.50
50.0	2.1	10.88	354.29	23.45
50.0	2.1	0.00	36.36	16.78
50.0	2.1	27.32	23.49	23.45
25.0	4.4	68.43	5.30	42.35
25.0	4.4	21.75	67.68	77.36
25.0	4.4	8.22	10.35	13.35
25.0	4.4	8.22	70.20	21.83
25.0	4.4	14.06	67.68	0.00
25.0	4.4	24.67	0.00	21.83
25.0	4.4	38.46	0.00	139.58
25.0	4.4	5.57	31.31	3.42
25.0	4.4	10.87	0.00	23.45
25.0	4.4	0.00	23.48	5.05
50.0	3.8	24.67	171.97	51.12
50.0	3.8	35.54	18.18	0.00
50.0	3.8	131.30	83.33	211.89
50.0	3.8	29.97	41.67	0.00
50.0	3.8	0.00	13.13	0.00
50.0	3.8	98.41	23.48	0.00
50.0	3.8	5.57	0.00	13.36
50.0	2.8	27.32	36.36	13.36
50.0	2.8	0.00	65.15	1.63
50.0	2.8	0.00	0.00	0.00
50.0	2.8	16.44	33.84	129.32
50.0	2.8	24.67	65.15	5.05
25.0	3.3	16.45	0.00	5.05
25.0	3.3	103.97	320.20	549.02
25.0	3.3	49.34	304.79	15.17
25.0	3.3	44.03	0.00	8.47
25.0	3.3	166.84	52.02	89.09
25.0	3.3	66.05	23.48	28.50
25.0	4.0	51.99	0.00	13.52
25.0	4.0	13.79	0.00	5.05
25.0	4.0	21.75	26.01	3.42
25.0	4.0	41.11	119.69	5.05
25.0	4.0	41.11	15.66	30.29
25.0	4.0	165.25	7.80	31.60
25.0	1.5	0.00	2.53	100.81
25.0	1.5	33.09	15.65	6.84
25.0	1.5	14.59	62.37	0.00
25.0	1.5	62.27	7.83	0.00
25.0	1.5	33.09	0.00	6.68
25.0	1.5	36.65	7.83	20.19
25.0	3.0	48.04	130.05	1.63

25.0	3.0	11.03	39.14	5.04
25.0	3.0	58.71	36.36	13.36
25.0	3.0	0.00	36.86	0.00
25.0	3.0	36.65	0.00	100.81
25.0	3.0	44.13	49.50	20.19
25.0	3.0	18.50	54.80	31.92
25.0	3.0	55.16	54.80	26.87
25.0	3.0	22.06	0.00	0.00
50.0	2.3	13.89	1485.86	1096.74
50.0	2.3	7.12	0.00	0.00
50.0	2.3	0.00	31.31	0.00
50.0	2.3	1169.49	28.54	0.00
50.0	2.3	38.31	2.53	11.73
50.0	2.3	0.00	15.65	21.80
50.0	2.3	3.39	23.48	0.00
50.0	2.3	31.86	36.36	0.00
50.0	2.3	0.00	13.13	0.00

APPENDIX-XV

^{32}P absorption by neighbouring *vateria* (cpm g^{-1} dry leaves) at different lateral distance from bamboo occurrence

Depth of ^{32}P placement	Lateral Distance of bamboo occurrence	15 days after ^{32}P application	31 days after ^{32}P application	45 days after ^{32}P application
50.0	5.5	16.08	57.32	250.00
50.0	5.5	117.25	98.98	23.45
50.0	5.5	0.00	7.80	531.92
50.0	5.5	28.23	10.35	0.00
25.0	2.5	28.23	0.00	18.41
25.0	2.5	26.00	0.00	1.63
25.0	2.5	0.00	0.00	0.00
25.0	2.5	0.00	33.84	167.91
25.0	2.5	44.31	39.14	13.35
25.0	2.5	0.00	0.00	0.00
25.0	2.5	28.24	0.00	11.73
50.0	2.3	0.00	23.48	23.45
50.0	2.3	0.00	18.18	0.00
50.0	2.3	5.00	26.01	5.04
50.0	2.3	0.00	5.30	1.63
50.0	2.3	31.00	44.20	16.78
50.0	4.4	26.00	953.28	656.68
50.0	4.4	0.00	10.35	0.00
50.0	4.4	0.00	28.54	6.78
50.0	4.4	0.00	65.15	8.47
50.0	4.4	0.00	39.14	5.05
50.0	3.6	283.50	614.14	315.64
25.0	4.3	62.00	0.00	8.47
25.0	4.3	72.00	10.35	15.15
25.0	4.3	0.00	1035.59	1834.85
25.0	4.3	0.00	46.97	11.73
25.0	4.3	0.00	18.18	0.00
25.0	4.3	0.00	0.00	0.00
25.0	4.3	0.00	10.35	0.00
50.0	2.7	15.50	51.51	40.23
50.0	2.7	36.00	23.48	0.00
50.0	2.7	0.00	20.96	0.00
25.0	2.5	81.50	0.00	67.16
25.0	2.5	0.00	5.30	0.00
25.0	2.5	48.63	15.66	0.00
25.0	2.5	24.31	39.14	3.42
25.0	2.5	0.00	41.67	3.42
25.0	2.5	12.15	13.13	0.00
25.0	3.4	0.00	0.00	238.44
25.0	3.4	23.92	127.53	198.21
25.0	3.4	3.92	18.18	8.47
25.0	3.4	230.58	2008.08	534.03
25.0	3.4	24.31	7.80	8.47
50.0	4.9	80.78	9331.57	43.65
50.0	4.9	60.78	78.00	0.00
50.0	4.9	0.00	15.66	11.73
25.0	4.6	35.29	36.36	31.92
25.0	4.6	20.39	18.18	25.24
25.0	4.6	3.92	5.30	0.00
25.0	6.3	179.22	541.66	3.42

25.0	6.3	674.50	340.90	4150.00
25.0	6.3	85.09	49.49	21.82
25.0	6.3	56.47	307.07	1.63
25.0	2.2	199.61	307.32	144.46
25.0	2.2	0.00	0.00	0.00
25.0	2.2	72.94	156.31	194.95
25.0	2.2	69.01	0.00	0.00
25.0	2.2	254.51	919.44	0.00
50.0	4.8	21.00	20.70	43.65
50.0	4.8	26.00	2.53	0.00
50.0	4.8	72.00	0.00	1.63
50.0	4.8	15.50	0.00	10.09
50.0	4.8	36.50	2.53	0.00
50.0	4.8	26.00	0.00	0.00
50.0	4.8	108.50	36.61	10.09
50.0	2.0	26.00	31.31	6.68
50.0	2.0	0.00	7.80	72.31
50.0	2.0	0.00	0.00	15.14
50.0	2.0	26.00	0.00	0.00
25.0	4.9	154.50	17614.89	345.77
25.0	4.9	484.50	2113.38	1094.95
25.0	4.9	0.00	497.22	401.46
25.0	4.9	0.00	1840.15	92.34
25.0	4.9	20.50	54.55	18.40
50.0	3.2	1700.00	1270.20	446.78
50.0	3.2	0.00	33.84	0.00
50.0	3.2	82.50	85.86	634.85
50.0	3.2	5.00	109.34	18.40
50.0	3.2	26.00	15.66	0.00
25.0	4.3	149.50	20.96	501.79
25.0	4.3	5.00	5.30	8.47
25.0	4.3	0.00	54.79	25.24
25.0	4.3	31.00	20.96	0.00
25.0	4.3	98.00	3200.00	652.93

APPENDIX XVI

Rooting intensity (number m^{-2}) in small medium and large sized bamboo clumps

Size classes	I	E	I	E	I	E	I	E	I	E	I	E	I	E	I	E
Small clumps																
Distance(m)	1.5	2.1	2.6	3	3.6	3.85	4.5	4.6	5.4	5.5	6.3	6.1	7.3	7.1	7.9	8.1
< 2mm	480	524	573	284	140	364	164	204	220	144	48	88	68	80	0	68
2-5 mm	140	152	204	152	28	12	4	4	12	4	0	0	0	0	0	0
Total	620	676	777	436	168	376	168	208	232	148	48	88	68	80	0	68
Distance	1.75	2.35	2.9	3.3	3.7	4	4.5	4.8	5.5	5.5	6.55	6.45	7.4	7.1		7.65
< 2mm	504	492	424	252	472	208	556	280	296	264	184	180	180	112		100
2-5mm	100	36	32	44	28	24	40	12	16	8	4	16	0	0		0
Total	604	528	456	296	500	232	596	292	312	272	188	196	180	112		100
Distance	1.65	2.25	2.3	2.7	3	3.3	3.7	3.8	4.6	4.5	5.5	5.3	6.4	6.1		6.5
< 2mm	428	376	396	240	352	288	296	292	324	236	230	176	116	136		100
2-5 mm	52	40	44	32	28	16	20	20	28	12	28	16	12	4		8
Total	480	416	440	272	380	304	316	312	352	248	258	192	128	140		108
Distance	1.2	1.8	2.5	2.9	3.4	3.8	4.6	4.7	5.6	5.6	6.6	6.5	7.7	7.5		8.5
< 2mm	312	236	304	173	152	168	156	128	104	104	104	96	72	80		60
2-5mm	52	32	32	32	20	8	16	0	8	4	4	0	0	0		0
Total	364	268	336	205	172	176	172	128	112	108	108	96	72	80		60
Distance	0.9	1.5	2.2	2.6	3.3	3.5	4.3	4.5	5.4	5.4	6.55	6.5	7.8	7.6	8.7	8.9
< 2mm	320	304	208	196	164	116	76	72	60	52	48	56	24	28	4	0
2-5 mm	56	28	28	28	20	12	8	4	0	0	0	0	0	0	0	0
Total	376	332	236	224	184	128	84	76	60	52	48	56	24	28	28	0
Distance	1.05	1.65	2.3	2.6	3.2	3.4	4.1	4.3	5.2	5.1	6.3	6.1	7.3	7.1	7.7	7.8
< 2mm	396	252	220	184	200	152	152	96	60	72	40	40	48	4	8	0
2-5mm	40	12	24	16	12	4	0	0	0	0	0	0	0	0	0	0
Total	436	264	244	200	212	156	152	96	60	72	40	40	48	4	8	0
Medium clumps																
Distance	2.1	2.7	3.2	3.6	4	4.3	4.9	5	5.9	6	6.7	6.85	7.5	7.5	8.3	8.15
< 2mm	492	496	544	464	548	412	388	280	304	168	284	180	152	164	100	68
2-5 mm	72	40	52	24	32	24	20	12	24	8	4	0	0	0	0	0
Total	564	536	596	488	580	436	408	292	328	176	288	180	152	164	164	68
Distance	1.95	2.55	3	3.4	4	4.4	4.8	5.1	5.7	5.9	6.55	6.75	7.3	7.4		8.2
< 2mm	536	456	488	260	272	160	268	248	284	188	200	156	156	92		88
2-5mm	64	48	52	28	24	16	24	16	16	24	16	12	8	12		0
Total	600	504	540	288	296	176	292	264	300	212	216	168	164	104		88
Distance	2.8	3.4	3.6	4	4.7	5.1	6	6.4	6.8	7.1	7.5	7.8	8.4	8.6		9.5
< 2mm	568	544	424	420	364	336	192	204	188	164	164	152	148	136		80
2-5 mm	60	44	52	40	24	12	8	8	12	16	4	4	12	0		0
Total	628	588	476	460	388	348	200	212	200	180	168	156	160	148		80
Distance	2.6	3.2	3.4	3.9	4.1	4.6	5	5.4	6	6.2	6.8	7	7.6	7.8		8.4
< 2mm	532	460	412	256	304	312	260	180	248	152	116	92	156	128		84
2-5mm	64	40	36	24	20	24	20	16	32	16	8	4	8	0		0
Total	596	500	448	280	324	336	280	196	280	168	124	96	164	128		84
Distance	2.8	3.4	3.5	4	4	4.3	4.6	5	5.1	5.4	5.7	6	6.1	6.4		6.7
< 2mm	296	224	288	200		216	212	124	236	156	184	108	104	112		64
2-5 mm	48	20	36	28		20	28	12	32	8	16	12	0	0		0
Total	344	244	324	228		236	240	136	268	164	200	120	104	112		64

Distance	2.36	2.96	3.3	3.8	4.2	4.5	5	5.2	5.8	6	6.5	6.8	7.1	7.2	7.7	7.8
< 2mm	668	548	456	340	332	244	308	264	292	248	200	208	204	156	156	96
2-5mm	56	28	28	36	28	12	32	20	16	16	20	4	12	4	0	0
Total	724	576	484	376	360	256	340	284	308	264	220	212	216	160	156	96
Large clumps																
Distance	3.2	3.8	3.8	4.3	4.5	4.9	5.2	5.5	6.1	6.4	7	7.2	7.6	7.9	8.3	8.5
< 2mm	328	268	428	316	372	280	260	260	220	140	80	116	112	52	32	52
2-5 mm	56	36	36	24	24	4	24	20	4	8	0	8	0	0	0	0
Total	384	304	464	340	396	284	284	280	224	148	80	124	112	52	32	52
Distance	4.1	4.7	5	5.5	5.7	6.2	6.4	6.8	7.1	7.4	7.7	8	8.3	8.5	9.1	9.3
< 2mm	352	272	320	304	192	112	156	136	180	104	96	72	100	48	76	56
2-5mm	44	32	24	24	36	8	32	8	16	8	8	4	4	0	20	0
Total	396	304	344	328	228	120	188	144	196	112	104	76	104	48	96	56
Distance	3.56	4.16	4.2	4.6	5	5.4	5.9	6.2	6.6	7	7.3	7.6	8.1	8.3	8.8	9
< 2mm	500	396	360	312	392	280	308	292	228	212	212	216	216	228	200	156
2-5 mm	56	32	40	20	24	16	12	12	16	4	12	20	16	20	20	4
Total	556	428	400	332	416	296	320	304	244	216	224	236	232	248	220	160
Distance	3.3	3.9	4.2	4.7	5.1	5.55	5.9	6.3	6.7	7	7.3	7.6	8.1	8.2		9.1
< 2mm	328	304	348	236	216	224	192	172	136	128	84	140	96	104		104
2-5mm	32	36	36	16	16	24	4	8	8	8	0	0	8	12		0
Total	360	340	384	252	232	248	196	180	144	136	84	140	104	116		104
Distance	3.02	3.62	3.6	4.2	4.1	4.6	4.6	5.1	5.2	5.6	5.7	6	6.4	6.7	7	7.3
< 2mm	404	288	300	216	308	220	172	156	136	116	124	120	96	92	72	52
2-5 mm	68	36	28	24	20	24	20	20	20	16	20	4	12	8	0	0
Total	472	324	328	240	328	244	192	176	156	132	144	124	108	100	72	52
Distance	3.34	3.94	4.3	4.7	5.2	5.6	6.2	6.4	7.1	7.4	7.9	8.1	8.7	8.8	9.7	9.8
< 2mm	280	236	272	184	240	180	172	148	152	112	140	84	120	56	84	36
2-5mm	36	24	36	24	32	16	16	12	8	0	0	0	0	0	0	0
Total	316	260	308	208	272	196	188	160	160	112	112	84	120	56	84	36

I - Internal face of the trench

E - External face of the trench

ROOT DISTRIBUTION PATTERN OF BAMBOO [*Bambusa arundinacea* (Retz.) Roxb. Gamble] AND ASSOCIATED COMPETITIVE EFFECTS

By

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ABSTRACT OF THE THESIS

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ABSTRACT

Root competition between bamboo [*Bambusa arundinacea* (Retz.) Willd.] and associated tree components in two mixed species systems and root distribution pattern of boundary planted bamboo clumps were evaluated. Root competition was assessed using ^{32}P soil injection technique in two cultural systems involving bamboo viz. teak (*Tectona grandis* Linn. f.) - bamboo and *Vateria* (*Vateria indica* Linn.) - bamboo). Experimental units were selected considering distance between bamboo clumps and the nearest *Vateria*/teak. ^{32}P was applied to two soil depths (25 and 50 cm). Each lateral distance-depth combination formed a ^{32}P treatment and it was replicated thrice. To characterise root distribution pattern, modified logarithmic spiral trenching method was used. For this, 18 boundary planted bamboo clumps were randomly selected and classified in to small, medium and large clumps based on clumps diameter ranges. Spiral trenches were dug around the clumps (10 m long). The number of severed roots exposed on both sides of the trench was assessed by placing a 50 × 50 cm quadrats against the vertical sides of the trench at 1 m intervals.

Isotopic studies revealed that, ^{32}P absorption by teak or *Vateria* increased as the lateral distance of bamboo occurrence increased. With respect to depth of application, deeper placement showed higher ^{32}P recovery than shallow placement by teak and *Vateria*. Uptake of bamboo was inversely related with lateral distance from treated plants. Bamboo clumps may exert a competitive effect upto an 5-6 m radial distance in ten year old clumps growing on lateritic soil. Beyond six metres, the magnitude of competition may be negligible. Recovery of ^{32}P from different soil depths show that more number of physiologically active roots are present at 25 cm than at 50 cm depth.

Excavation studies showed that locations close to the clumps recorded higher rooting intensities and there was a linear decrease in rooting intensity with increasing distance. Size of the bamboo clumps showed discernible differences in respect of spatial root distribution pattern. The medium and small size clumps recorded higher rooting intensities upto 7.5m, beyond this limit the large clumps recorded higher rooting intensities. There were significant difference in bamboo root distribution with depth, 10-30 cm depth of soil horizon registered the higher root counts with nearly 60% of total root counts. Thus, a considerable overlap between the bamboo roots and crop rooting zone in the 30 cm depth and 5-6 m lateral distance zone is possible. However care should be taken while cropping in association with bamboo in this rooting zone.