UNDERSTOREY PRODUCTIVITY OF AGRISILVICULTURAL SYSTEMS AS AFFECTED BY TREE POPULATION DENSITY AND FERTILISER REGIMES

BY

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THESIS

Submitted in partial fulfilment of the requirement for the degree

Master of Science in Forestry

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Vellanikkara, Thrissur - 680 654

1996

DECLARATION

I hereby declare that this thesis entitled ***"Understorey productivity of agrisilvicultural systems as affected by tree population density and fertiliser regimes"*** *is a bonafide record of research work done by me during the course of research and that this thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title of any other University or Society.*

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ACKNOWLEDGEMENTS

It is with great devotion, I place on record my deep sense of gratitude and indebtedness to my guide **DR. B. MOHANKUMAR**, Associate Professor & Head, Department of Silviculture and Agroforestry, College of Forestry, Vellanikkara, for his expert guidance, sustained interest, constant evaluation and whole hearted co-operation right from the planning of the work to the preparation of this manuscript.

My heartfelt thanks is, due, to **DR. P.A. WAHID**, Associate Dean, College of Agriculture, Pilicode, for his valuable advices during the radioisotope study and for making critical suggestions about the thesis.

I am thankful to **DR. K. GOPIKUMAR**, Associate Professor, College of Forestry, Vellanikkara for kindly providing various facilities and for critically going through this manuscript.

My sincere thanks to Sri. **V.K.G. UNNITHAN**, Associate Professor, Department of Agricultural Statistics, College of Horticulture, Vellanikkara for his valuable suggestions and for thoroughly reading through the thesis.

I extend my cordial thanks to Mrs. **N.V. KAMALAM**, Safety Officer, Radiotracer Laboratory, Vellanikkara for the assistance rendered during the radioisotope study.

It is my pleasant privilege to express my sincere gratitude to **DR. A. AUGUSTINE**, Assistant Professor, Biochemistry, College of Horticulture, Vellanikkara for the facilities and help rendered.

My sincere thanks is also, due, to **DR. A.V.R. KESAVA RAO**, Department of Agricultural Meteorology, College of Horticulture, Vellanikkara.

I am deeply indebted to **DR. A.I. JOSE**, Associate Dean, i/c., College of Forestry for his constant support, for the successful completion of this research work.

The encouragement provided by my teachers, **DR. K. SUDHAKARA, DR. N.K. VIJAYAKUMAR, DR. P.K. ASHOKAN** and **DR. L.C. BABU** are acknowledged.

I am grateful to all staff of the College of Forestry for their co-operation and support.

The Junior Research Fellowship awarded by the Kerala Agricultural University is gratefully acknowledged.

United States Department of Agriculture (USDA) is gratefully acknowledged as this work forms a part of the USDA project entitled "Light utilisation and canopy nitrogen use efficiency of component crops in some selected agroforestry systems" (IN-AES-575 and Grant No.PG-IN-775) currently being undertaken at the College of Forestry, Vellanikkara.

My sincere thanks to Sabu, V.R., Shivprasad, A., Jamaludheen, V. and Varghese, K.K., who were a constant source of support and encouragement.

The co-operation rendered by the field staff, Saithu, K.K., Muhammed, R.K. and Narayani, K.N. are gratefully acknowledged.

Special thanks are also, due, to my friends, Ramakrishna Hegde, Rajesh, N., Sunilkumar, K.K., Animon, M.M., Kannan, C.S., Vinod, S., Vinayan, R., Jaya Shankar, S.,Shajikumar, Y.M., Viju Varghese and Justin Stanley, K.S.

My heartfelt thanks to Mr. R. Noel, Ambika Computers, Vellanikkara for the care and interest he has taken in typing this thesis.

Finally, I thank my parents, sisters and brother for their moral support.

Above all I thank 'THE **ALMIGHTY**'.

JOSEPH THOMAS

Dedicated to
My Beloved Parents

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Introduction

INTRODUCTION

Ginger (*Zingiber officinale* Roscoe, Family: Zingiberaceae) is an important spice crop of the humid tropical regions. In India it is cultivated over an area of 55,500 ha, with a production of 1,56,180 tonnes of dry ginger as per 1991-92 figures (Spices Board, 1995).

The traditional system of ginger production in peninsular India represents a unique, but little studied agroforestry system. It involves, growing a sciophytic commercial crop under the shade of planted and/or naturally regenerated trees in homesteads. Although research reports on crop management and protection abound, much of it relate to monocultural situations (Sreekumar *et al.*, 1981; Korla *et al.*, 1989; Das *et al.*, 1990; Balasubramanian and Gopalan, 1992; Mohanty *et al.*, 1993).

Being a shade loving plant (Bai, 1981), ginger is grown in association with a wide variety of shade trees (Jaswal *et al.*, 1993; Spices Board, 1995). However, only limited research has been carried out to standardise the shade levels and/or optimise density of shade trees in integrated ginger-multipurpose tree production systems.

In Kerala, ginger is often grown as an intercrop in homegardens and other tree based farming systems. *Ailanthus triphysa* (Dennst.) Alston. is a prominent multipurpose tree in the home gardens of Kerala (Kumar *et al.,* 1994). Many farmers grow ginger and other shade-loving commercial crops in association with ailanthus and other multipurpose trees.

The term agroforestry connotes with such integrated land use systems involving woody perennial species and other life forms (Nair, 1993). Agrisilviculture is a branch of agroforestry where the field crop components are integrated with fast growing multipurpose tree species. Agroforestry systems are capable of meeting the food, fuel, fodder, fertiliser and timber requirements of the society (Nair, 1993). Additionally, trees in managed species mixtures, have the potential to bring about 'microsite enrichment', through processes such as efficient cycling of plant nutrients and nutrient pumping (Huxley, 1985; Nair 1984a ; Mathew *et al.,* 1992).

Interference of trees, however is a major constraint in agrisilviculture. As tree age increases and canopy is formed, intensity of light at the ground level decreases, thereby affecting understorey productivity (Mathew *et al.*, 1992). Interspecific competition for nutrients and water (Buck, 1986; Nair, 1993; George *et al.*, 1996) is yet another determinant of understorey productivity.

Ailanthus triphysa owing to its compact crown (Mathew *et al.*, 1992), relatively lower lateral root spread and deep rooting tendency (Jamaludheen, 1994), is a promising component for many agrisilviculture systems. Literature relating to the performance of ailanthus as a tree component in agroforestry, however is scarce. Many aspects of the functional dynamics of such an agroforestry system, such as competition for site resources and partitioning of nutrients and light between the tree and ginger also remains uninvestigated. Hence, the present study was taken up with the following objectives:

1. To assess the productivity of ginger as a component of an agrisilviculture system involving ailanthus, at various population densities and fertiliser levels.

2. To analyse the partitioning of solar radiation among the different components of such a system.

3. To characterise the nature of below ground interactions between the field crop and tree component of the system.

Review of Literature

REVIEW OF LITERATURE

Growing arable crops in association with tree species forms a dominant land use system in many parts of the tropics. The term 'Agroforestry' describes such integrated land use practices. Site conservation and optimal productivity are cardinal aspects of all agroforestry land management systems around the world (Nair, 1993). He also classified the various agroforestry systems around the world, based on structural, functional, socio-economic and ecological attributes. Such a classification is perhaps necessary to evaluate the existing agroforestry systems and to develop action plans for their improvement. Based on structural components, agroforestry is subdivided into agrisilviculture (crops, pasture/animals and trees), silvopastoral (pasture/animals and trees) and agrosilvopastoral (crops, pasture/animals and trees). Improved fallow, taungya, alley cropping, multitiered tree gardens, multipurpose trees on croplands, combinations involving plantation crops, home gardens, shelter belts and wind breaks form examples of agrisilviculture. The presence of woody perennials in such integrated land use systems has both advantages (soil conservation and fertility improvement) as well as disadvantages (decreased productivity by competitive interactions). Interestingly many tropical spice crops (ginger, pepper cardamomum, clove, nutmeg etc.) and beverage crops (tea, coffee and cacao) are grown in association with either planted tree crops or as understorey crops in natural forests (Nair, 1993; Tejwani, 1994; Kumar *et al.*, 1995).

2.1 Ginger based agrisilvicultural systems

Although ginger (*Zingiber officinale* Roscoe) is commonly grown in association with a wide spectrum of tree species, information on its performance as an understorey crop is scarce. According to many, ginger can be grown as an intercrop in arecanut (Thangaraj *et al.*, 1983; Nair, 1984b; Singh *et al.*,1986) and coconut gardens (Bai, 1981). Cultivation of ginger close to bamboo brakes is another possibility (Singh *et al.*, 1992). It is also grown in association with poplar (Jaswal *et al.*, 1993).

2.1.1 Influence of shade on the growth, yield and quality attributes of ginger

Moderate levels of shade exerts a positive influence on plant height (Aclan and Quisumbing, 1976; Jayachandran *et al.*, 1991). Although Bai (1981), observed a negative effect of shade levels on tillering, Jaswal *et al.* (1993) reported a positive relationship in this respect. They also recorded a positive influence of shade on the number of leaves per plant. Leaf area index is also known to be positively influenced by shade (Ravisankar and Muthuswamy, 1988). In this context Bai (1981) reported that total content of chlorophyll and nitrogen, phosphorus and potassium percentages of green foliage increased with an increase in shade intensity.

Yield of ginger also is influenced by shade. Bai and Nair (1982) and Jayachandran *et al.* (1991) recorded maximum yield in plants grown under 25 per cent shade. More than 50 per cent shade was, however, reported to be detrimental. Jaswal *et al.* (1993) recorded maximum yield (ginger - poplar agrisilviculture system) in the treatment having a relative illumination of 46%. Positive influence of shade on yield has also been reported by Wilson and Ovid (1993). Plants grown in shade was seen to show maximum dry matter accumulation in rhizome in the early part of its life (Ravisankar and Muthuswamy, 1986). They also reported a greater recovery of dry ginger from plants grown under shade. Jayachandran *et al.* (1991) and Jaswal *et al.* (1993), however, recorded a greater recovery of dry ginger from plants grown in full sunlight.

Rhizome quality is not adversely affected by shade (Ravisankar and Muthuswamy, 1987). Non volatile ether extract was reported to be positively correlated with shade (Ancy and Jayachandran, 1993). Babu and Jayachandran (1994), however, observed that non volatile ether extract and fibre content decreased with increasing shade, while oil content increased.

Varietal influence is a crucial factor in determining the productivity of ginger both in the open and intercropping situations. Thangaraj *et al.* (1983), Varughese (1989) and George (1992) have evaluated and recommended varieties for different shade regimes.

2.2 Factors affecting productivity of agrisilviculture systems

2.2.1 Tree characteristics

Tree components exert a marked influence on system productivity. There are several reports relating the influence of root and canopy architecture, crown characteristics and other tree attributes on the productive efficiency of agroforestry systems (Toky and Bisht 1992; Mathew *et al.*, 1992; George, 1993; Jamaludheen, 1994). This includes the role of trees in bringing about 'microsite enrichment' through processes such as efficient cycling of plant nutrients, nutrient pumping (Huxley, 1985) and biological nitrogen fixation (Nair, 1989).

Canopy architecture and structure play an important role in interception of the incoming solar radiation. Terjeing and Louise (1972) reported that conical trees intercepted a higher amount of radiation, especially at higher altitudes. Norman and Jarvis (1974) also evaluated the influence of canopy structure on interception of radiation. They concluded that the path length of light through the crown silhouette area and canopy volume did not significantly affect shading capacities in five stands of tree species studied. According to Mathew *et al.* (1992), the cladophyllous canopy of *Casuarina equisetifolia* facilitated increased light infiltration and thereby increased the herbage yield of understorey fodder crops.

2.2.2 Tree management practices (spacing /tree population density)

2.2.2.1 Implications on tree growth and productivity

Several workers have reported that stand density exerts a pronounced effect on crown diameter, diameter at breast height and biomass production of trees (Wang, 1987; Rana *et al.*, 1988; Okario and Maghembe, 1994).

Fuel and fodder yields of *Leucaena leucocephala* have been reported to be negatively correlated with spacing (Mittal and Singh, 1989; Singh *et al.*, 1990; Laeeq and Hussain, 1990; Khot *et al.* 1991; Saha and Maiti, 1994). Significant differences were observed in poplar grown at different spacings (Jha *et al.*, 1991). Total biomass production of *Gliricidia sepium* increased under closer spacings (Karim and Savill, 1991). Mishra *et al.* (1992) also reported an increasing trend in biomass production with increasing plant density. An increase in height and basal stem diameter of *Vateria indica* seedlings with increasing density was reported (KAU, 1992). Ola Adams (1993) observed significant differences in dry weights of small branches and big roots of *Tectona grandis* under variable spacing. He also reported greater biomass production of *Terminalia superba* under narrower spacings. *Eucalyptus* spp., *Acacia auriculiformis, Cassia siamea, Gmelina arborea* and *Dalbergia sissoo* are also reported to show greater biomass yield under closer spacings (Chakrabarti, 1993; Singh and Singh, 1994). Puri *et al.* (1994) observed higher shoot-root ratio in *Populus deltoides* grown at closer spacings.

However, a large number of workers also did not observe any significant variation in tree growth characteristics as a function of stand density. For instance, no significant difference in height, diameter and number of branches were observed when *Prosopis juliflora* was grown at different spacings (Singh *et al.*, 1989). *Leucaena leucocephala* also did not show much difference in height, collar and crown diameter when grown at various spacings (Gill *et al.*, 1991; Roy and Gill, 1991a). Tree height and leaf nitrogen content of *Gliricidia sepium* was not related to row spacings (Karim and Savill, 1991). They also observed that for equivalent tree densities, a lower rectangularity of planting, showed better performance of individual trees. However, closer within row spacings decreased biomass production per plant. Specific gravity of wood also has been reported to decrease with increasing plant density (Sharma *et al.*, 1992). *Ailanthus triphysa* and *Grevillea robusta* did not show significant differences with respect to height when grown at various densities (KAU, 1992). In eucalyptus hybrid tallest trees with maximum girth at breast height was observed under the lowest density studied (Singh and Singh, 1994). Non significant difference in tree growth with respect to tree spacing in poplar has also been reported (Jaswal *et al.*, 1993).

In summary, the effects of population density on tree growth and productivity appears to variable. In general closer densities favour increased fuel and fodder yields.

2.2.2.2 Implications on the associated crop

Tree population density influences growth and productivity of the associated crops also. Planting geometry is a major factor in this context, which may be particularly important in alley cropping, agrisilviculture and silvopastoral systems. Above and below ground biomass of maize intercropped with *Gliricidia sepium* were dependent on alley widths (Lapitan and Dalmacio, 1987). Best results were obtained from alleys of medium width. Increasing stubble height of alleys was reported to reduce yield of sorghum (Palled *et al.*, 1989). Regarding the determinants of alley width, the tree species in question is an important determinant. Trees with spreading dense crowns result in greater shading effect. *Leucaena leucocephala* was reported to have greater shading effect than *Azadirachta indica,* eucalyptus hybrid and *Dalberigia sissoo* (Ramshe *et al.*, 1990). However, Jama *et al.* (1991) recorded maximum maize yield, from plants grown in the closest *Leucaena leucocephala* spacing.

Fodder yield of anjan grass (*Cenchrus ciliaris*) has reported to be positively correlated with tree spacing (Rana *et al.*, 1988). Tree population density is also known to affect the nutritional quality of forage. Benavides *et al.* (1989) reported that quality of king grass (*Pennisetum purpureum x P. typhoides*) increased with increase in tree density. Pasture production is reported to be maximum at the medium tree density (Eastham *et al.*, 1990; Singh *et al.*, 1990).

Although several authors have highlighted the positive aspects of integrated tree-arable crop production systems, reports characterising their negative role also abound in the literature. Intercropping with trees depressed crop yields of maize, black gram, cluster bean and groundnut (Mittal and Singh, 1989; Ramshe *et al.*, 1990; Rai *et al.*, 1990; Kananji, 1992). Reduction in crop yields (maize and green gram) under narrower tree spacing/higher population density has been reported by Roy and Gill (1991b), Jama and Getahun (1991), Saha and Maiti (1994) and Ramshe *et al.* (1994). In contrast few workers (Kananji, 1992; Okario and Maghembe, 1994) observed that tree spacing did not have any significant effect on the yield of the associated crops.

2.2.3 Other tree management practices

2.2.3.1 Lopping

Management practices such as lopping is known to improve understorey crop yield (Singh *et al.*, 1989a; Singh and Pathak, 1990). Pruning of *Gmelina arborea* and *Acacia mangium* was found necessary to sustain understorey crop yield (Sato and Dalmacio, 1991). Pruning has also been found to justify narrower alleys in alley cropping systems (Karim *et al.*, 1993). Manipulation with regard to planting geometry could, perhaps minimise shading of the companion crops.

2.2.3.2 Chemical fertilisers

2.2.3.2.1 Tree growth

An adequate supply of nutrients is essential for proper growth and development of plants. Increasing population pressure and the consequent lack of space, demands the use of fertilisers for sustaining crop productivity. Fertiliser application improved growth of eucalyptus trees (Gupta and Mohan, 1989; Singh *et al.*, 1991). Nitrogenous fertilisers increased total above ground biomass of eucalyptus (El-Baha, 1991; Grewal and Juneja, 1991). Height and basal area of eucalyptus was also seen to be enhanced by fertiliser application

(Cromer *et al.*, 1993). Furthermore, Gupta and Prasad (1994), recorded upto seven-fold increase in biomass of eucalyptus under the influence of fertilisers.

Growth of leucaena was seen to increase linearly with phosphorus application (Hussain *et al.*, 1991a). Potassium fertilisers have also shown to have a positive influence on growth of leucaena (Hussain *et al.*, 1991b).

Fertiliser application increased tree height and diameter of *Paraserianthes falcataria* at three years of age (Wan Rasidah *et al.*, 1988). Wan Rasidah and Sulaiman (1992), however, observed that fertilisers did not have any significant effect on growth of *Paraserianthes falcataria* at six years of age. Beneficial affects of fertilisers on growth of slash pine (Shoulers and Tiarks, 1990), *Enterolobium timbouvamart* (Seghal *et al.*, 1992), *Terminalia myriocarpa* seedlings (Mohan, 1992) and *Gmelina arborea* (Ogbonnaya, 1994) are also reported.

However, spruce and poplar showed no marked response to fertiliser application (Morrisson, 1991). Varying levels of fertilisers also did not show any marked influence on height and basal stem diameter of

Vateria indica, Ailanthus triphysa and *Grevillea robusta* (KAU, 1992). Furthermore, Heliman and Xie (1994) did not observe marked influence of fertilisers on growth of poplar upto two years. The third year however, was characterised by an increase in leaf size and leaf area index.

2.2.3.2.2 Influence of chemical fertilisers on growth and productivity of the associated crops

The guiding principle in fertiliser application of mixed cropping systems has been to fertilise the component crops adequately and separately (Nair, 1984a). Literature relating to the performance of understorey crops in agrisilvicultural systems, with respect to fertilisers applied to the tree component are scarce. Palada *et al.* (1992) evaluated the performance of agricultural crops in fertilised and unfertilised alleys of leucaena. Both alley cropping and fertiliser application were seen to increase vegetable yields. Yields were not significantly different between alley cropped plots with and without fertiliser application. It was thus concluded that alley cropping with leucaena can reduce fertiliser requirements of vegetable crops. According to Peden *et al.* (1993) application of fertilisers to trees can promote crop growth, provided the tree species in question uses it slowly. Shannon *et al.* (1994) suggested that cropping with moderate fertilisers could be the best means to stabilise yield and to increase productivity, where long fallow periods are no longer possible.

2.2.4 Stage of stand development

Age of the woody perennial component is an important factor in determining the magnitude of interspecific competition for light, water and nutrients. Thus intercropping without appreciable reduction in crop yield may be feasible only during the early growing period of the field crop.

Increasing age of the tree component is reported to reduce crop yields (Dhukia *et al.*, 1988; Roy and Gill, 1991b). Tree age at which understorey crops sustain yield loss may also vary with species (Srinivasan *et al.*, 1990). Interspecific root competition is reported to be minimal in the initial years of plantation (Dhyani *et al.*, 1990). Yield of maize was unaffected when leucaena was undersown into a maize crop (Field, 1991). Leucaena was, however, reported to be taller in the sole cropping situation. Detrimental effect of field crops on tree growth has also been reported by Couto *et al.* (1994). With regard to poplar it has been reported that notable reduction in understorey crop yield occurred from the third/fourth year onwards (Ralhan *et al.*, 1992; Park *et al.*, 1994).

In this context Hafeez and Hafeezullah (1993) reported that wider alleys of poplar facilitated intercropping upto the fifth or even sixth year.

Fodder yield was reported to be reduced more by five year old leucaena than eucalyptus (Suresh *et al.*, 1991). According to Mathew *et al.* (1992) reduction in fodder yield is most likely only after tree canopy formation.

2.2.5 Shade tolerance

Tolerance to shade by understorey crop is another cardinal factor in determining productivity of agroforestry systems. The average fruit yield of tomato, cucumber, bean, capsicum, melon and okra grown under shade is known to be higher than those in open (El-Aidy, 1984). Ginger (Bai and Nair, 1982), large and small cardamomum (Singh *et al.*, 1989b; Kumar *et al.*, 1995) are also shade loving crops. Loss of yield due to shade has, however, been reported in the case of cassava (Ramanujam *et al.*, 1984) and winter wheat (Mc Master *et al.*, 1987).

2.3 System dynamics

Tree based farming systems are characterised by microsite enrichment (MacDicken and Vergara, 1990; Kumar, 1994). Stem flow, preferential trapping of atmospheric inputs, enhanced nutrient uptake from depth, deep rooting nature of tree roots and efficient nutrient cycling are the common soil enrichment processes (Young, 1991). Apart from soil enrichment, presence of trees also helps in soil conservation, improvement of soil physical conditions and improvement of microclimate (Nair, 1989).

It is however, impossible to conclude, that the above advantages of agroforestry are always available. Considerable depletion of soil nutrients has been reported in short rotation, fast growing species eg. eucalyptus (Negi and Sharma, 1984; Singh, 1984).

2.4 Root interactions

A combination of deep and shallow rooting species in agroforestry systems would be ideal to make best use of available site resources. Studies, however, reveal that chances for below ground competition are high in agroforestry. Measurement of the quantities and spatial distribution of roots, thus becomes necessary. The use of slowly diffusing radionuclides, such as ^{32}P is considered to be a precise method in this respect. In such cases the position of the label can be correlated with root activity pattern (Nye and Tinker, 1977; Vose, 1980). Literature on root activity of agroforestry systems is very fragmentary. Sankar *et al.* (1988) analysed root activity patterns of black pepper vine and *Erythrina* support trees. Ninety per cent of root activity was confined to a radial distance of 30 cm from the vine. Pepper vines trained on *Erythrina* spp. had a larger lateral root spread than those trained on teak poles. George *et al.* (1996), studied the root activity pattern of a silvopastoral system, involving various tree species and fodder crops. Recovery pattern of ^{32}P isotope injected in the soil revealed that 65 to 85 per cent of the fine roots responsible for absorption were concentrated in the 0-15 cm layer of the soil profile. Isotope recovery from tree monocultures were generally low, suggesting stimulatory effect of nutrient absorption by trees in presence of an associated field crop.

On a final note, there are many determinants of productivity in agroforestry systems. Tree population density, management practices, stage of stand development, root interactions and shade tolerance of the companion crop, are probably crucial in this regard. Ginger based agri-silviculture systems maintain high levels of productivity only under light to medium shade. However, choice of appropriate varieties is important in this respect.

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 (13°31'N latitude and 76°13'E longitude and at an elevation of 40.29 m above sea level), during the period from May 1994 to June 1995.

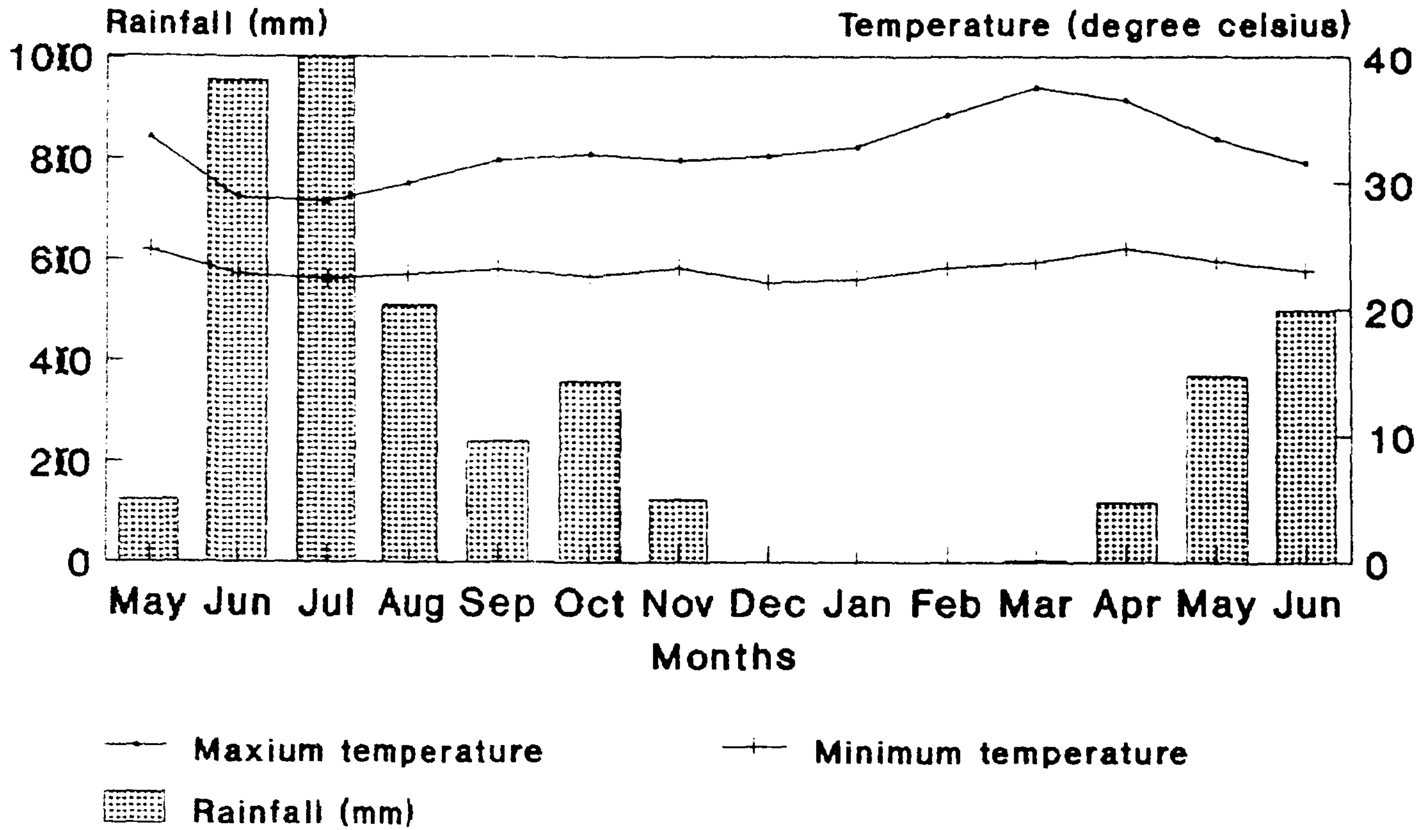
3.1.1 Climate

Vellanikkara enjoys a warm humid climate, having a mean annual rainfall of 2668.6 mm (mean corresponding to the twelve year period from 1981-1993), most of which is received during the South-West monsoon (June to August). The mean maximum temperature ranges from 29.1°C (July) to 36°C (May) and the mean minimum temperature varies from 21.9°C (January) to 25°C (May).

3.1.2 Soil

The soil of the experimental site is oxisol having a pH of 5.81.

Fig. 1 Weather Parameters during the experimental period (May 1994 - June 1995)



3.2 Field experiment

A split plot experiment (Fig. 2) on *Ailanthus triphysa* (Dennst.) Alston., initiated in June 1991, (having three replications) with the following treatments, was used for the present study,

A. Main plot treatments

Tree population densities

D_1 3333 trees ha^{-1} (3 x 1 m spacing)

D_2 2500 trees ha^{-1} (2 x 2 m spacing)

D_3 1600 trees ha^{-1} (3 x 2 m spacing)

D_4 1111 trees ha^{-1} (3 x 3 m spacing)

B. Sub plot treatments

Fertiliser levels

	(Kg N	:	P_2O_5	:	K_2O ha^{-1})
F_1	0	:	0	:	0
F_2	50	:	25	:	25
F_3	100	:	50	:	50
F_4	150	:	75	:	75

(Fertilisers were applied, as per the treatment protocol, twice; August 1992 and September 1993).

Ginger (*Zingiber officinale* Roscoe) was raised, as an understorey crop in all treatment combinations,

FIG. 2 SCHEMATIC LAYOUT PLAN OF THE FIELD EXPERIMENT
SHOWING THE EXPERIMENTAL UNITS FOR ISOTOPE APPLICATION

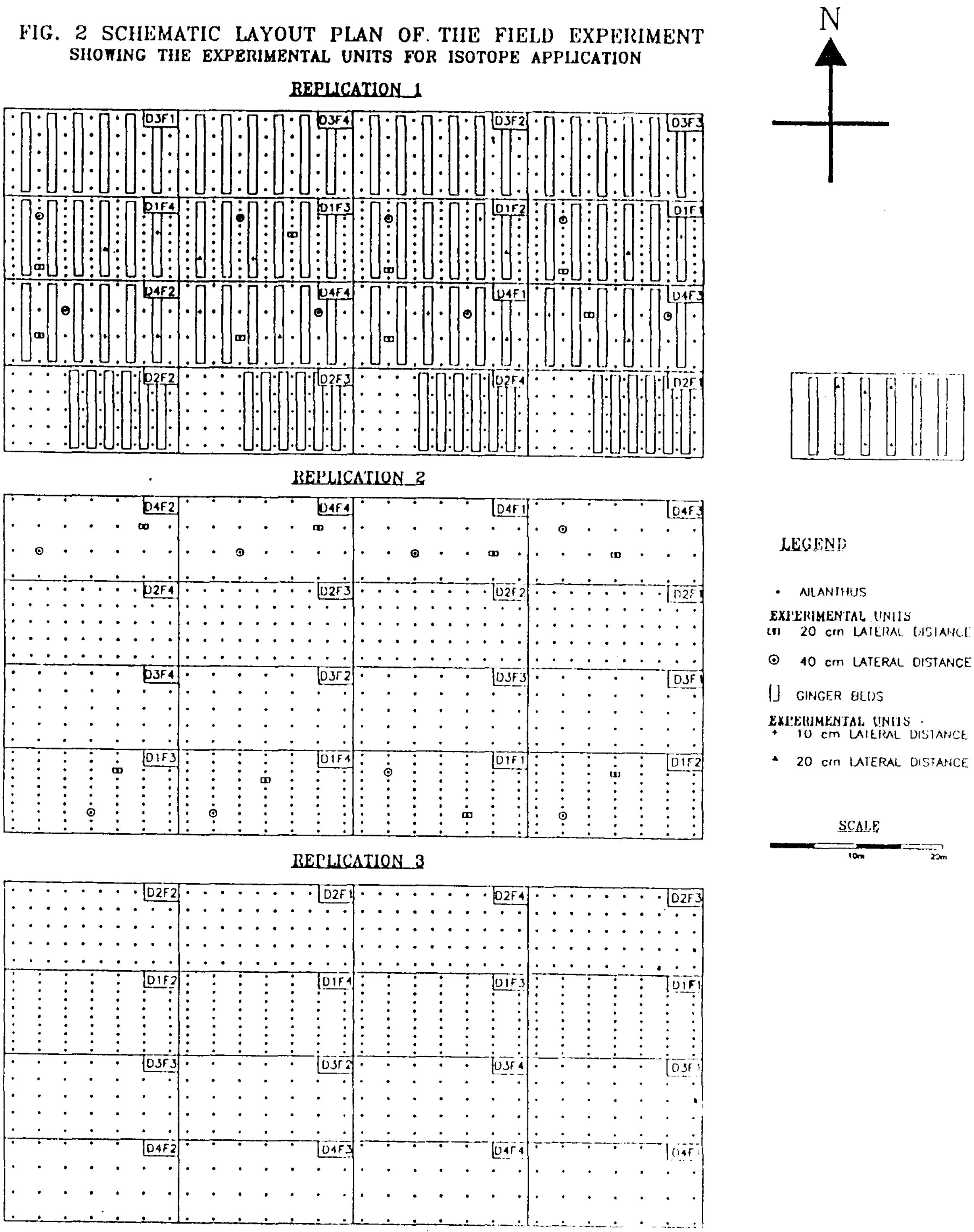


Plate 1. Growth of ginger (*Zingiber officinale* Roscoe) at 124 days after planting as affected by cropping situation

1a. Ginger monoculture

1b. At 1111 trees per hectare

1c. At 1600 trees per hectare

1d. At 2500 trees per hectare

1e. At 3333 trees per hectare

on beds (9 x 1 m size) made in the interspaces of ailanthus tree rows, following the package of practices recommendations (KAU, 1993). There were six beds each in all plots. Additional tree and ginger plots (monocultures) were established in adjoining area for comparative purposes. With respect to variety of ginger the cultivar Kuruppampady, owing to its reputation as a dry ginger type, relatively tolerant to disease and pest, besides being tolerant to shade, was chosen for this purpose (Varughese, 1989; George, 1992; KAU, 1993).

3.3 Tree crop component

Ailanthus triphysa (Dennst.) Alston., a member of the family Simaroubaceae, is a large deciduous tree with cylindrical bole, and is reported to be a strong light demander (Troup, 1921). The wood of this tree is used in match, packing case, paper and pulp industries. It also forms a dominant woody perennial component of home gardens in Kerala (Kumar *et al.*, 1994).

3.3.1 Observations on tree growth characteristics

Tree height, collar diameter and diameter at breast height of all trees (excluding the border trees) were measured twice during the experimental period; (28th May 1994 and 19th April 1995), using a graduated pole and tape respectively . Crown widths of trees were measured (April 1995) by projecting the crown on the ground, in two perpendicular directions (NS and EW) and computing their means. Plot-wise estimations of stand leaf area index was made (March 1995) using a plant Canopy Analyser ('Li-cor 2000', Li cor, Lincoln, Neberaska), each replicated ten times.

3.3.2 Pest incidence score

Ailanthus trees (excluding border trees) in all treatment combinations were visually scored using a, '0' (not infected) to '9' (severely infected) scale for incidence of insect pests (*Atteva fabriciella* and *Eligma narcissus*). This was done visually on the basis of intensity of defoliation and growth retardation.

3.4 Field crop component

Ginger (*Zingiber officinale* Roscoe) a member of the family Zingiberaceae, is a rhizomatous, herbaceous perennial. Apart from being used as a flavourant in food products, ginger also finds place as an ingredient in medicines and toiletry articles. India is the largest producer and exporter of this spice crop in the world. Kerala alone accounts for about forty per cent of total dry ginger production in the country.

Pakistan, Bangladesh, U.S.A., Morocco and Saudi Arabia are the major importers of dried ginger. In Kerala ginger is mainly grown as a component of homegardens and/or in association with various woody perennials (as shade trees).

3.4.1 Cultural practices

Ginger rhizome bits 15 g, treated with Dithane M 45 @ 3g/L, Bavistin @ 1g/L and Ekalux @ 1 ml/L as a prophylactic measure against disease and pest incidence, were sown at a spacing of 25 x 25 cm on beds of 9 x 1 m in the interspaces of ailanthus (depth 4-5 cm) between 16th-22nd of May 1994.

Immediately after sowing, the rhizome bits were covered with farm yard manure @ 30 t/ha. Fertilisers were applied @ 75 kg N, 50 kg P_2O_5 and 50 kg K_2O ha^{-1} (KAU, 1993). The beds were also mulched (@ 15 t/ha) with green leaves. Mulching @ 7.5 t/ha was repeated along with the second (60 days after planting) and third (120 days) split doses of chemical fertilisers (KAU, 1993). The beds were occasionally weeded and earthed up also.

3.4.2 Biometric observations

Destructive sampling of ginger was done on 55th, 116th and 211th days after planting. For this, 1 m^2 area each was selected from three random beds/per plot. All ginger clumps in the selected quadrats were uprooted and observations on average tiller height (measured from the base of the culm to the tip of the unopened leaf), number of tillers per plant, number of leaves per plant and root length were recorded.

In addition, leaf area was measured using a 'Li cor model 3100' area meter (Li cor, Lincoln, Neberaska), which was then used to compute the ginger leaf area index and mean leaf area per plant. Leaf area measurements were confined to the 55th and 116th day observations only, as at the later stages, most of the leaves were dried up.

3.4.2.1 Biomass

The leaves, culms, roots, residual rhizomes (planted) and new rhizomes were separated, cleaned and their fresh weights determined using a mono pan balance. Sub-samples of the separated parts were taken and oven dried (70°C until constant weights) and dry weights estimated. However, on 55th day, the below ground portions (roots + residual rhizomes) were not fractionated and on 211th day observations, no residual rhizomes were present.

Ginger crop was finally harvested on 234 days after planting. Three replicates of 1 m^2 area each was selected from the three remaining beds/plot. The mature rhizomes were then cleaned (roots and soil) and fresh weights taken. Sub-samples from the harvested rhizomes were then air dried for about a week, followed by oven drying (70°C) and dry weights estimated.

3.5 Radiation measurements

Light measurements were made from 17th March to 27th April 1995. Integrated values (at hourly intervals from 6 am to 6 pm) of photosynthetically active radiation (PAR) in the open and under the canopy at 50 cm and 150 cm were recorded using a point quantum sensor and a line quantum sensor (Li cor model 1000), with a data logger (Li cor, Lincoln, Neberaska), respectively for all treatment combinations.

3.6 Characterisation of root interactions

Root interaction of the ginger-ailanthus agrisilvicultural system was characterised by employing the ^{32}P

soil injection technique. Two separate experiments involving ginger and ailanthus (respectively as treated plants) were laid out for this purpose. Ginger plants were treated with ^{32}P to characterise the extent of root competition between ginger and the associated tree component for nutrients applied to the former, while the experiment involving ailanthus (as the treated plant) aimed at evaluating root competition for nutrients applied to the tree component. Two population density levels of ailanthus (1111, 3333 trees ha^{-1}) besides, tree and ginger monocultures were selected for this purpose (Fig. 2).

In the first experiment (ginger as treated plant), two lateral distances (10, 20 cm) of ^{32}P application (sub-plot factor) were superimposed on the intercropped (two population density levels) and ginger monoculture plots (three levels of main plot factor) following split plot design. In the second experiment (ailanthus as the treated plant) two lateral distances (20, 40 cm sub-sub plot factor) were superimposed on the population density treatments (1111, 3333 trees ha^{-1} main plot factor) with and without ginger (sub-plot factor) following a split-split plot design.

The experimental units for ^{32}P application were selected on the basis of uniformity of growth (ailanthus) and maximum distance as far as possible between the experimental units, to ensure minimum interference among the adjacent units. Each treatment in both experiments was replicated four times. ^{32}P was applied at a uniform depth of 20 cm from the surface of the ginger bed/ground level.

For the purpose of soil injection of ^{32}P, eight equally spaced holes (2.5 cm dia.) per unit were drilled into the soil a day in advance at the required depth and lateral distances. PVC access tubes were inserted into these holes and their open ends covered with plastic caps to prevent any possible entry of rain water. ^{32}P solution at the rate of 0.5 mCi, at a carrier level of 1000 ppm P was dispensed into the access tubes at the rate of 2 ml per hole on 24th September 1994, using an automatic dispensor (Wahid *et al.*, 1988). After dispensing, the access tubes were 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.

Plate 2. Radioisotope experimental units

2a. Ailanthus (*Ailanthus triphysa)*

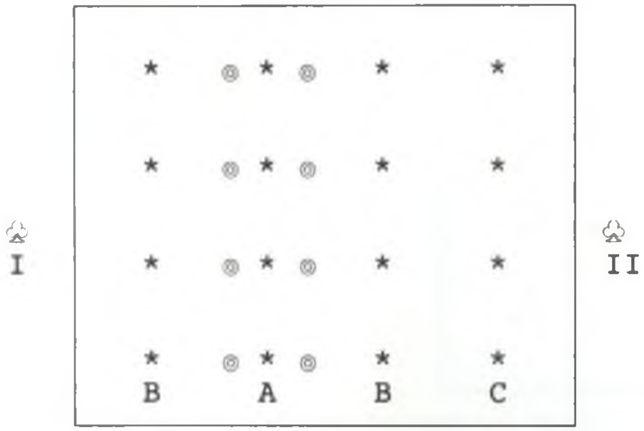
2b. Ginger (*Zingiber officinale)*

3.6.1 Leaf sampling and radioassay

Most recently matured leaves from the treated as well as neighbouring ginger/tree (both experiments) were sampled for radioassay (Fig. 3a, b, c, d). Sampling was done at 15, 30 and 45 days after application of ^{32}P. The leaf samples were dried at 70°C and radioassayed for ^{32}P content by Cerenkov counting technique (Wahid *et al.*, 1985) at the Radiotracer Laboratory, 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). The digest was then transferred to a counting vial. The final contents in the vial was made to 20 ml volume. The vials were counted in a Liquid Scintillation Counter (Wallac 1409, Pharmacia, Finland) by Cerenkov counting technique. Count rates were expressed as cpm (counts per minute) values. The cpm values were corrected for background as well as decay. After $\log_{10}$ transformation the data were analysed following the analysis of variance technique. Assuming that recovery of radioactivity in the foliage is a reflection of the density of active roots, the root activity percentage at a particular lateral distance was calculated using the formula.

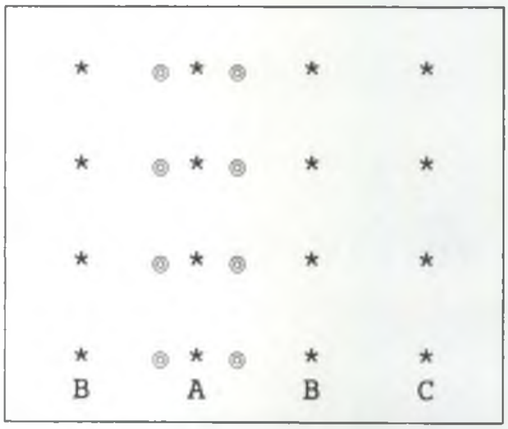
$$\text{\% root activity at a particular lateral distance} = \frac{\text{Count rate (cpm g}^{-1}\text{) for that lateral distance}}{\text{Total cpm for all treatments}} \times 100$$

Fig.3a Diagram showing an experimental unit of ginger in the intercropped situation and method of sampling



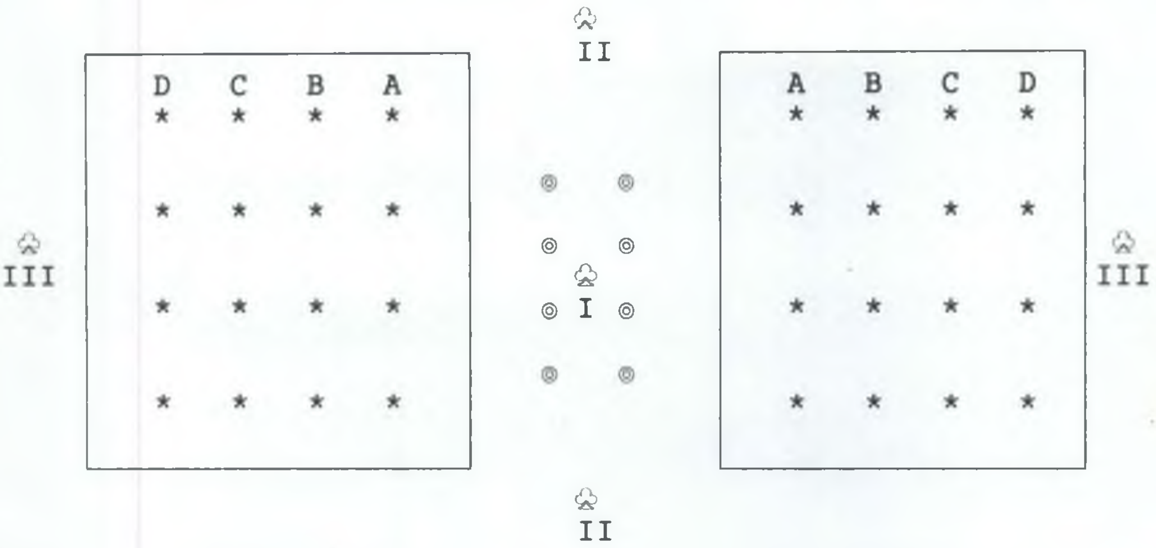
♣	Ailanthus	*	Ginger
I	Neighbouring tree (1.375 m)	A	Treated plants
II	Neighbouring tree (1.625 m)	B	Neighbouring plants (25 cm)
◎	Treatment hole	C	Neighbouring plants (50 cm)

Fig.3b Diagram showing an experimental unit of ginger in the monoculture situation and method of sampling



* Ginger
A Treated plants
B Neighbouring plants (25 cm)
C Neighbouring plants (50 cm)
◎ Treatment hole

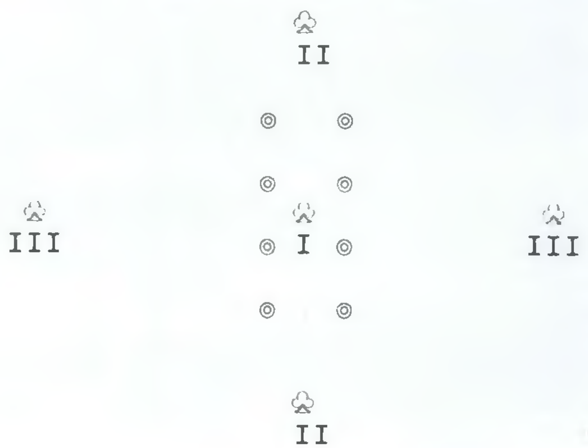
Fig.3c Diagram showing an experimental unit of *Ailanthus* in the intercropped situation and method of sampling



Ailanthus
◎ Treatment hole
I Treated tree
II Neighbouring trees (NS)
III Neighbouring trees (EW)

* Ginger
A Neighbouring ginger plants (1.125 m)
B Neighbouring ginger plants (1.375 m)
C Neighbouring ginger plants (1.625 m)
D Neighbouring ginger plants (1.875 m)

Fig.3d Diagram showing an experimental unit of *Ailanthus* in the monoculture situation and method of sampling



Ailanthus
◎ Treatment hole
I Treated tree

II Neighbouring trees (NS)
III Neighbouring trees (EW)

3.7 Phytochemical analyses

Triplicate samples of ginger foliage (collected at 55, 116, 211 days after planting), mature rhizomes and tree foliage (collected at monthly intervals from June 1994 to June 1995) were analysed for nitrogen, phosphorus and potassium contents. Total nitrogen was estimated following the micro-kjeldahl method, after the samples were ground to pass through a 2 mm sieve. Phosphorus and potassium contents of ground samples were determined after digesting the sample in triple acid mixture (HNO_3, H_2SO_4 and $HClO_4$ in the ratio 10:1:3). Phosphorus was estimated following the vanado-molybdo phosphoric yellow colour method and potassium by flame photometry (Jackson, 1958).

3.7.1 Quality attributes of ginger

Ground samples of dried mature rhizomes were analysed for essential oil and oleoresin contents. Twenty gram samples were mixed with 20 g ammonium sulphate (non-frothing agent) and 200 ml distilled water in a round bottom flask and the essential oil extracted by clevenger apparatus for 3.5 hours (till there was no further increase in oil level). Percentage essential oil was calculated using the formula (Vol. of oil extracted (ml)/20 g) x 100.

For oleoresin extraction, ground samples (5 g) were placed in a soxhlet extractor and heated in a waterbath (3 hours), with petroleum ether (b.p. 40° - 60°C). The extract was then transferred to a 500 ml flask and petroleum ether evaporated. The difference in weight of flask was noted and percentage oleoresin calculated by the formula (increase in wt. of flask (g)/5 g) x 100.

3.8 Soil chemical analyses

Soil samples were collected (before and after the ginger experiment) from the top 15 cm layer at three random points between tree rows in different treatments. The samples were air dried and ground to pass through a 2 mm sieve. Triplicate samples were analysed as follows.

Soil pH was determined using an aqueous suspension of soils (in 1:2 ratio) using an 'Elico' pH meter, organic carbon by the Walkley and black method and total nitrogen (micro-kjeldahl method). Available P was extracted using Bray-1 extractant and the phosphorus content determined colorimetrically (chloromolybdic acid blue colour method). The reducing agent was stannous chloride. Available potassium was estimated flame photometrically using 1N neutral ammonium acetate solution as the extractant (Jackson, 1958).

3.9 Statistical analysis

The experimental data pertaining to the various observations were statistically analysed following the analysis of variance technique, using MSTAT statistical package.

Results

RESULTS

4.1 Ailanthus growth as affected by tree population density and fertiliser regimes

Neither population density nor fertiliser regimes influenced height and radial growth of 3-4 year old ailanthus saplings (Tables 1 and 2; Appendix IV). Stand density was, however significant with respect to stand leaf area index. With increasing density, leaf area index increased. Population densities ranging from 1600-3333 trees per hectare (TPHA) were significantly superior to that of 1111 TPHA. Furthermore, fertiliser levels also showed variations in terms of pest incidence index (*Atteva fabriciella* and *Eligma narcissus*). Trees in the control (no fertiliser) and the highest dose of chemical fertilisers (150:75:75; N: P_2O_5: K_2o kg ha^{-1} yr^{-1}) registered relatively higher pest incidence scores (Table 2; Appendix IV).

4.2 Influence of tree population density and fertiliser regimes on foliar nutrient content of ailanthus

4.2.1 Nitrogen

Tree population density did not affect the foliar nitrogen content in the upper portion of the tree crown (Table 3; Appendix V). Although higher N levels were

Table 1 Effect of tree population density and fertiliser levels on height and radial growth of *Ailanthus* saplings at 3 years of age

Treatments	Mean tree height (m)	Diameter at breast height (cm)	Basal stem diameter (cm)
Density (trees ha^{-1})			
3333	2.40	4.60	8.44
2500	2.40	4.62	8.66
1600	2.25	4.41	8.51
1111	1.99	3.79	7.23
F test	NS	NS	NS
SEM (±)	14.342	0.249	0.309
Fertiliser levels ($N:P_2O_5:K_2O$ kg ha^{-1} yr^{-1})			
0:0:0	2.17	4.14	7.55
50:25:25	2.48	4.71	8.80
100:50:50	2.35	4.57	8.63
150:75:75	2.04	4.00	7.85
F test	NS	NS	NS
SEM (±)	11.638	0.214	0.337
Density x fertiliser interaction			
F test	NS	NS	NS
SEM (±)	23.275	0.428	0.674

Table 2 Effect of tree population density and fertiliser levels on height, radial growth, crown width, leaf area index and pest incidence of *Ailanthus* saplings at 4 years of age

Treatments	Mean tree height (m)	Diameter at breast height (cm)	Basal stem diameter (cm)	Crown width (m)	Leaf area index	Pest incidence score
Density (trees ha^{-1})						
3333	3.41	5.92	11.06	1.55	3.93	1.105
2500	3.41	6.23	11.27	1.61	3.17	1.222
1600	3.19	6.42	11.66	1.69	2.71	0.663
1111	2.87	5.14	10.02	1.58	1.96	1.426
F test	NS	NS	NS	NS	<0.01	NS
SEM (±)	18.928	0.293	0.353	6.307	0.176	0.336
CD (0.05)	-	-	-	-	0.611	-
Fertiliser levels ($N:P_2O_5:K_2O$ kg ha^{-1} yr^{-1})						
0:0:0	3.03	5.50	10.24	1.59	2.94	1.438
50:25:25	3.43	6.30	11.49	1.58	2.89	0.965
100:50:50	3.36	6.24	11.53	1.72	2.88	0.637
150:75:75	3.04	5.66	10.74	1.55	3.07	1.376
F test	NS	NS	NS	NS	NS	<0.05
SEM (±)	14.491	0.259	0.452	5.215	0.155	0.182
CD (0.05)	-	-	-	-	-	0.560
Density x fertiliser interaction						
F test	NS	NS	NS	NS	NS	NS
SEM (±)	28.982	0.517	0.904	10.430	0.309	0.364

Table 3 Effect of tree population density and fertiliser levels on foliar N content (%) of *Ailanthus* in the upper portion of the tree crown

Treatments	JUN '94	JUL '94	AUG '94	SEP '94	OCT '94	NOV '94	DEC '94	JAN '95	FEB '95	MAR '95	APR '95	MAY '95	JUN '95
Density (trees ha^{-1})													
3333	2.32	2.58	2.39	2.48	2.04	1.99	1.98	1.79	1.70	1.61	2.39	1.95	1.75
2500	2.33	2.56	2.50	2.61	2.02	1.88	1.86	1.72	1.68	1.98	2.52	2.00	1.74
1600	2.12	2.74	2.22	2.42	1.84	1.84	1.82	1.76	1.64	1.63	2.46	1.83	1.73
1111	2.30	2.71	2.40	2.35	2.08	1.92	1.91	1.68	1.60	1.77	2.13	1.83	1.71
F test	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
SEM (±)	0.089	0.064	0.069	0.060	0.082	0.034	0.043	0.080	0.032	0.170	0.153	0.069	0.089
Fertiliser levels ($N:P_2O_5:K_2O$ kg ha^{-1} yr^{-1})													
0:0:0	2.22	2.64	2.39	2.59	2.04	1.86	1.90	1.76	1.68	1.58	2.23	1.88	1.79
50:25:25	2.31	2.61	2.29	2.49	1.83	1.91	1.88	1.67	1.44	1.62	2.43	2.09	1.77
100:50:50	2.29	2.76	2.45	2.54	2.03	1.84	1.87	1.73	1.71	1.91	2.20	1.80	1.66
150:75:75	2.24	2.58	2.37	2.24	2.09	2.02	1.92	1.78	1.79	1.88	2.63	1.83	1.72
F test	NS	NS	NS	NS	<0.05	<0.05	NS	NS	<0.05	NS	NS	<0.01	NS
SEM(±)	0.077	0.097	0.093	0.096	0.066	0.045	0.033	0.068	0.072	0.106	0.161	0.046	0.095
CD (0.05)	-	-	-	-	0.19	0.13	-	-	0.21	-	-	0.13	-
Density x fertiliser interaction													
F test	<0.01	NS	NS	NS	NS	<0.01	NS	NS	NS	NS	NS	<0.01	NS
SEM(±)	0.154	0.194	0.186	0.191	0.133	0.089	0.066	0.136	0.144	0.213	0.323	0.092	0.189

found at higher densities particularly during the monsoon season, a pronounced seasonal trend in this respect was lacking. Fertiliser regimes, affected foliar nitrogen content (upper crown) during October 1994, November 1994, February 1995 and May 1995. The high dose of chemical fertilisers resulted in higher N levels during October, November and February. In contrast, higher nitrogen content was recorded at the low fertiliser level (50:25:25) during the month of May. Interaction effects (density x fertiliser) though significant during June 1994, November 1994 and May 1995 (Table 4; Appendix V) did not reveal any consistent trend.

Stand density affected nitrogen content in the lower portion of the tree crown during, June 1994, October 1994, November 1994 and December 1994 (Table 5; Appendix V). The stands with 3333, 2500 and 1111 TPHA registered higher values as compared to the population density of 1600 TPHA. Foliar nitrogen content (lower crown) was also influenced by fertiliser regimes during September 1994, October 1994, November 1994, December 1994, January 1995, March 1995 and May 1995. There was, however, no consistent pattern. Interaction effects (density x fertiliser) were significant with respect to foliar nitrogen in the lower portion of the tree crown during November 1994, December 1994 and May 1995 (Table 6; Appendix V). It also did not yield any predictable pattern.

Table 4 **Two-way tables showing combined effects of tree population density and fertiliser levels on foliar N content of *Ailanthus* (upper crown)**

	JUN '94				NOV '94				MAY '95			
	3333	2500	1600	1111	3333	2500	1600	1111	3333	2500	1600	1111
0 : 0 : 0	2.10	2.75	1.96	2.08	1.82	1.77	1.98	1.87	1.91	1.94	1.91	1.75
50 : 25 : 25	2.73	1.87	2.24	2.40	2.10	1.80	1.77	1.96	2.03	2.52	1.77	2.03
100 : 50 : 50	2.26	2.59	1.84	2.45	1.82	1.91	1.59	2.05	2.05	1.68	1.70	1.77
150 : 75 : 75	2.17	2.10	2.43	2.26	2.24	2.03	2.01	1.82	1.80	1.87	1.91	1.75

	JUN '94	NOV '94	MAY '95
CD for fertiliser levels within density	→ 0.45	→ 0.26	→ 0.26
CD for densities at each fertiliser level	→ 0.49	→ 0.25	→ 0.33

Table 5 Effect of tree population density and fertiliser levels on foliar N content (%) of *Ailanthus* in the lower portion of the tree crown

Treatments	JUN '94	JUL '94	AUG '94	SEP '94	OCT '94	NOV '94	DEC '94	JAN '95	FEB '95	MAR '95	APR '95	MAY '95	JUN '95
Density (trees ha^{-1})													
3333	1.63	2.31	2.00	2.02	2.02	1.98	1.83	1.71	1.72	1.51	1.97	1.88	1.82
2500	1.69	2.38	2.24	2.27	2.14	2.05	1.80	1.79	1.58	1.66	1.91	1.88	1.69
1600	1.60	2.44	2.04	1.92	1.71	1.66	1.72	1.57	1.69	1.56	1.62	1.93	1.75
1111	1.99	2.39	1.94	2.33	2.00	1.91	1.83	1.58	1.66	1.52	2.06	1.88	1.80
F test	<0.01	NS	NS	NS	<0.01	<0.05	<0.05	NS	NS	NS	NS	NS	NS
SEM (±)	0.051	0.048	0.095	0.120	0.044	0.069	0.019	0.054	0.070	0.042	0.108	0.059	0.057
CD (0.05)	0.18	-	-	-	0.15	0.24	0.06	-	-	-	-	-	-
Fertiliser levels ($N:P_2O_5:K_2O$ kg ha^{-1} yr^{-1})													
0:0:0	1.78	2.23	2.10	2.27	1.84	1.99	1.77	1.59	1.61	1.38	1.98	2.01	1.82
50:25:25	1.57	2.27	1.93	1.83	1.89	1.62	1.70	1.51	1.63	1.51	1.94	2.12	1.83
100:50:50	1.83	2.54	2.07	2.17	2.07	1.94	1.78	1.84	1.69	1.68	1.86	1.57	1.65
150:75:75	1.73	2.48	2.12	2.29	2.08	2.05	1.93	1.72	1.72	1.66	1.78	1.87	1.78
F test	NS	NS	NS	<0.01	<0.05	<0.01	<0.01	<0.01	NS	<0.05	NS	<0.01	NS
SEM(±)	0.073	0.092	0.094	0.088	0.058	0.048	0.031	0.047	0.069	0.067	0.163	0.061	0.072
CD (0.05)	-	-	-	0.26	0.17	0.14	0.09	0.13	-	0.19	-	0.18	-
Density x fertiliser interaction													
F test	NS	NS	NS	NS	NS	<0.05	<0.01	NS	NS	NS	NS	<0.05	NS
SEM(±)	0.146	0.184	0.187	0.176	0.117	0.095	0.061	0.094	0.138	0.134	0.326	0.123	0.143

Table 6 Two-way tables showing combined effects of tree population density and fertiliser levels on foliar N content of *Ailanthus* (lower crown)

	NOV '94				DEC '94				MAY '95			
	3333	2500	1600	1111	3333	2500	1600	1111	3333	2500	1600	1111
0 : 0 : 0	2.01	2.05	1.94	1.98	1.75	1384	1.68	1.82	2.33	1.70	1.98	2.01
50 : 25 : 25	1.82	1.59	1.45	1.61	1.70	1.61	1.68	1.80	2.08	2.26	2.05	2.10
100 : 50 : 50	1.96	2.31	1.52	1.98	1.98	1.59	1.66	1.89	1.40	1.61	1.84	1.45
150 : 75 : 75	2.12	2.26	1.75	2.05	1.89	2.15	1.87	1.80	1.70	1.96	1.84	1.98

	NOV '94	DEC '94	MAY '95
CD for fertiliser levels within density	→ 0.28	→ 0.18	→ 0.36
CD for densities at each fertiliser level	→ 0.34	→ 0.16	→ 0.37

4.2.2 Phosphorous

Stand density exerted a perceptible influence on foliar phosphorous content in the upper portion of the tree crown during August 1994, October 1994, December 1994, January 1995 and June 1995 (Table 7; Appendix V). In general the moderate densities recorded higher values. Fertiliser regimes also influenced foliar phosphorous levels (upper crown) during July 1994, December 1994, February 1995, March 1995, May 1995 and June 1995. It, however, did not yield any consistent trend. Interaction effects (density x fertiliser) were significant in respect of the phosphorous level in the upper portion of the tree crown during July 1994, August 1994, December 1994, January 1995, March 1995, and May 1995 (Table 8; Appendix V). No clear trend, however, was discernible.

Both tree population density (July 1994, September 1994, March 1995 and April 1995) and fertiliser regimes (September 1994, October 1994, December 1994, March 1995 and May 1995) influenced phosphorous content in the lower portion of the tree crown (Table 9; Appendix V). Tree population densities with 2500 and 1111 TPHA recorded higher values. No clear cut pattern was discernible with respect to fertiliser application. Interaction effects

Table 7 Effect of tree population density and fertiliser levels on foliar P content (%) of *Ailanthus* in the upper portion of the tree crown

Treatments	JUN '94	JUL '94	AUG '94	SEP '94	OCT '94	NOV '94	DEC '94	JAN '95	FEB '95	MAR '95	APR '95	MAY '95	JUN '95
Density (trees ha^{-1})													
3333	0.13	0.14	0.16	0.14	0.10	0.11	0.12	0.10	0.15	0.13	0.19	0.14	0.08
2500	0.13	0.14	0.18	0.15	0.12	0.11	0.11	0.11	0.15	0.12	0.19	0.14	0.09
1600	0.11	0.15	0.18	0.14	0.11	0.11	0.10	0.10	0.14	0.09	0.19	0.15	0.08
1111	0.13	0.14	0.15	0.15	0.10	0.11	0.10	0.11	0.14	0.12	0.17	0.14	0.10
F test	NS	NS	<0.05	NS	<0.01	NS	<0.05	<0.05	NS	NS	NS	NS	<0.01
SEM (±)	0.006	0.003	0.006	0.004	0.003	0.005	0.004	0.002	0.004	0.013	0.007	0.008	0.003
CD (0.05)	-	-	0.02	-	0.01	-	0.01	0.009	-	-	-	-	0.01
Fertiliser levels ($N:P_2O_5:K_2O$ kg ha^{-1} yr^{-1})													
0:0:0	0.11	0.15	0.18	0.15	0.11	0.11	0.11	0.11	0.15	0.10	0.18	0.14	0.10
50:25:25	0.13	0.15	0.16	0.15	0.10	0.11	0.12	0.10	0.13	0.10	0.19	0.15	0.08
100:50:50	0.13	0.14	0.17	0.15	0.11	0.11	0.11	0.11	0.15	0.12	0.17	0.15	0.08
150:75:75	0.12	0.13	0.16	0.14	0.11	0.11	0.09	0.11	0.14	0.14	0.20	0.13	0.09
F test	NS	<0.05	NS	NS	NS	NS	<0.01	NS	<0.01	<0.01	NS	<0.05	<0.05
SEM(±)	0.006	0.004	0.007	0.005	0.003	0.004	0.004	0.003	0.004	0.007	0.007	0.006	0.004
CD (0.05)	-	0.01	-	-	-	-	0.01	-	0.01	0.03	-	0.017	0.01
Density x fertiliser interaction													
F test	NS	<0.01	<0.05	NS	NS	NS	<0.01	<0.01	NS	<0.05	NS	<0.05	NS
SEM(±)	0.12	0.008	0.014	0.010	0.006	0.008	0.007	0.005	0.008	0.014	0.015	0.011	0.007

Table 8 Two-way tables showing combined effects of tree population density and fertiliser levels on foliar P content of *Ailanthus* (upper crown)

JUL '94

	3333	2500	1600	1111
0 : 0 : 0	0.14	0.16	0.15	0.15
50 : 25 : 25	0.17	0.13	0.16	0.13
100 : 50 : 50	0.14	0.12	0.14	0.16
150 : 75 : 75	0.12	0.14	0.13	0.13

AUG '94

	3333	2500	1600	1111
0 : 0 : 0	0.21	0.18	0.18	0.16
50 : 25 : 25	0.15	0.19	0.15	0.15
100 : 50 : 50	0.13	0.17	0.21	0.16
150 : 75 : 75	0.16	0.18	0.17	0.13

DEC '94

	3333	2500	1600	1111
0 : 0 : 0	0.15	0.09	0.12	0.08
50 : 25 : 25	0.15	0.10	0.11	0.11
100 : 50 : 50	0.10	0.12	0.09	0.14
150 : 75 : 75	0.09	0.11	0.08	0.08

	JUL '94	AUG '94	DEC '94
CD for fertiliser levels within density	→ 0.02	→ 0.05	→ 0.01
CD for densities at each fertiliser level	→ 0.03	→ 0.05	→ 0.02

JAN '95

	3333	2500	1600	1111
0 : 0 : 0	0.10	0.12	0.11	0.11
50 : 25 : 25	0.10	0.10	0.11	0.10
100 : 50 : 50	0.10	0.11	0.10	0.14
150 : 75 : 75	0.10	0.12	0.10	0.10

MAR '95

	3333	2500	1600	1111
0 : 0 : 0	0.13	0.09	0.10	0.10
50 : 25 : 25	0.13	0.09	0.08	0.11
100 : 50 : 50	0.14	0.14	0.08	0.12
150 : 75 : 75	0.11	0.16	0.11	0.16

MAY '95

	3333	2500	1600	1111
0 : 0 : 0	0.14	0.14	0.14	0.13
50 : 25 : 25	0.14	0.17	0.15	0.15
100 : 50 : 50	0.17	0.13	0.13	0.17
150 : 75 : 75	0.12	0.12	0.16	0.11

	JAN '95	MAR '95	MAY '95
CD for fertiliser levels within density	→ 0.01	→ 0.05	→ 0.04
CD for densities at each fertiliser level	→ 0.02	→ 0.06	→ 0.04

Table 9 Effect of tree population density and fertiliser levels on foliar P content (%) of *Ailanthus* in the lower portion of the tree crown

Treatments	JUN '94	JUL '94	AUG '94	SEP '94	OCT '94	NOV '94	DEC '94	JAN '95	FEB '95	MAR '95	APR '95	MAY '95	JUN '95
Density (trees ha^{-1})													
3333	0.09	0.14	0.14	0.13	0.10	0.10	0.11	0.10	0.14	0.07	0.11	0.12	0.08
2500	0.09	0.13	0.17	0.13	0.10	0.12	0.11	0.10	0.14	0.08	0.13	0.13	0.08
1600	0.09	0.12	0.14	0.11	0.10	0.10	0.11	0.10	0.15	0.08	0.10	0.12	0.07
1111	0.10	0.13	0.14	0.13	0.10	0.10	0.12	0.10	0.14	0.08	0.14	0.12	0.08
F test	NS	<0.01	NS	<0.05	NS	NS	NS	NS	NS	<0.05	<0.01	NS	NS
SEM (±)	0.005	0.003	0.008	0.004	0.005	0.006	0.002	0.003	0.003	0.002	0.004	0.007	0.004
CD (0.05)	-	0.01	-	0.01	-	-	-	-	-	0.005	0.01	-	-
Fertiliser levels ($N:P_2O_5:K_2O$ kg ha^{-1} yr^{-1})													
0:0:0	0.08	0.13	0.15	0.14	0.09	0.11	0.11	0.10	0.15	0.09	0.11	0.13	0.08
50:25:25	0.09	0.13	0.14	0.12	0.10	0.10	0.10	0.10	0.14	0.08	0.14	0.13	0.07
100:50:50	0.09	0.13	0.16	0.12	0.11	0.10	0.12	0.10	0.14	0.08	0.12	0.10	0.07
150:75:75	0.09	0.13	0.15	0.13	0.10	0.10	0.12	0.10	0.15	0.08	0.11	0.13	0.08
F test	NS	NS	NS	<0.05	<0.01	NS	<0.05	NS	NS	<0.01	NS	<0.01	NS
SEM(±)	0.004	0.004	0.007	0.005	0.003	0.004	0.005	0.003	0.003	0.002	0.009	0.004	0.04
CD (0.05)	-	-	-	0.01	0.01	-	0.01	-	-	0.005	-	0.01	-
Density x fertiliser interaction													
F test	<0.05	<0.01	NS	NS	<0.01	<0.01	<0.01	NS	NS	<0.01	<0.05	<0.01	NS
SEM(±)	0.008	0.008	0.014	0.010	0.005	0.007	0.011	0.005	0.006	0.004	0.018	0.007	0.009

Table 10 Two-way tables showing combined effects of tree population density and fertiliser levels on foliar P content of *Ailanthus* (lower crown)

JUN '94

	3333	2500	1600	1111
0 : 0 : 0	0.07	0.08	0.08	0.10
50 : 25 : 25	0.11	0.10	0.08	0.08
100 : 50 : 50	0.07	0.07	0.09	0.11
150 : 75 : 75	0.09	0.09	0.09	0.11

CD for fertiliser levels within density → 0.02
CD for densities at each fertiliser level → 0.03

JUL '94

	3333	2500	1600	1111
0 : 0 : 0	0.13	0.13	0.14	0.12
50 : 25 : 25	0.14	0.12	0.15	0.12
100 : 50 : 50	0.15	0.13	0.09	0.13
150 : 75 : 75	0.14	0.15	0.10	0.14

CD for fertiliser levels within density → 0.02
CD for densities at each fertiliser level → 0.03

OCT '94

	3333	2500	1600	1111
0 : 0 : 0	0.08	0.09	0.11	0.09
50 : 25 : 25	0.10	0.10	0.10	0.10
100 : 50 : 50	0.12	0.11	0.10	0.12
150 : 75 : 75	0.09	0.11	0.10	0.10

CD for fertiliser levels within density → 0.01
CD for densities at each fertiliser level → 0.03

NOV '94

	3333	2500	1600	1111
0 : 0 : 0	0.10	0.11	0.11	0.12
50 : 25 : 25	0.11	0.12	0.08	0.10
100 : 50 : 50	0.09	0.13	0.08	0.11
150 : 75 : 75	0.09	0.11	0.12	0.08

CD for fertiliser levels within density → 0.02
CD for densities at each fertiliser level → 0.03

DEC '94

	3333	2500	1600	1111
0 : 0 : 0	0.08	0.13	0.12	0.11
50 : 25 : 25	0.14	0.09	0.08	0.10
100 : 50 : 50	0.12	0.09	0.13	0.14
150 : 75 : 75	0.12	0.15	0.09	0.12

CD for fertiliser levels within density → 0.02
CD for densities at each fertiliser level → 0.02

MAR '95

	3333	2500	1600	1111
0 : 0 : 0	0.09	0.09	0.10	0.08
50 : 25 : 25	0.07	0.07	0.07	0.08
100 : 50 : 50	0.07	0.08	0.10	0.08
150 : 75 : 75	0.07	0.09	0.07	0.08

CD for fertiliser levels within density → 0.01
CD for densities at each fertiliser level → 0.01

APR '95

	3333	2500	1600	1111
0 : 0 : 0	0.13	0.09	0.13	0.10
50 : 25 : 25	0.12	0.19	0.10	0.14
100 : 50 : 50	0.10	0.15	0.10	0.16
150 : 75 : 75	0.11	0.09	0.08	0.16

CD for fertiliser levels within density → 0.05
CD for densities at each fertiliser level → 0.05

MAY '95

	3333	2500	1600	1111
0 : 0 : 0	0.15	0.12	0.13	0.14
50 : 25 : 25	0.13	0.15	0.12	0.12
100 : 50 : 50	0.09	0.11	0.11	0.10
150 : 75 : 75	0.11	0.13	0.13	0.15

CD for fertiliser levels within density → 0.02
CD for densities at each fertiliser level → 0.04

were significant during June 1994, July 1994, October 1994, November 1994, December 1994, March 1995, April 1995 and May 1995 (Table 10; Appendix V). Here again no consistent trend, was observed.

4.2.3 Potassium

Stand density did not affect potassium content in the upper portion of the tree crown (Table 11; Appendix V). Fertiliser regimes however, were significant during September 1994, October 1994, February 1995 and May 1995, although they did not reveal any distinctive trends in this regard. Interaction effects (density x fertiliser levels) in respect of potassium content in the upper crown foliage were significant during July 1994, September 1994, October 1994, April 1995, May 1995 and June 1995 (Table 12; Appendix V). No predictable relationships, were however available in this respect.

Tree population densities (June 1994, July 1994 and April 1995) and fertiliser regimes (March, April and May 1995) exerted marked influence on foliar potassium content in the lower portion of tree crown (Table 13; Appendix V). Relatively higher values were recorded in the stand with 1111 TPHA and at the low (50:25:25; N : P_2O_5 : K_2O kg ha^{-1} yr^{-1}) fertiliser dosage. Interaction effects were also found to be significant in respect of the lower portion of

Table 11 Effect of tree population density and fertiliser levels on foliar K content (%) of *Ailanthus* in the upper portion of the tree crown

Treatments	JUN '94	JUL '94	AUG '94	SEP '94	OCT '94	NOV '94	DEC '94	JAN '95	FEB '95	MAR '95	APR '95	MAY '95	JUN '95
Density (trees ha^{-1})													
3333	0.66	0.75	0.64	0.80	0.61	0.57	0.75	0.60	0.65	0.51	0.83	0.76	0.62
2500	0.64	0.70	0.65	0.73	0.70	0.50	0.66	0.65	0.57	0.54	0.78	0.70	0.52
1600	0.59	0.69	0.61	0.76	0.61	0.61	0.75	0.63	0.56	0.48	0.85	0.69	0.52
1111	0.68	0.73	0.69	0.80	0.63	0.47	1.23	0.68	0.58	0.55	0.72	0.71	0.57
F test	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
SEM (±)	0.025	0.033	0.052	0.031	0.043	0.047	0.232	0.045	0.027	0.032	0.031	0.052	0.046
Fertiliser levels ($N:P_2O_5:K_2O$ kg ha^{-1} yr^{-1})													
0:0:0	0.60	0.70	0.71	0.78	0.74	0.52	1.25	0.65	0.60	0.47	0.81	0.76	0.58
50:25:25	0.67	0.73	0.60	0.81	0.53	0.55	0.71	0.62	0.50	0.48	0.81	0.82	0.52
100:50:50	0.62	0.76	0.63	0.80	0.64	0.52	0.70	0.68	0.71	0.53	0.75	0.63	0.61
150:75:75	0.69	0.68	0.65	0.70	0.63	0.56	0.73	0.62	0.55	0.58	0.82	0.65	0.53
F test	NS	NS	NS	<0.05	<0.05	NS	NS	NS	<0.05	NS	NS	<0.05	NS
SEM(±)	0.031	0.038	0.043	0.027	0.045	0.036	0.247	0.044	0.044	0.029	0.026	0.044	0.026
CD (0.05)	-	-	-	-	0.13	-	-	-	0.12	-	-	0.12	-
Density x fertiliser interaction													
F test	NS	<0.01	NS	<0.01	<0.05	NS	NS	NS	NS	NS	<0.05	<0.05	<0.01
SEM(±)	0.062	0.076	0.086	0.054	0.090	0.072	0.495	0.087	0.088	0.059	0.051	0.088	0.051

Table 12 Two-way tables showing combined effects of tree population density and fertiliser levels on foliar K content of *Ailanthus* (upper crown)

JUL '94

	3333	2500	1600	1111
0 : 0 : 0	0.84	0.67	0.79	0.50
50 : 25 : 25	0.70	0.77	0.72	0.72
100 : 50 : 50	0.63	0.75	0.73	0.91
150 : 75 : 75	0.82	0.62	0.50	0.78

CD for fertiliser levels within density → 0.22
CD for densities at each fertiliser level → 0.22

SEP '94

	3333	2500	1600	1111
0 : 0 : 0	0.78	0.80	0.69	0.86
50 : 25 : 25	0.73	0.72	0.86	0.91
100 : 50 : 50	0.83	0.65	0.89	0.81
150 : 75 : 75	0.83	0.77	0.58	0.62

CD for fertiliser levels within density → 0.16
CD for densities at each fertiliser level → 0.17

OCT '94

	3333	2500	1600	1111
0 : 0 : 0	0.79	0.77	0.70	0.71
50 : 25 : 25	0.43	0.56	0.62	0.52
100 : 50 : 50	0.77	0.52	0.68	0.59
150 : 75 : 75	0.45	0.95	0.45	0.68

CD for fertiliser levels within density → 0.26
CD for densities at each fertiliser level → 0.27

APR '95

	3333	2500	1600	1111
0 : 0 : 0	0.89	0.67	0.89	0.78
50 : 25 : 25	0.82	0.79	0.94	0.67
100 : 50 : 50	0.70	0.79	0.76	0.73
150 : 75 : 75	0.92	0.87	0.80	0.68

CD for fertiliser levels within density → 0.14
CD for densities at each fertiliser level → 0.17

MAY '95

	3333	2500	1600	1111
0 : 0 : 0	0.81	0.65	0.65	0.92
50 : 25 : 25	0.87	0.75	0.81	0.87
100 : 50 : 50	0.71	0.52	0.75	0.55
150 : 75 : 75	0.65	0.90	0.55	0.49

CD for fertiliser levels within density → 0.25
CD for densities at each fertiliser level → 0.28

JUN '95

	3333	2500	1600	1111
0 : 0 : 0	0.68	0.68	0.45	0.51
50 : 25 : 25	0.63	0.36	0.52	0.57
100 : 50 : 50	0.67	0.52	0.57	0.67
150 : 75 : 75	0.47	0.54	0.53	0.56

CD for fertiliser levels within density → 0.14
CD for densities at each fertiliser level → 0.21

Table 13 Effect of tree population density and fertiliser levels on foliar K content (%) of *Ailanthus* in the lower portion of the tree crown

Treatments	JUN '94	JUL '94	AUG '94	SEP '94	OCT '94	NOV '94	DEC '94	JAN '95	FEB '95	MAR '95	APR '95	MAY '95	JUN '95
Density (trees ha^{-1})													
3333	0.28	0.54	0.40	0.55	0.64	0.57	0.73	0.58	0.58	0.41	0.49	0.57	0.54
2500	0.34	0.54	0.47	0.62	0.60	0.53	0.63	0.58	0.52	0.35	0.54	0.54	0.40
1600	0.29	0.63	0.43	0.61	0.60	0.55	0.72	0.59	0.58	0.46	0.37	0.61	0.53
1111	0.45	0.74	0.41	0.58	0.56	0.49	0.67	0.58	0.51	0.36	0.49	0.62	0.40
F test	<0.01	<0.01	NS	NS	NS	NS	NS	NS	NS	NS	<0.01	NS	NS
SEM (±)	0.023	0.029	0.031	0.043	0.032	0.052	0.043	0.027	0.029	0.024	0.019	0.026	0.046
CD (0.05)	0.07	0.01	-	-	-	-	-	-	-	-	0.07	-	-
Fertiliser levels ($N:P_2O_5:K_2O$ kg ha^{-1} yr^{-1})													
0:0:0	0.33	0.56	0.42	0.65	0.62	0.53	0.70	0.58	0.53	0.35	0.42	0.72	0.46
50:25:25	0.31	0.64	0.43	0.54	0.59	0.49	0.68	0.56	0.49	0.43	0.59	0.62	0.47
100:50:50	0.36	0.67	0.48	0.58	0.63	0.56	0.69	0.56	0.60	0.42	0.47	0.43	0.48
150:75:75	0.35	0.58	0.39	0.60	0.58	0.56	0.69	0.64	0.57	0.37	0.40	0.57	0.45
F test	NS	NS	NS	NS	NS	NS	NS	NS	NS	<0.01	<0.05	<0.01	NS
SEM(±)	0.019	0.030	0.038	0.035	0.034	0.036	0.032	0.029	0.037	0.017	0.040	0.033	0.038
CD (0.05)	-	-	-	-	-	-	-	-	-	0.05	0.12	0.10	-
Density x fertiliser interaction													
F test	<0.05	NS	NS	<0.01	<0.01	NS	<0.05	<0.05	NS	<0.01	<0.01	<0.01	NS
SEM(±)	0.038	0.061	0.076	0.069	0.068	0.072	0.063	0.058	0.075	0.034	0.080	0.066	0.075

Table 14 Two-way tables showing combined effects of tree population density and fertiliser levels on foliar K content of *Ailanthus* (lower crown)

	JUN '94				SEP '94				OCT '94				DEC '94			
	3333	2500	1600	1111	3333	2500	1600	1111	3333	2500	1600	1111	3333	2500	1600	1111
0 : 0 : 0	0.25	0.38	0.28	0.42	0.80	0.53	0.69	0.57	0.52	0.78	0.45	0.71	0.78	0.57	0.68	0.78
50 : 25 : 25	0.28	0.36	0.26	0.37	0.62	0.52	0.52	0.48	0.67	0.52	0.68	0.47	0.70	0.62	0.71	0.68
100 : 50 : 50	0.27	0.26	0.37	0.55	0.42	0.68	0.57	0.63	0.81	0.40	0.75	0.55	0.60	0.78	0.78	0.58
150 : 75 : 75	0.32	0.36	0.27	0.43	0.37	0.74	0.63	0.63	0.55	0.71	0.53	0.52	0.84	0.55	0.71	0.65

	JUN '94	SEP '94	OCT '94	DEC '94
CD for fertiliser levels within density	→ 0.11	→ 0.19	→ 0.19	→ 0.18
CD for densities at each fertiliser level	→ 0.12	→ 0.23	→ 0.21	→ 0.22

	JAN '95				MAR '95				APR '95				MAY '95			
0 : 0 : 0	0.52	0.53	0.63	0.62	0.42	0.27	0.50	0.20	0.54	0.27	0.57	0.30	0.88	0.55	0.62	0.84
50 : 25 : 25	0.63	0.42	0.65	0.52	0.42	0.43	0.51	0.37	0.62	0.84	0.35	0.57	0.57	0.52	0.78	0.60
100 : 50 : 50	0.50	0.68	0.49	0.55	0.35	0.44	0.52	0.38	0.32	0.78	0.31	0.47	0.32	0.40	0.55	0.42
150 : 75 : 75	0.67	0.63	0.58	0.62	0.44	0.25	0.31	0.47	0.50	0.27	0.23	0.62	0.50	0.68	0.50	0.60

	JAN '95	MAR '95	APR '95	MAY '95
CD for fertiliser levels within density	→ 0.17	→ 0.10	→ 0.23	→ 0.19
CD for densities at each fertiliser level	→ 0.16	→ 0.12	→ 0.21	→ 0.19

the tree crown during June 1994, September 1994, October 1994, December 1994, January 1995, March 1995, April 1995 and May 1995 (Table 14; Appendix V).

4.3 Soil chemical properties as affected by tree population density and fertiliser regimes

Base line soil data of (1991) the experimental site (prior to planting ailanthus) showed a mean pH of 5.45, organic carbon content of 1.93% and available K of 40.67 ppm. Soil analysis before and after the ginger experiment (1994), however, showed that stand density and soil chemical properties (Tables 15 and 16; Appendix VI) are strongly related. Surprisingly the highest total soil nitrogen (Table 15; Appendix VI) content was recorded in the lowest stand density (1111 TPHA). Difference in available P was not statistically significant. The stands with 2500 and 1111 TPHA were superior in terms of available K and organic carbon respectively. After the ginger crop (Table 16; Appendix VI), however the population density of 2500 TPHA recorded the least value for available P, the stand with 3333 TPHA the highest available K and the stand with 1111 TPHA the maximum soil organic carbon content.

Fertiliser levels though significant with respect to various soil parameters, did not reveal any characteristic

Table 15 Effect of tree population density and fertiliser levels on soil chemical properties before the ginger experiment

(Tree age - 3 years)

Treatments	Total N (%)	Available P (ppm)	Available K (ppm)	OC (%)	OM (%)	C : N Ratio	Soil pH
Density (trees ha^{-1})							
3333	0.11	10.37	61.25**	1.52**	2.61**	13.83**	5.77**
2500	0.15	10.35	85.42**	1.71**	2.93**	11.17**	5.76**
1600	0.13	11.97	76.46*	1.48**	2.54**	10.92**	5.87*
1111	0.15	11.35	70.83**	2.14**	3.67**	14.58**	5.84**
F test	<0.01	NS	<0.01	<0.01	<0.01	<0.01	<0.01
SEM (±)	0.002	0.632	0.356	0.059	0.102	0.435	0.003
CD (0.05)	0.001	-	1.23	0.20	0.35	1.56	0.01
Fertiliser levels ($N:P_2O_5:K_2O$ kg ha^{-1} yr^{-1})							
0:0:0	0.13	14.10	44.17**	1.28**	2.19**	9.83**	5.74**
50:25:25	0.13	10.36*	93.30**	1.84**	3.16**	14.17**	5.86**
100:50:50	0.13	8.82**	78.96	1.85**	3.19**	13.42**	5.84**
150:75:75	0.14	10.76*	77.50	1.88**	3.22**	13.08**	5.80**
F test	NS	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
SEM(±)	0.004	0.586	0.680	0.087	0.150	0.458	0.004
CD (0.05)	-	1.71	1.99	0.25	0.43	1.34	0.01
Density x fertiliser interaction							
F test	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
SEM(±)	0.008	1.171	1.361	0.175	0.301	0.915	0.001
Ginger monoculture	0.15	13.43	79.17	2.82	4.84	18.33	5.90

* Paired 't' values comparing treatment with ginger monoculture, significant at 5% level

** Paired 't' values comparing treatment with ginger monoculture, significant at 1% level

Table 16 Effect of tree population density and fertiliser levels on soil chemical properties after the ginger experiment

(Tree age - 4 years)

Treatments	Total N (%)	Available P (ppm)	Available K (ppm)	OC (%)	OM (%)	C : N Ratio	Soil pH
Density (trees ha^{-1})							
3333	0.14	11.13	108.75	1.86	3.19	13.08	6.03
2500	0.15	8.42	95.21**	2.05	3.52	13.83	6.00
1600	0.14	10.21	88.96**	1.74	3.00	12.08	6.00
1111	0.15	11.22	92.92**	2.35	4.03	15.50	5.97
F test	NS	<0.05	<0.01	<0.01	<0.01	<0.01	<0.01
SEM (±)	0.003	0.432	1.928	0.051	0.087	0.250	0.003
CD (0.05)	-	1.50	6.67	0.18	0.30	0.87	0.01
Fertiliser levels ($N:P_2O_5:K_2O$ kg ha^{-1} yr^{-1})							
0:0:0	0.15	10.45	78.75**	1.67**	2.87**	11.00**	6.00
50:25:25	0.15	9.91	107.71	2.27	3.90	15.33	6.05
100:50:50	0.14	9.62	97.08**	1.92**	3.29**	13.42**	5.95
150:75:75	0.14	11.02	102.29**	2.13*	3.66*	14.75	6.00
F test	NS	NS	<0.01	<0.01	<0.01	<0.01	<0.01
SEM(±)	0.003	0.392	1.188	0.075	0.129	0.441	0.003
CD (0.05)	-	-	3.46	0.22	0.37	1.29	0.01
Density x fertiliser interaction							
F test	NS	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
SEM(±)	0.005	0.783	2.375	0.150	0.257	0.882	0.006
Ginger monoculture	0.15	10.53	110.00	2.61	4.48	16.66	6.04

* Paired 't' values comparing treatment with ginger monoculture, significant at 5% level

** Paired 't' values comparing treatment with ginger monoculture, significant at 1% level

Table 17 Two-way tables showing combined effects of tree population density and fertiliser levels on soil chemical properties before the ginger experiment

N (%)

	3333	2500	1600	1111
0 : 0 : 0	0.083	0.153	0.150	0.153
50 : 25 : 25	0.097	0.157	0.133	0.133
100 : 50 : 50	0.120	0.157	0.087	0.150
150 : 75 : 75	0.127	0.137	0.153	0.150

CD for fertiliser levels within density → 0.02
CD for densities at each fertiliser level → 0.02
Ginger monoculture → 0.15

P (ppm)

	3333	2500	1600	1111
0 : 0 : 0	12.27	8.27**	17.43**	18.43**
50 : 25 : 25	8.07**	11.97	9.90**	11.50
100 : 50 : 50	8.87**	10.90*	8.13**	7.40**
150 : 75 : 75	12.27	10.27*	12.43	8.07**

CD for fertiliser levels within density → 3.42
CD for densities at each fertiliser level → 3.67
Ginger monoculture → 13.43

K (ppm)

0 : 0 : 0	48.33**	41.67**	57.50**	29.17**
50 : 25 : 25	120.83**	133.33**	85.83**	33.33**
100 : 50 : 50	41.67**	116.67**	53.33**	104.17**
150 : 75 : 75	34.17**	50.00**	109.17**	116.67**

CD for fertiliser levels within density → 3.97
CD for densities at each fertiliser level → 3.66
Ginger monoculture → 79.17

OC (%)

0 : 0 : 0	1.10**	1.04**	1.36**	1.60**
50 : 25 : 25	1.31**	2.15**	2.05**	1.85**
100 : 50 : 50	1.92**	2.41**	0.64**	2.45**
150 : 75 : 75	1.75**	1.24**	1.87**	2.64

CD for fertiliser levels within density → 0.51
CD for densities at each fertiliser level → 0.48
Ginger monoculture → 2.82

Contd.....

Table 17 contd....

	OM (%)				C:N ratio				Soil pH			
	3333	2500	1600	1111	3333	2500	1600	1111	3333	2500	1600	1111
0 : 0 : 0	1.88**	1.79**	2.33**	2.75**	13.33**	6.67**	9.00**	10.33**	5.63**	5.73**	5.77**	5.78**
50 : 25 : 25	2.25**	3.68**	3.52**	3.16**	14.00**	13.33**	15.67**	13.67**	5.91	5.75**	5.95**	5.84**
100 : 50 : 50	3.31**	4.13**	1.09**	4.21**	14.67**	15.33**	7.00**	16.67**	5.80**	5.74**	5.87**	5.95**
150 : 75 : 75	3.00**	2.13**	3.21**	4.54**	13.33**	9.33**	12.00**	17.67	5.75**	5.76**	5.89	5.80**

	OM (%)	C:N ratio	Soil pH
CD for fertiliser levels within density	→ 0.88	→ 2.67	→ 0.02
CD for densities at each fertiliser level	→ 0.83	→ 2.79	→ 0.02
Ginger monoculture	→ 4.84	→ 18.33	→ 5.90

* Paired 't' values comparing treatment with ginger monoculture, significant at 5% level
** Paired 't' values comparing treatment with ginger monoculture, significant at 1% level

Table 18 Two-way tables showing combined effects of tree population density and fertiliser levels on soil chemical properties after the ginger experiment

	P (ppm)				K (ppm)				OC (%)			
	3333	2500	1600	1111	3333	2500	1600	1111	3333	2500	1600	1111
0 : 0 : 0	11.00	9.63	10.60	10.57	90.00**	98.33**	61.67**	65.00**	1.83**	1.59**	1.49**	1.79**
50 : 25 : 25	10.27	9.80	8.50**	11.07	76.67**	126.67**	110.83	116.67**	1.33**	2.38*	2.22**	3.17**
100 : 50 : 50	9.77	8.67**	10.13	9.90	116.67**	90.00**	90.00**	91.67**	2.18**	2.48	1.18**	1.83**
150 : 75 : 75	13.50**	5.60**	11.60*	13.37*	151.67**	65.83**	93.33**	98.33**	2.09**	1.75**	2.10**	2.60

	P (ppm)	K (ppm)	OC (%)
CD for fertiliser levels within density	→ 2.29	→ 6.93	→ 0.44
CD for densities at each fertiliser level	→ 2.47	→ 8.93	→ 0.41
Ginger monoculture	→ 10.53	→ 110.0	→ 2.61

	OM (%)				C:N ratio				Soil pH			
0 : 0 : 0	3.14**	2.73**	2.55**	3.07**	12.33**	10.67**	9.67**	11.33**	6.09	5.98	6.00	5.94
50 : 25 : 25	2.29**	4.08*	3.81**	5.44**	9.33**	15.00**	15.67	21.333**	6.04	5.96	6.16*	6.03
100 : 50 : 50	3.75**	4.26	2.02**	3.15**	15.33*	17.33	9.00**	12.00**	5.97	6.01	5.85*	5.95
150 : 75 : 75	3.58**	3.00**	3.60**	4.46	15.33*	12.33**	14.00**	17.33	6.01	6.06	5.99	5.95

	OM (%)	C:N ratio	Soil pH
CD for fertiliser levels within density	→ 0.75	→ 2.57	→ 0.02
CD for densities at each fertiliser level	→ 0.71	→ 2.39	→ 0.02
Ginger monoculture	→ 4.48	→ 16.66	→ 6.04

* Paired 't' values comparing treatment with ginger monoculture, significant at 5% level
** Paired 't' values comparing treatment with ginger monoculture, significant at 1% level

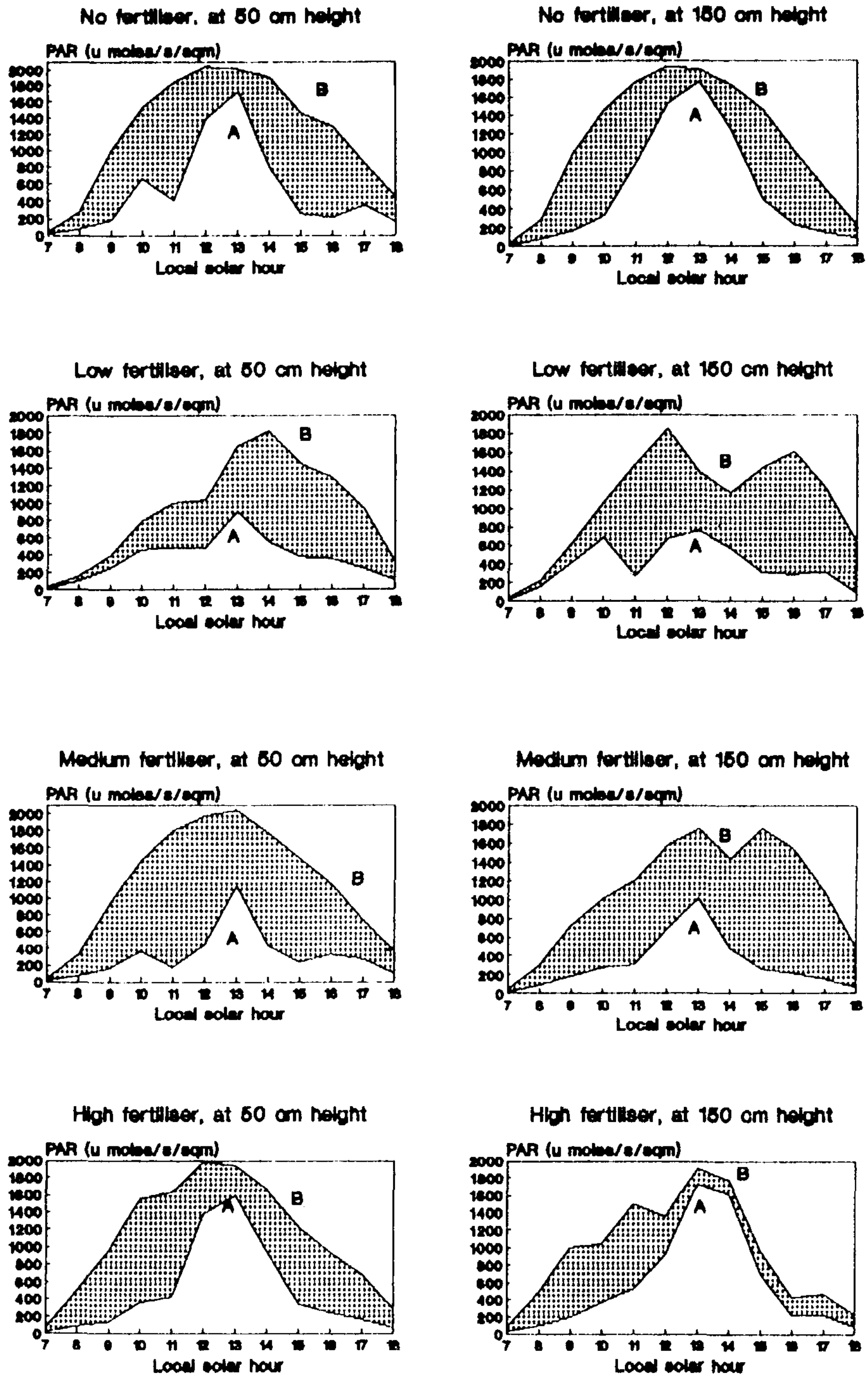
trend. Density x fertiliser effect also was significant with respect to the various soil parameters both before (Table 17; Appendix VI) and after (Table 18; Appendix VI) the ginger experiment.

A comparison of the soil chemical data, within various tree population densities and fertiliser levels, with that in the open (using 't' test) showed that nitrogen and available P status of the soil under tree and in the open are statistically at par. With regard to soil potassium, presence of trees, regardless of density and fertiliser levels adversely affected its availability. Similar observations were registered with regard to organic carbon, C:N ratio and soil pH also.

4.4 Relative proportion of photosynthetically active radiation (PAR) intercepted by ailanthus canopy as affected by tree population density and fertiliser regimes

To characterise the light availability beneath the canopy, the diurnal courses of PPFD (photosynthetic photon flux density) at 50 and 150 cm above ground were examined. PAR was higher at 150 cm as compared to 50 cm height, from the ground level (Fig. 4,5,6 and 7; Appendix XVIII). In general higher densities intercepted more light (PAR). The proportion of the incoming solar radiation intercepted by the tree crowns ranged from 28%

Fig. 4 Relative proportion of PAR intercepted by ailanthus canopy (shaded region) as affected by fertiliser regimes & height above ground level at 3333 TPHA



A - beneath canopy ; B - above canopy

Fig. 5 Relative proportion of PAR intercepted by ailanthus canopy (shaded region) as affected by fertiliser regimes & height above ground level at 2500 TPHA

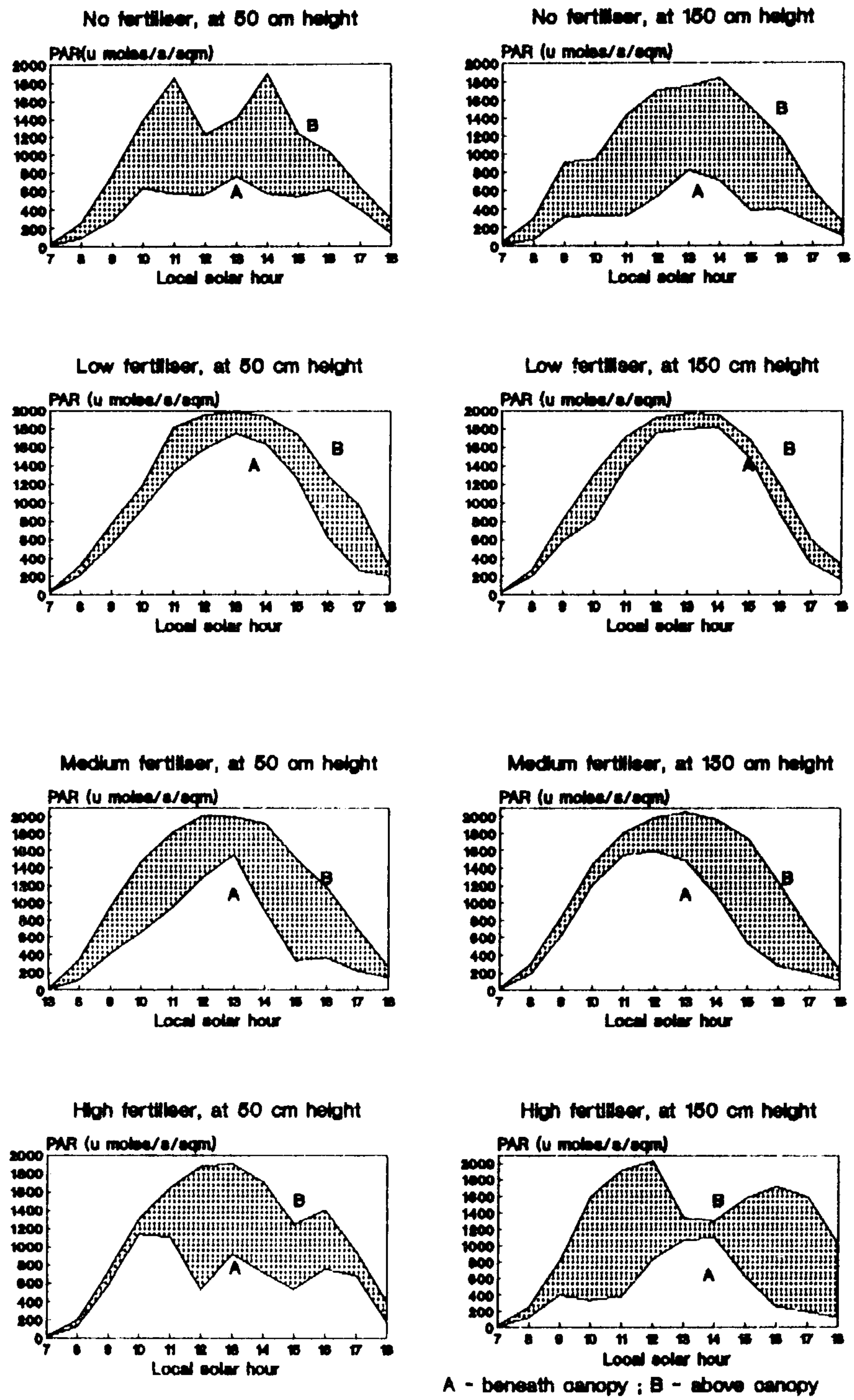


Fig. 7 Relative proportion of PAR intercepted by ailanthus canopy (shaded region) as affected by fertiliser regimes & height above ground level at 1111 TPHA

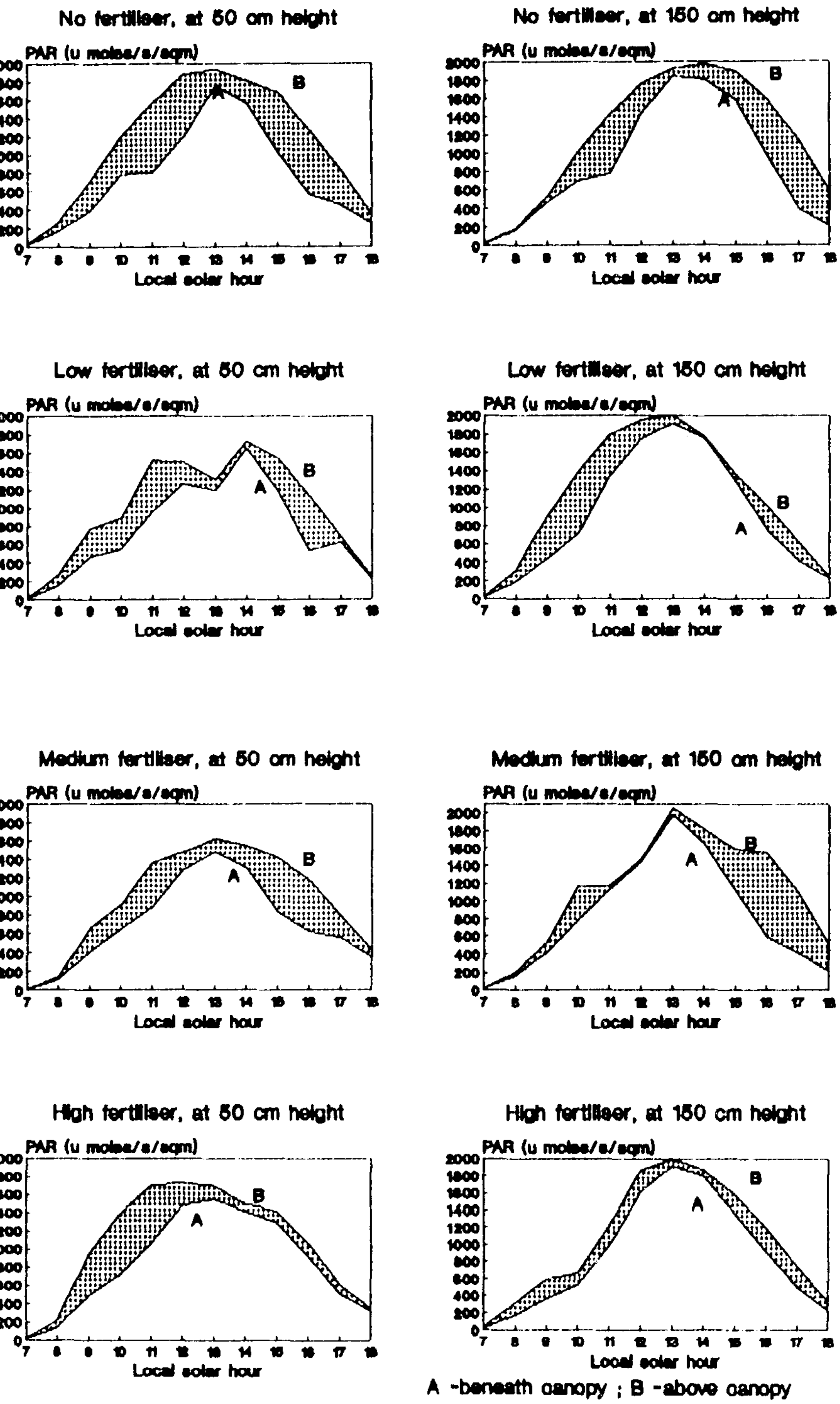
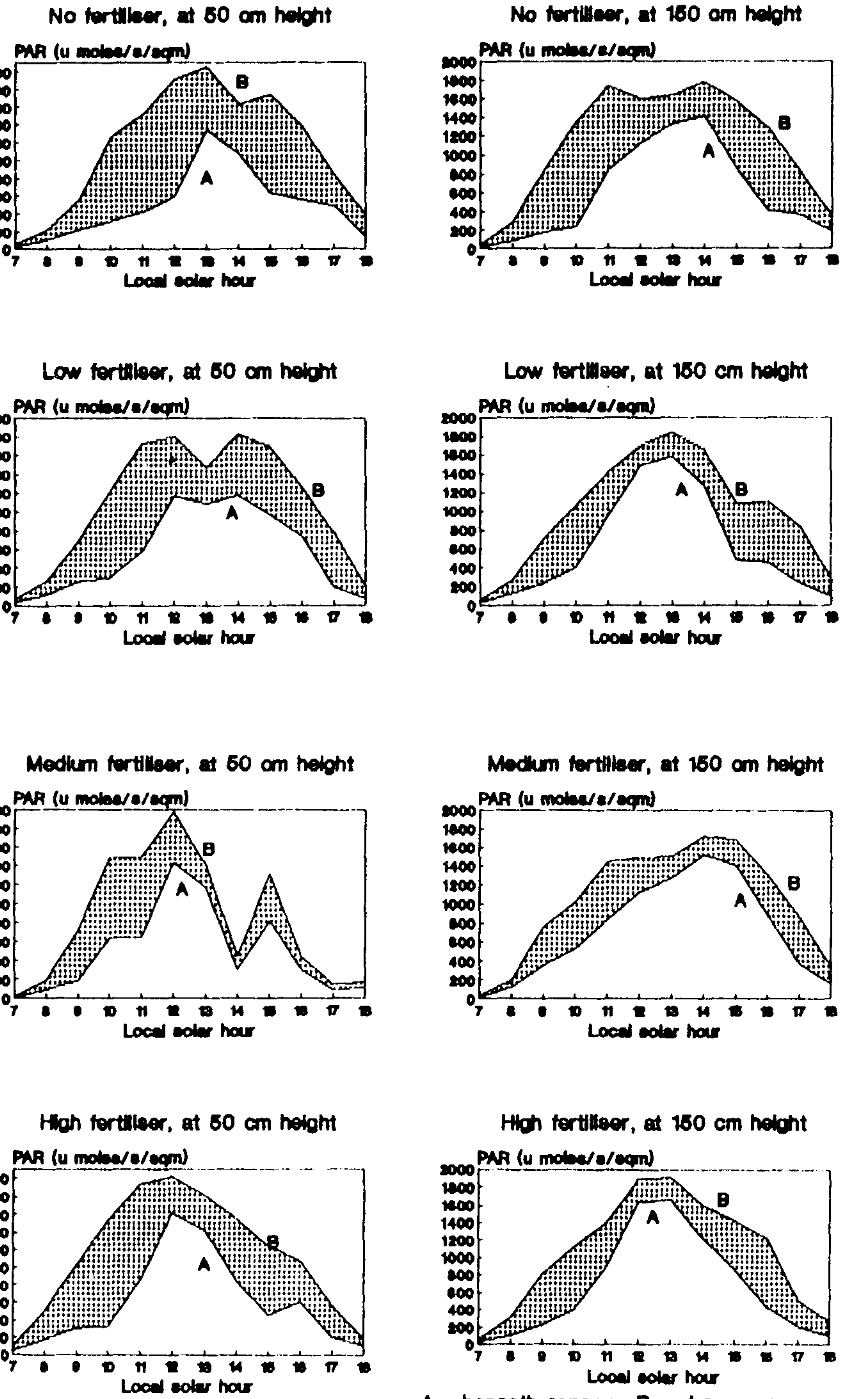


Fig. 6 Relative proportion of PAR intercepted by ailanthus canopy (shaded region) as affected by fertiliser regimes & height above ground level at 1600 TPHA



A - beneath canopy ; B - above canopy

Table 17 Two-way tables showing combined effects of tree population density and fertiliser levels on soil chemical properties before the ginger experiment

N (%)

	3333	2500	1600	1111
0 : 0 : 0	0.083	0.153	0.150	0.153
50 : 25 : 25	0.097	0.157	0.133	0.133
100 : 50 : 50	0.120	0.157	0.087	0.150
150 : 75 : 75	0.127	0.137	0.153	0.150

CD for fertiliser levels within density → 0.02
CD for densities at each fertiliser level → 0.02
Ginger monoculture → 0.15

P (ppm)

	3333	2500	1600	1111
0 : 0 : 0	12.27	8.27**	17.43**	18.43**
50 : 25 : 25	8.07**	11.97	9.90**	11.50
100 : 50 : 50	8.87**	10.90*	8.13**	7.40**
150 : 75 : 75	12.27	10.27*	12.43	8.07**

CD for fertiliser levels within density → 3.42
CD for densities at each fertiliser level → 3.67
Ginger monoculture → 13.43

K (ppm)

	3333	2500	1600	1111
0 : 0 : 0	48.33**	41.67**	57.50**	29.17**
50 : 25 : 25	120.83**	133.33**	85.83**	33.33**
100 : 50 : 50	41.67**	116.67**	53.33**	104.17**
150 : 75 : 75	34.17**	50.00**	109.17**	116.67**

CD for fertiliser levels within density → 3.97
CD for densities at each fertiliser level → 3.66
Ginger monoculture → 79.17

OC (%)

	3333	2500	1600	1111
0 : 0 : 0	1.10**	1.04**	1.36**	1.60**
50 : 25 : 25	1.31**	2.15**	2.05**	1.85**
100 : 50 : 50	1.92**	2.41**	0.64**	2.45**
150 : 75 : 75	1.75**	1.24**	1.87**	2.64

CD for fertiliser levels within density → 0.51
CD for densities at each fertiliser level → 0.48
Ginger monoculture → 2.82

Contd.....

Table 17 contd....

	OM (%)				C:N ratio				Soil pH			
	3333	2500	1600	1111	3333	2500	1600	1111	3333	2500	1600	1111
0 : 0 : 0	1.88**	1.79**	2.33**	2.75**	13.33**	6.67**	9.00**	10.33**	5.63**	5.79**	5.77**	5.78**
50 : 25 : 25	2.25**	3.68**	3.52**	3.16**	14.00**	13.33**	15.67**	13.67**	5.91	5.75**	5.95**	5.84**
100 : 50 : 50	3.31**	4.13**	1.09**	4.21**	14.67**	15.33**	7.00**	16.67**	5.80**	5.74**	5.87**	5.95**
150 : 75 : 75	3.00**	2.13**	3.21**	4.54**	13.33**	9.33**	12.00**	17.67	5.75**	5.76**	5.89	5.80**

	OM (%)	C:N ratio	Soil pH
CD for fertiliser levels within density	→ 0.88	→ 2.67	→ 0.02
CD for densities at each fertiliser level	→ 0.83	→ 2.79	→ 0.02
Ginger monoculture	→ 4.84	→ 18.33	→ 5.90

* Paired 't' values comparing treatment with ginger monoculture, significant at 5% level
** Paired 't' values comparing treatment with ginger monoculture, significant at 1% level

Table 18 Two-way tables showing combined effects of tree population density and fertiliser levels on soil chemical properties after the ginger experiment

	P (ppm)				K (ppm)				OC (%)			
	3333	2500	1600	1111	3333	2500	1600	1111	3333	2500	1600	1111
0 : 0 : 0	11.00	9.63	10.60	10.57	90.00**	98.33**	61.67**	65.00**	1.83**	1.59**	1.49**	1.79**
50 : 25 : 25	10.27	9.80	8.50**	11.07	76.67**	126.67**	110.83	116.67**	1.33**	2.38*	2.22**	3.17**
100 : 50 : 50	9.77	8.67**	10.13	9.90	116.67**	90.00**	90.00**	91.67**	2.18**	2.48	1.18**	1.83**
150 : 75 : 75	13.50**	5.60**	11.60*	13.37*	151.67**	65.83**	93.33**	98.33**	2.09**	1.75**	2.10**	2.60

	P (ppm)	K (ppm)	OC (%)
CD for fertiliser levels within density	→ 2.29	→ 6.93	→ 0.44
CD for densities at each fertiliser level	→ 2.47	→ 8.93	→ 0.41
Ginger monoculture	→ 10.53	→ 110.0	→ 2.61

	OM (%)				C:N ratio				Soil pH			
0 : 0 : 0	3.14**	2.73**	2.55**	3.07**	12.33**	10.67**	9.67**	11.33**	6.09	5.98	6.00	5.94
50 : 25 : 25	2.29**	4.08*	3.81**	5.44**	9.33**	15.00**	15.67	21.333**	6.04	5.96	6.16*	6.03
100 : 50 : 50	3.75**	4.26	2.02**	3.15**	15.33*	17.33	9.00**	12.00**	5.97	6.01	5.85*	5.95
150 : 75 : 75	3.58**	3.00**	3.60**	4.46	15.33*	12.33**	14.00**	17.33	6.01	6.06	5.99	5.95

	OM (%)	C:N ratio	Soil pH
CD for fertiliser levels within density	→ 0.75	→ 2.57	→ 0.02
CD for densities at each fertiliser level	→ 0.71	→ 2.39	→ 0.02
Ginger monoculture	→ 4.48	→ 16.66	→ 6.04

* Paired 't' values comparing treatment with ginger monoculture, significant at 5% level
** Paired 't' values comparing treatment with ginger monoculture, significant at 1% level

Table 19 Relative proportion of photosynthetically active radiation (PAR) available below *Ailanthus* canopy as affected by tree population density and fertiliser regimes

Treatments	Relative illumination below canopy (%)	
	(above ground level) 50 cm	150 cm
A. Density (Trees ha^{-1})		
3333	35	40
2500	54	52
1600	49	54
1111	72	75
B. Fertiliser levels ($N:P_2O_5:K_2O$ kg ha^{-1} yr^{-1})		
Control	48	50
50:25:25	58	61
100:50:50	51	56
150:75:75	54	54

(1111 TPHA) to 65% (3333 TPHA). Mean relative proportion of PAR (%) available at the various densities and fertiliser regimes increased in the order 1111 > 2500 > 1600 > 3333 TPHA at 50 cm height and 1111 > 1600 > 2500 > 3333 TPHA at 150 cm height (Table 19). Fertiliser levels did not exhibit any consistent effect on light extinction by the tree canopy although in the 2500 TPHA, the medium and low doses of chemical fertilisers resulted in a relatively lower rate of extinction (Fig 5).

4.5 Growth, yield and tissue nutrient concentration of ginger as affected by tree population density and fertiliser regimes

4.5.1 Growth characteristics

Tree population density influenced the mean tiller height, at 116 and 211 days after planting (DAP). Maximum tiller height, was recorded in the treatments having 1600 and 3333 TPHA, at 116 and 211 DAP respectively (Tables 20, 21 and 23; Appendices VII, VIII and IX). Fertiliser levels exerted a marked influence on mean tiller height only at 116 DAP. The highest fertiliser level (150:75:75, N: P_2O_5 : K_2O Kg ha^{-1} yr^{-1}) registered the maximum value in this respect. This, however, was statistically at par with that of the low fertiliser (50:25:25) treatment. Mean tiller height of plants grown in the open was invariably lower than that of ginger grown in association with ailanthus trees.

Stand density was a strong determinant of the number of tillers per clump, at 55 and 116 DAP (Tables 20 and 21; Appendices VII and VIII). At 55 DAP, 2500 TPHA recorded the highest tiller number. The stand with 1600 TPHA, however recorded, maximum number of tillers at 116 DAP. Fertiliser levels exerted a marked influence on the tiller number only at 211 DAP. Application of chemical fertilisers to the tree component however, decreased tiller number at this stage. Open grown ginger consistently had lower tiller number as compared to ginger grown in the interspaces of ailanthus both at 55 and 116 DAP. However, at 211 DAP, 3333 TPHA recorded maximum tiller number, followed by open grown ginger.

Tree population density had a profound effect on the number of leaves per clump (Tables 20, 21 and 23; Appendices VII, VIII and IX). Intermediate density (2500 TPHA) recorded the maximum number of leaves at 55 and 116 DAP. At 211 DAP, 3333 TPHA recorded the highest number of leaves per clump. Fertiliser levels were significant only at 211 DAP. Nonetheless the treatment without fertiliser recorded the highest value in this regard. Ginger intercropped with ailanthus registered higher leaf number, as compared to open grown ginger.

Leaf area per clump and ginger leaf area index (LAI) were highest, at the maximum and intermediate levels of tree population density, at 55 and 116 DAP respectively (Tables 20 and 21; Appendices VII and VIII). At 116 DAP, fertiliser levels played a major role in this regard. High dose of chemical fertilisers (150:75:75) recorded the highest leaf area and LAI. Comparison of the ginger leaf area/LAI in the open and under shade suggest that shade grown ginger was superior in this respect.

Stand density had a marked influence on the mean length of roots. Tree population densities of 3333 and 1600 TPHA recorded greater root length at 55 and 116 DAP (Tables 20 and 21; Appendices VII and VIII). At 211 DAP (Table 23; Appendix IX), however, treatments with 2500 and 1111 TPHA registered higher values. Fertiliser levels also influenced root length at 116 DAP. The highest dose of chemical fertilisers registered the highest value in this respect, despite being statistically at par with 50:25:25 ($N:P_2O_5:K_2O$ kg ha^{-1} yr^{-1}). Shade and open grown ginger were statistically at par with respect to root length at 55 and 211 DAP (Tables 20 and 23; Appendices VII and IX). At 116 DAP, however, the treatments with 3333 and 1600 TPHA was superior to that of open grown ginger.

Interaction effects (density x fertiliser) with respect to, tiller height, number of tillers per clump (116 and 211 DAP), leaf area and LAI (116 DAP) and number tree population density, at 55 and 116 DAP respectively (Tables 20 and 21; Appendices VII and VIII). At 116 DAP, fertiliser levels played a major role in this regard. High dose of chemical fertilisers (150:75:75) recorded the highest leaf area and LAI. Comparison of the ginger leaf area/LAI in the open and under shade suggest that shade grown ginger was superior in this respect.

Stand density had a marked influence on the mean length of roots. Tree population densities of 3333 and 1600 TPHA recorded greater root length at 55 and 116 DAP (Tables 20 and 21; Appendices VII and VIII). At 211 DAP (Table 23; Appendix IX), however, treatments with 2500 and 1111 TPHA registered higher values. Fertiliser levels also influenced root length at 116 DAP. The highest dose of chemical fertilisers registered the highest value in this respect, despite being statistically at par with 50:25:25 ($N:P_2O_5:K_2O$ kg ha^{-1} yr^{-1}). Shade and open grown ginger were statistically at par with respect to root length at 55 and 211 DAP (Tables 20 and 23; Appendices VII and IX). At 116 DAP, however, the treatments with 3333 and 1600 TPHA was superior to that of open grown ginger.

Interaction effects (density x fertiliser) with respect to, tiller height, number of tillers per clump (116 and 211 DAP), leaf area and LAI (116 DAP) and number

Table 20 Biometric observations on ginger as an understorey crop in a three year old *Ailanthus* stand at 55 days after planting

Treatments	Mean tiller height (cm)	Mean root length (cm)	Number of leaves/clump	Number tillers/clump	Leaf area/clump (cm^2)	Leaf area index
Density (trees ha^{-1})						
3333	35.16*	22.38	9.25**	1.38	206.10**	0.329**
2500	33.36	21.66	9.53**	1.45*	157.92	0.246
1600	34.96*	23.01	8.44**	1.27	185.89**	0.294*
1111	30.32	19.23	8.46**	1.39	161.38	0.257
F test	NS	<0.01	<0.01	<0.05	<0.01	<0.01
SEM (±)	1.110	0.372	0.158	0.035	6.581	0.012
CD (0.05)	-	1.28	0.54	0.12	22.77	0.041
Fertiliser levels ($N:P_2O_5:K_2O$ kg ha^{-1} yr^{-1})						
0:0:0	32.01	20.80	8.81	1.37	169.15	0.265
50:25:25	34.46	22.31	9.05	1.37	189.08	0.302
100:50:50	32.85	20.98	8.94	1.39	178.23	0.284
150:75:75	34.50	22.19	8.87	1.36	174.81	0.274
F test	NS	NS	NS	NS	NS	NS
SEM (±)	1.039	0.601	0.335	0.041	9.455	0.015
Density x fertiliser interaction						
F test	NS	NS	NS	NS	NS	NS
SEM (±)	2.079	1.201	0.670	0.083	18.909	0.031
Ginger monoculture	29.57	20.82	7.15	1.21	136.49	0.218

* Paired 't' values comparing treatment with ginger monoculture, significant at 5% level
** Paired 't' values comparing treatment with ginger monoculture, significant at 1% level

Table 21 Biometric observations on ginger as an understorey crop in a three year old Ailanthus stand at 116 days after planting

Treatments	Mean tiller height (cm)	Mean root length (cm)	Number of leaves/clump	Number tillers/clump	Leaf area/clump (cm^2)	Leaf area index
Density (trees ha^{-1})						
3333	53.70	26.05*	69.11	6.71	1286.92	1.96
2500	55.54	23.95	84.97**	7.57*	1793.13**	2.73**
1600	59.12	26.09*	84.68**	7.62*	1624.82**	2.53**
1111	49.61	23.23	62.02	6.24	890.03	1.38
F test	<0.01	<0.01	<0.01	<0.05	<0.01	<0.01
SEM (±)	0.881	0.457	2.954	0.217	94.847	0.163
CD (0.05)	3.05	1.57	10.23	0.76	328.22	0.57
Fertiliser levels ($N:P_2O_5:K_2O$ kg ha^{-1} yr^{-1})						
0:0:0	51.91	23.43	72.89	6.86	1107.19	1.69
50:25:25	56.35	25.24	75.13	7.01	1410.75*	2.17*
100:50:50	52.69	23.87	72.87	6.86	1404.84*	2.12*
150:75:75	57.03	26.79*	79.89	7.40	1672.12**	2.61**
F test	<0.01	<0.05	NS	NS	<0.01	<0.01
SEM (±)	1.040	0.757	3.002	0.249	90.782	0.146
CD (0.05)	3.04	2.21	-	-	264.99	0.42
Density x fertiliser interaction						
F test	<0.05	NS	NS	<0.05	<0.01	<0.05
SEM (±)	2.08	1.514	6.004	0.499	181.564	0.292
Ginger monoculture	42.25	22.98	52.64	6.25	941.92	1.38

* Paired 't' values comparing treatment with ginger monoculture, significant at 5% level
** Paired 't' values comparing treatment with ginger monoculture, significant at 1% level

Table 22 Two-way tables showing combined effects of tree population density and fertiliser levels on biometric characters of ginger at 116 days after planting

Tiller height (cm)

	3333	2500	1600	1111
0 : 0 : 0	45.13	57.25	57.99	47.26
50 : 25 : 25	56.16	56.19	60.56	52.47
100 : 50 : 50	54.45	53.80	57.48	45.04
150 : 75 : 75	59.06	54.92	60.46	53.68

CD for fertiliser levels within density → 6.06
CD for densities at each fertiliser level → 6.07
Ginger monoculture → 42.25

Number of tillers/clump

	3333	2500	1600	1111
0 : 0 : 0	5.47*	8.40**	7.55**	6.03
50 : 25 : 25	6.78	7.09**	7.13**	7.04**
100 : 50 : 50	7.74**	7.01*	7.50**	5.20**
150 : 75 : 75	6.84*	7.80**	8.28**	6.69

CD for fertiliser levels within density → 1.46
CD for densities at each fertiliser level → 1.46
Ginger monoculture → 6.25

Leaf area (cm^2)

	3333	2500	1600	1111
0 : 0 : 0	548.54**	1524.62**	1446.51**	909.08
50 : 25 : 25	1516.00**	2016.45**	1200.02*	910.51
100 : 50 : 50	1733.98**	1636.55**	1595.38**	653.46**
150 : 75 : 75	1349.15**	1994.90**	2257.35**	1087.08**

CD for fertiliser levels within density → 529.97
CD for densities at each fertiliser level → 563.53
Ginger monoculture → 941.92

Leaf area index

	3333	2500	1600	1111
0 : 0 : 0	0.827**	2.323**	2.213**	1.417
50 : 25 : 25	2.390**	3.027**	1.800*	1.460
100 : 50 : 50	2.493**	2.513**	2.553**	0.933**
150 : 75 : 75	2.133**	3.067**	3.540**	1.707*

CD for fertiliser levels within density → 0.84
CD for densities at each fertiliser level → 0.93
Ginger monoculture → 1.38

* Paired 't' values comparing treatment with ginger monoculture, significant at 5% level
** Paired 't' values comparing treatment with ginger monoculture, significant at 1% level

Table 23 Biometric observation on ginger as an understorey crop in a three year old *Ailanthus* stand at 211 days after planting

Treatments	Mean tiller height (cm)	Number of tillers/clump	Number of leaves/clump	Root length (cm)
Density (trees ha^{-1})				
3333	52.86**	4.71	47.60**	16.12
2500	47.26**	3.72	35.63**	17.74
1600	46.62**	4.19	38.07**	16.18
1111	44.01**	4.42	34.41*	17.82
F test	<0.05	NS	<0.05	<0.05
SEM (±)	1.687	0.210	2.067	0.362
CD (0.05)	5.83	-	7.15	1.25
Fertiliser levels ($N:P_2O_5:K_2O$ kg ha^{-1} yr^{-1})				
0:0:0	48.98	4.64	45.22**	15.93
50:25:25	49.19	3.68	34.55*	16.43
100:50:50	45.54	4.67	40.92**	17.53
150:75:75	47.04	4.04	35.03**	17.96
F test	NS	<0.01	<0.05	NS
SEM (±)	1.600	0.203	2.619	0.56
CD (0.05)	-	0.59	7.65	-
Density x fertiliser interaction				
F test	<0.05	<0.01	<0.05	NS
SEM (±)	3.200	0.406	5.239	1.128
Ginger monoculture	28.06	4.60	20.03	16.00

* Paired 't' values comparing treatment with ginger monoculture, significant at 5% level
** Paired 't' values comparing treatment with ginger monoculture, significant at 1% level

Table 24 Two-way tables showing combined effects of tree population density and fertiliser levels on biometric characters of ginger at 211 days after planting

	Mean tiller height (cm)				Number of leaves/clump				Number of tiller/clump			
	3333	2500	1600	1111	3333	2500	1600	1111	3333	2500	1600	1111
0 : 0 : 0	48.06**	54.77**	51.70**	41.39**	39.96**	57.56**	40.39**	42.96**	4.50	5.09	3.54	5.43
50 : 25 : 25	58.72**	43.51**	45.22**	49.32**	52.29**	29.74**	30.35**	30.81**	4.28	3.08	3.70	3.66
100 : 50 : 50	46.33**	45.89**	44.37**	45.12**	49.93**	33.38**	49.11**	31.24**	5.76	3.54	5.75	3.64
150 : 75 : 75	57.82**	44.89**	45.21**	40.24**	48.24**	26.85*	32.43**	32.61**	4.30	3.17	3.75	4.94

	Mean tiller height (cm)	Number of leaves/clump	Number of tiller/clump
CD for fertiliser levels within density	→ 9.34	→ 15.28	→ 1.18
CD for densities at each fertiliser level	→ 9.95	→ 15.02	→ 1.25
Ginger monoculture	→ 28.06	→ 20.03	→ 4.60

* Paired 't' values comparing treatment with ginger monoculture, significant at 5% level
** Paired 't' values comparing treatment with ginger monoculture, significant at 1% level

of leaves per clump (211 DAP), were significant (Tables 22 and 24; Appendices VIII and IX). Increasing levels of chemical fertilisers, in general increased tiller height, tiller number, leaf area and leaf area index at 116 DAP. No clear trend was however, discernible at 211 DAP.

4.5.2 Biomass

4.5.2.1 Above ground

Total above ground biomass yield as well as the various biomass fractions (culm and leaf), were significantly influenced by tree population density at 55 and 116 DAP (Tables 25, 27 and 29; Appendices VII, VIII and XII). In general, higher tree population densities (1600 to 3333 TPHA), recorded higher above ground (fresh and dry) weights. At 211 DAP, 3333 TPHA, registered the highest total above ground biomass yield (Table 25; Appendix XII) and culm and leaf weights (Table 31; Appendix IX) and was significantly superior to the open grown ginger crop. Fertiliser levels were significant with respect to leaf (fresh and dry) weight at 116 DAP and culm and total above ground fresh weight at 211 DAP (Tables 25, 29 and 31; Appendices VIII, IX and XII). High rates of chemical fertilisers (150:75:75) and control (0:0:0) plots recorded the highest values at 116 and 211 DAP respectively.

4.5.2.2 Below ground

Stand density was a cardinal determinant of the total below ground biomass at 55, 116 and 211 DAP (Tables 25 and 27; Appendices VII and XII). The treatment with 2500 TPHA recorded the highest value (fresh and dry weights) at 55 and 116 DAP. At 211 DAP, 1111 TPHA recorded the highest total below ground biomass. This, however, was statistically at par with that of 2500 TPHA.

Tree population density did not affect root fresh and dry weights at 116 and 211 DAP, although residual rhizome (fresh and dry) weights were significantly influenced by stand density at 116 DAP (Table 29; Appendix VIII). Highest value in this regard was recorded in the treatment with 3333 TPHA.

Fertiliser levels affected total below ground biomass only at 55 DAP (Table 27; Appendix VII). The high dose of chemical fertilisers (150:75:75), recorded the highest value in this regard.

Tree population density affected rhizome (fresh and dry) weights at 116 DAP (Table 29; Appendix VIII) and dry weight of rhizome at 211 DAP (Table 31; Appendix IX). At 116 DAP, 2500 TPHA recorded the highest value. At 211 DAP however, 1111 TPHA topped in this regard but it was statistically at par with that of 2500 TPHA.

Table 25 Total above and below ground biomass of understorey ginger crop at 55, 116 and 211 days after planting as affected by tree population density and fertiliser levels (tonnes ha^{-1})

Treatments	Total above ground biomass						Total below ground biomass			
	Fresh weight			Dry weight			Fresh weight		Dry weight	
	55	116	211	55	116	211	116	211	116	211
Density (Trees ha^{-1})										
3333	2.70**	16.79	6.12**	0.22**	1.31	1.16*	14.24	24.43	1.48	5.21
2500	2.87**	21.57	3.68	0.23**	1.72**	0.99	17.04	29.82	1.78	6.34*
1600	2.61**	22.16	3.51	0.20**	1.84**	0.75	16.32	26.25	1.68	5.43
1111	2.22	15.49	3.93	0.17	1.33	0.86	13.97	30.97	1.47	6.85*
F test	<0.01	<0.01	<0.05	<0.01	<0.01	NS	<0.05	NS	NS	<0.05
SEM (±)	0.059	0.721	0.061	0.004	0.061	0.100	0.614	1.891	0.070	0.326
CD (0.05)	0.20	2.49	0.21	0.01	0.21	-	2.12	-	-	1.13
Fertiliser levels (N : P_2O_5 : K_2O kg $ha^{-1}yr^{-1}$)										
0 : 0 : 0	2.62	18.40	5.41**	0.20	1.51	1.10	15.16	27.16	1.58	5.97
50 : 25 : 25	2.58	18.68	3.43	0.21	1.52	0.77	15.12	27.39	1.62	5.83
100 : 50 : 50	2.52	18.01	4.63*	0.20	1.49	0.92	15.03	27.14	1.56	5.80
150 : 75 : 75	2.68	20.91	3.78	0.21	1.68	0.98	16.26	29.78	1.64	6.23
F test	NS	NS	<0.05	NS	NS	NS	NS	NS	NS	NS
SEM (±)	0.135	0.880	0.450	0.010	0.066	0.082	0.705	1.329	0.076	0.341
CD (0.05)	-	-	1.31	-	-	-	-	-	-	-
Density x fertiliser interaction										
F test	NS	<0.01	<0.01	<0.05	<0.01	<0.01	<0.05	NS	<0.05	NS
SEM (±)	0.270	1.76	0.900	0.020	0.132	0.164	1.409	2.657	0.153	0.683
Ginger monoculture	2.10	13.41	1.46	0.16	1.18	0.41	15.27	22.65	1.56	4.69

* Paired 't' values comparing treatment with ginger monoculture, significant at 5% level
** Paired 't' values comparing treatment with ginger monoculture, significant at 1% level

Table 26 Two-way tables showing combined effects of tree population density and fertiliser levels on total biomass yield of ginger at 55, 116 and 211 days after planting

Total above ground biomass (tonnes ha^{-1})

Fresh weight

116 DAP

	3333	2500	1600	1111
0 : 0 : 0	11.18	24.71*	22.82	14.90
50 : 25 : 25	17.67	19.09	19.71	18.27
100 : 50 : 50	19.75	20.02	22.27	10.01
150 : 75 : 75	18.56	22.45	23.83*	18.79

CD for fertiliser levels within density → 5.14
CD for densities at each fertiliser level → 5.08
Ginger monoculture → 13.41

211 DAP

	3333	2500	1600	1111
0 : 0 : 0	5.36**	7.23**	3.13	5.91**
50 : 25 : 25	7.51**	2.08	2.01	2.10
100 : 50 : 50	6.40**	2.31	6.06**	3.75
150 : 75 : 75	5.21**	3.10	2.85	3.96

CD for fertiliser levels within density → 2.63
CD for densities at each fertiliser level → 2.94
Ginger monoculture → 1.46

Dry weight

55 DAP

0 : 0 : 0	0.20*	0.25**	0.20*	0.17
50 : 25 : 25	0.26**	0.17	0.22**	0.19
100 : 50 : 50	0.21*	0.25**	0.20*	0.14
150 : 75 : 75	0.21*	0.25**	0.19	0.20*

CD for fertiliser levels within density → 0.05
CD for densities at each fertiliser level → 0.05
Ginger monoculture → 0.16

116 DAP

0 : 0 : 0	0.96	1.93**	1.88**	1.26
50 : 25 : 25	1.31	1.56	1.64*	1.59*
100 : 50 : 50	1.56	1.65*	1.86**	0.87
150 : 75 : 75	1.42	1.73**	1.97**	1.61*

CD for fertiliser levels within density → 0.38
CD for densities at each fertiliser level → 0.39
Ginger monoculture → 1.18

211 DAP

0 : 0 : 0	0.94*	1.75**	0.75	0.98*
50 : 25 : 25	1.33**	1.62**	0.36	0.76
100 : 50 : 50	1.09*	0.73	1.16**	0.69
150 : 75 : 75	1.30**	0.85	0.75	1.03*

CD for fertiliser levels within density → 0.48
CD for densities at each fertiliser level → 0.54
Ginger monoculture → 0.41

Contd.....

Table 26 contd. ...

Total below ground biomass (tonnes ha^{-1})

116 DAP (Fresh weight)

	3333	2500	1600	1111
0 : 0 : 0	10.33*	18.90	17.21	14.19
50 : 25 : 25	15.86	13.83	14.96	15.83
100 : 50 : 50	15.98	17.84	16.31	9.99
150 : 75 : 75	14.79	17.59	16.79	15.86

CD for fertiliser levels within density → 4.11
CD for densities at each fertiliser level → 4.13
Ginger monoculture → 15.27

116 DAP (Dry weight)

	3333	2500	1600	1111
0 : 0 : 0	1.09*	1.96	1.77	1.53
50 : 25 : 25	1.60	1.56	1.64	1.67
100 : 50 : 50	1.70	1.89	1.61	1.05
150 : 75 : 75	1.54	1.71	1.70	1.63

CD for fertiliser levels within density → 0.44
CD for densities at each fertiliser level → 0.46
Ginger monoculture → 1.56

* Paired 't' values comparing treatment with ginger monoculture, significant at 5% level
** Paired 't' values comparing treatment with ginger monoculture, significant at 1% level

Table 27 Biomass yield of understorey ginger crop in a three year old *Ailanthus* stand at 55 days after planting

Treatments	Fresh weight (kg ha^{-1})			Dry weight (kg ha^{-1})		
	Culm	Leaf blade	Below ground	Culm	Leaf blade	Below ground
Density (trees ha^{-1})						
3333	1835.77**	864.93**	3574.93	114.59**	104.85**	334.74
2500	1954.93**	912.43**	5673.27**	116.49**	110.35**	534.65**
1600	1784.61*	826.28**	4682.11**	106.47**	101.65**	442.61**
1111	1503.27	714.93	4257.43*	88.12	87.62	395.05*
F test	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
SEM (±)	56.357	18.176	189.333	2.772	2.241	18.479
CD (0.05)	195.03	62.91	655.20	9.60	7.76	63.95
Fertiliser levels ($N:P_2O_5:K_2O$ kg ha^{-1} yr^{-1})						
0:0:0	1809.93	810.77	4574.10**	106.64	91.26	462.73**
50:25:25	1722.11	858.78	4612.11**	107.22	105.07	432.72**
100:50:50	1733.01	784.68	3918.01	102.31	96.20	363.88
150:75:75	1813.52	864.36	5083.52**	107.51	103.93	483.71**
F test	NS	NS	<0.01	NS	NS	<0.01
SEM (±)	100.145	45.590	216.291	5.513	5.487	21.544
CD (0.05)	-	-	631.33	-	-	62.88
Density x fertiliser interaction						
F test	NS	NS	<0.01	NS	NS	<0.01
SEM (±)	200.29	91.179	432.583	11.027	10.973	43.088
Ginger monoculture	1438.78	662.1	3568.78	83.9	81.45	330.80

* Paired 't' values comparing treatment with ginger monoculture, significant at 5% level
** Paired 't' values comparing treatment with ginger monoculture, significant at 1% level

Table 28 Two-way tables showing combined effects of tree population density and fertiliser levels on biomass yield of ginger at 55 days after planting

	Fresh weight below ground (kg ha^{-1})				Dry weight below ground (kg ha^{-1})			
	3333	2500	1600	1111	3333	2500	1600	1111
0 : 0 : 0	3967.75	6414.42**	3612.11	4572.11*	343.49	603.31**	337.23	422.89*
50 : 25 : 25	3112.11	4815.45*	6675.45**	3845.45	285.79	444.15*	642.93**	357.99
100 : 50 : 50	3261.09	5301.09**	3545.45	3564.42	296.51	493.53**	334.02	331.48
150 : 75 : 75	4228.78	6162.11**	4895.45*	5047.75*	413.18	597.61**	456.26**	467.78**
CD for fertiliser levels within density	→ 1262.68				→ 125.77			
CD for densities at each fertiliser level	→ 1270.35				→ 126.02			
Ginger monoculture	→ 3568.78				→ 330.80			

* Paired 't' values comparing treatment with ginger monoculture, significant at 5% level
** Paired 't' values comparing treatment with ginger monoculture, significant at 1% level

Table 29 Biomass yield of understorey ginger crop in a three year old *Ailanthus* stand at 116 days after planting

	Fresh weight (kg ha^{-1})				
Treatments	**Leaf blade**	**Culm**	**Root**	**Rhizome**	**Residual rhizome**
Density (trees ha^{-1})					
3333	5349.41	11442.23	1908.90*	10639.73	1690.45
2500	6972.89**	14596.40**	1947.23*	13904.73	1186.28
1600	7153.76**	15004.73**	2367.23	12867.23	1082.12
1111	4625.28	10867.23	2150.57	10642.23	1173.78
F test	<0.01	<0.01	NS	<0.01	<0.05
SEM (±)	358.655	506.902	162.270	437.011	116.702
CD (0.05)	1241.16	1754.17	-	1512.31	403.86
Fertiliser levels ($N:P_2O_5:K_2O$ kg ha^{-1} yr^{-1})					
0:0:0	5588.08	12816.00	1918.90	12024.73	1211.28
50:25:25	5888.62*	12796.40	2017.40	11663.07	1382.12
100:50:50	5817.67*	12197.23	1885.57*	12001.40	1143.78
150:75:75	6806.96**	14100.57	2498.07	12364.73	1395.45
F test	<0.05	NS	<0.05	NS	NS
SEM(±)	287.289	659.196	155.611	584.629	158.197
CD (0.05)	838.58	-	454.22	-	-
Density x fertiliser interaction					
F test	<0.05	<0.01	NS	<0.05	NS
SEM(±)	574.578	1318.392	311.221	1169.258	316.394
Ginger monoculture	4314.6	9092.2	2592.2	11458.9	1223.78

Contd.....

Table 29 contd.......

	Dry weight (kg ha^{-1})				
Treatments	Leaf blade	Culm	Root	Rhizome	Residual rhizome
Density (trees ha^{-1})					
3333	672.28	641.34	94.88	1213.04	187.41*
2500	859.14	858.70**	106.00	1546.61	125.30
1600	935.16*	820.79*	212.64	1422.36	110.58
1111	704.27	627.90	125.77	1212.78	132.93
F test	<0.01	<0.05	NS	<0.05	<0.05
SEM (±)	37.794	40.310	28.356	56.044	10.965
CD (0.05)	130.78	139.49	-	193.95	37.95
Fertiliser levels ($N:P_2O_5:K_2O$ kg ha^{-1} yr^{-1})					
0:0:0	752.49	671.07	111.51	1342.51	131.87
50:25:25	772.55	752.04	122.10	1356.32	150.83
100:50:50	760.10	727.41	173.04	1340.45	116.14
150:75:75	885.71	798.21	132.64	1355.52	157.38
F test	<0.05	NS	NS	NS	NS
SEM(±)	35.339	46.837	31.493	71.265	17.708
CD (0.05)	103.15	-	-	-	-
Density x fertiliser interaction					
F test	NS	<0.01	NS	<0.05	NS
SEM(±)	70.677	93.675	62.986	142.530	35.417
Ginger monoculture	670.63	508.78	154.49	1277.30	132.00

* Paired 't' values comparing treatment with ginger monoculture, significant at 5% level
** Paired 't' values comparing treatment with ginger monoculture, significant at 1% level

Table 30 Two-way tables showing combined effects of tree population density and fertiliser levels on biomass yield of ginger at 116 days after planting

Leaf fresh weight (kg ha^{-1})

	3333	2500	1600	1111
0 : 0 : 0	3605.50*	7056.97**	7511.77**	4178.10
50 : 25 : 25	5347.60**	7409.00**	5702.70**	5095.20*
100 : 50 : 50	6257.00**	6097.33**	7649.57**	3266.80**
150 : 75 : 75	6187.52**	7328.27**	7751.00**	5961.03**

CD for fertiliser levels within density → 1677.12
CD for densities at each fertiliser level → 1899.72
Ginger monoculture → 4314.60

Culm fresh weight (kg ha^{-1})

	3333	2500	1600	1111
0 : 0 : 0	7575.57	17655.57**	15308.90**	10725.57*
50 : 25 : 25	12325.57**	11675.57**	14008.90**	13175.57**
100 : 50 : 50	13492.23**	13928.90**	14625.57**	6742.23**
150 : 75 : 75	12375.57**	15125.57**	16075.57**	12825.57**

CD for fertiliser levels within density → 3848.23
CD for densities at each fertiliser level → 3763.01
Ginger monoculture → 9092.20

Rhizome fresh weight (kg ha^{-1})

0 : 0 : 0	7675.57**	15255.57**	13908.90**	11258.90
50 : 25 : 25	11908.90	11575.57	11242.23	11925.57
100 : 50 : 50	12165.57	14738.90**	13375.57*	7725.57**
150 : 75 : 75	10808.90	14048.90**	12942.23	11658.90

CD for fertiliser levels within density → 3412.92
CD for densities at each fertiliser level → 3306.59
Ginger monoculture → 11458.90

Culm dry weight (kg ha^{-1})

0 : 0 : 0	440.10	1033.23**	598.21	621.37*
50 : 25 : 25	673.68**	736.12**	819.95**	778.40**
100 : 50 : 50	795.19**	810.50**	934.96**	368.98*
150 : 75 : 75	656.40*	854.93**	936.06**	742.47**

CD for fertiliser levels within density → 273.42
CD for densities at each fertiliser level → 274.15
Ginger monoculture → 508.78

Contd....

Table 30 contd.....

Rhizome dry weight (kg ha^{-1})

	3333	2500	1600	1111
0 : 0 : 0	865.87**	1684.60**	1503.77*	1315.80
50 : 25 : 25	1336.30	1375.48	1338.75	1374.73
100 : 50 : 50	1421.90	1660.00**	1412.55	867.33**
150 : 75 : 75	1228.10	1466.37*	1434.37	1293.23

CD for fertiliser levels within density → 416.03

CD for densities at each fertiliser level → 408.35

Ginger monoculture → 1277.30

* Paired 't' values comparing treatment with ginger monoculture, significant at 5% level

** Paired 't' values comparing treatment with ginger monoculture, significant at 1% level

Table 31 Biomass yield of understorey ginger crop in a three year old *Ailanthus* stand at 211 days after planting

	Fresh weight (kg ha^{-1})			
Treatments	Culm	Leaf blade	Root	Rhizome
Density (trees ha^{-1})				
3333	4031.97**	2090.30**	1219.47	23215.30
2500	2390.30	1290.30*	1419.47	28402.80
1600	2473.63	1040.30	1394.47	24861.13
1111	2756.97*	1173.63*	1661.13	29306.97*
F test	<0.05	<0.05	NS	NS
SEM (±)	332.849	210.520	179.009	1758.683
CD (0.05)	1151.85	728.52	-	-
Fertiliser levels ($N:P_2O_5:K_2O$ kg ha^{-1} yr^{-1})				
0:0:0	3727.80**	1681.97	1219.47	25944.47
50:25:25	2206.97	1219.47	1369.47	26019.47
100:50:50	3156.97**	1473.63	1440.30	25702.80
150:75:75	2561.13*	1219.47	1665.30	28119.47
F test	<0.05	NS	NS	NS
SEM(±)	311.972	167.645	148.322	1239.059
CD (0.05)	910.62	-	-	-
Density x fertiliser interaction				
F test	<0.01	<0.01	NS	NS
SEM(±)	623.944	335.289	296.644	2478.118
Ginger monoculture	998.60	465.30	1548.60	21098.63

Contd.....

Table 31 contd.......

Treatments	Dry weight ($kg\ ha^{-1}$)			
	Culm	Leaf blade	Root	Rhizome
Density (trees ha^{-1})				
3333	570.23**	593.04*	232.39	4980.78
2500	450.50*	537.59*	247.45	6099.36*
1600	391.31	364.80	314.99	5112.03
1111	378.91	487.37	302.83	6545.73**
F test	NS	NS	NS	<0.05
SEM (±)	54.471	52.995	36.983	302.675
CD (0.05)	-	-	-	1047.44
Fertiliser levels ($N:P_2O_5:K_2O$ $kg\ ha^{-1}\ yr^{-1}$)				
0:0:0	519.96	582.42**	235.48	5739.76
50:25:25	363.77	403.01	286.95	5542.26
100:50:50	427.30	492.55*	232.39	5567.32
150:75:75	479.92	504.81*	342.84	5888.56
F test	NS	<0.05	NS	NS
SEM(±)	51.047	41.622	41.421	332.137
CD (0.05)	-	121.49	-	-
Density x fertiliser interaction				
F test	<0.05	<0.01	NS	NS
SEM(±)	102.093	83.244	82.842	664.273
Ginger monoculture	146.86	260.00	271.46	4420.13

* Paired 't' values comparing treatment with ginger monoculture, significant at 5% level
** Paired 't' values comparing treatment with ginger monoculture, significant at 1% level

Table 32 Two-way tables showing combined effects of tree population density and fertiliser levels on biomass yield of ginger at 211 days after planting

Culm fresh weight (kg ha^{-1})

	3333	2500	1600	1111
0 : 0 : 0	3848.63**	4631.97**	1965.30*	4465.30**
50 : 25 : 25	4731.97**	1315.30	1515.30	1265.30
100 : 50 : 50	4148.63**	1565.30	4265.30**	2648.63**
150 : 75 : 75	3398.63**	2048.63**	2148.63**	2648.63**

CD for fertiliser levels within density → 1821.22
CD for densities at each fertiliser level → 1947.61
Ginger monoculture → 998.60

Leaf fresh weight (kg ha^{-1})

	3333	2500	1600	1111
0 : 0 : 0	1515.30**	2598.63**	1165.30**	1448.63**
50 : 25 : 25	2781.97**	765.30	498.63	831.97
100 : 50 : 50	2248.63**	748.63	1798.63**	1098.63**
150 : 75 : 75	1815.30**	1048.63**	698.63	1315.30**

CD for fertiliser levels within density → 978.67
CD for densities at each fertiliser level → 1110.80
Ginger monoculture → 465.30

Culm dry weight (kg ha^{-1})

	3333	2500	1600	1111
0 : 0 : 0	433.78**	810.49**	398.14**	437.43**
50 : 25 : 25	643.80**	307.65**	170.55	333.10**
100 : 50 : 50	502.30**	338.50**	594.27**	274.13*
150 : 75 : 75	901.05**	345.35**	402.30**	470.98**

CD for fertiliser levels within density → 297.99
CD for densities at each fertiliser level → 318.69
Ginger monoculture → 146.86

Leaf dry weight (kg ha^{-1})

	3333	2500	1600	1111
0 : 0 : 0	500.65**	935.42**	352.78	540.85**
50 : 25 : 25	684.03**	308.99	189.94	429.06**
100 : 50 : 50	588.98**	393.71*	568.36**	419.17**
150 : 75 : 75	598.52**	512.23**	348.12	560.39**

CD for fertiliser levels within density → 242.97
CD for densities at each fertiliser level → 278.38
Ginger monoculture → 260.00

* Paired 't' values comparing treatment with ginger monoculture, significant at 5% level
** Paired 't' values comparing treatment with ginger monoculture, significant at 1% level

Comparisons with open grown ginger, in terms of above and below ground biomass, suggest that the mixed cropping (ginger + ailanthus) system was superior.

Density x fertiliser interaction, was significant with respect to total above and below ground biomass (Table 25; Appendix XII), leaf and culm weights (116, 211 DAP) and fresh and dry weights of rhizome (116 DAP). There was however, no predictable relationships in this regard (Tables 30 and 32; Appendices VIII and IX).

4.5.3 Ginger yield and quality at final harvest (234 DAP)

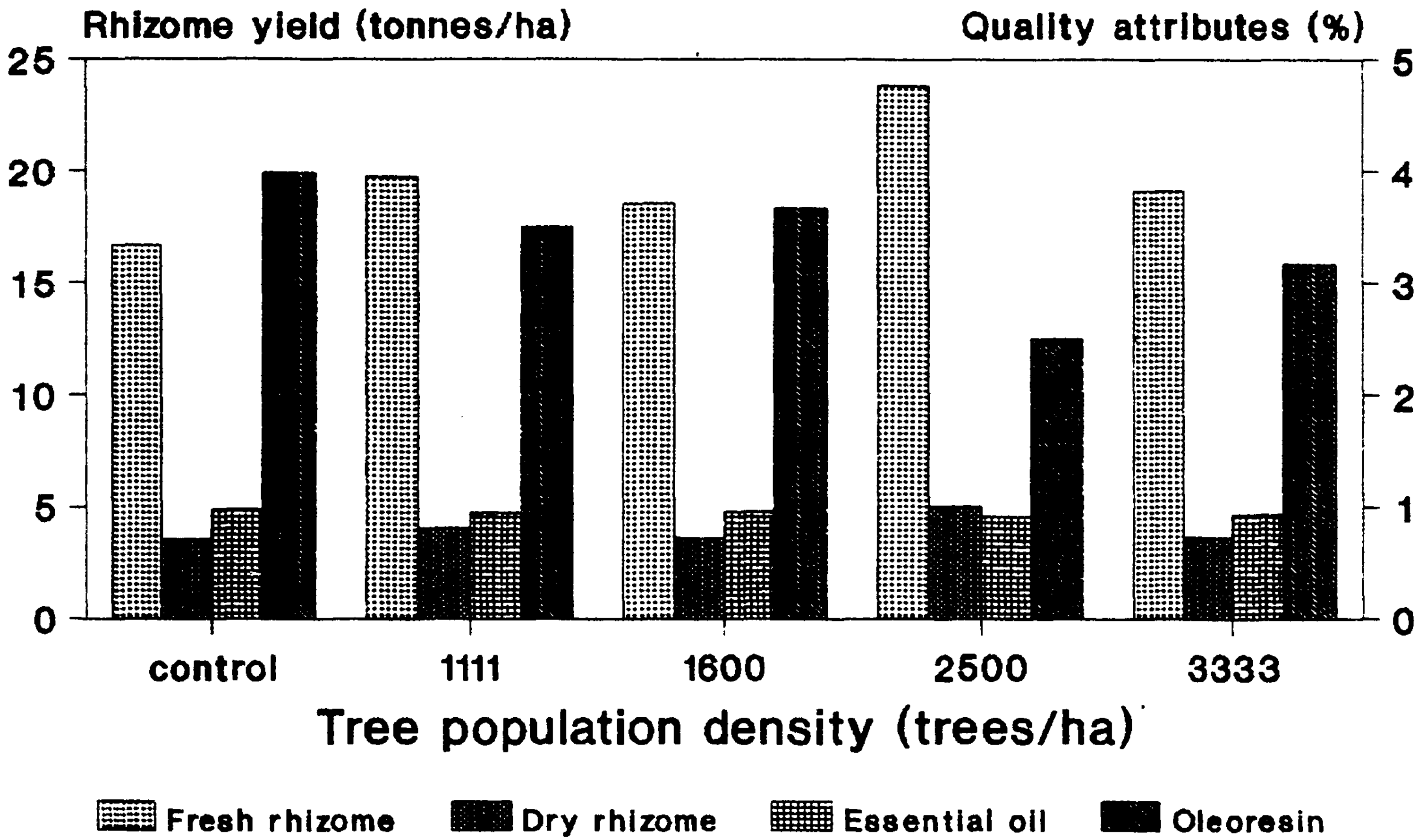
Ginger yield was maximum in the tree population density of 2500 TPHA (Table 33; Fig. 8; Appendix X). The differences, however, were significant only with respect to fresh weight of rhizomes. Nonetheless the 't' test for comparing mixed species versus monocultural situations yielded significant differences in respect of the dry rhizome yield. The 2500 TPHA registered a 42% increase in dry rhizome yield over the control (ginger monoculture). The lowest tree population density (1111 TPHA) recorded the second highest ginger yield. It was, however statistically at par with that of the tree population densities 3333 and 1600 TPHA as far as the fresh ginger yield was concerned.

Table 33 Yield and quality of understorey ginger crop in a three year old *Ailanthus* stand at 234 days after planting

Treatments	Yield (tonnes ha^{-1})		Quality attributes	
	Fresh rhizome	Dry rhizome	Essential oil (%)	Oleoresin (%)
Density (trees ha^{-1})				
3333	19.141	3.653	0.933	3.167
2500	23.816	5.025*	0.912*	2.500*
1600	18.549	3.589	0.958	3.667
1111	19.745	4.037	0.946	3.500
F test	<0.05	NS	NS	NS
SEM (±)	1.082	0.318	0.014	0.241
CD (0.05)	3.745	-	-	-
Fertiliser levels ($N:P_2O_5:K_2O$ kg ha^{-1} yr^{-1})				
0:0:0	20.478	3.913	0.912	3.500
50:25:25	20.612	4.391	0.954	3.333
100:50:50	20.303	4.099	0.929	2.667
150:75:75	19.857	3.900	0.954	3.333
F test	NS	NS	NS	NS
SEM (±)	0.768	0.173	0.014	0.255
Density x fertiliser interaction				
F test	NS	NS	NS	NS
SEM (±)	1.536	0.346	0.028	0.509
Ginger monoculture	16.66	3.54	0.983	3.98

* Paired 't' values comparing treatment with ginger monoculture, significant at 5% level
** Paired 't' values comparing treatment with ginger monoculture, significant at 1% level

Fig.8 Yield and quality attributes of ginger as affected by tree population density



As regards to fertilisers, application of chemical fertilisers to the tree component of the system did not bring about any marked effect on the understorey crop yield.

Quality attributes of ginger (essential oil and oleoresin) were also not affected by tree population density and fertiliser regimes. Nonetheless 't' test comparisons suggest that sole cropped ginger is superior to 2500 TPHA with respect to essential oil and oleoresin contents (Table 33; Appendix X).

4.5.4 Tissue nutrient concentrations

Tree population density affected foliar nitrogen and phosphorous contents only at 116 DAP. Maximum nitrogen was recorded in the treatment with 2500 TPHA. In terms of phosphorus, 3333 and 2500 TPHA recorded the highest values. Potassium content however, was not affected by stand density (Table 34; Appendix XI). Fertiliser levels did not play any significant role in determining the tissue nutrient concentrations. Tree population density influenced only potassium content of the mature rhizomes (Table 34; Appendix XI). The treatment with 3333 TPHA, recorded the highest value in this regard. Open grown ginger, recorded higher nitrogen and potassium contents as compared to shade grown ginger at 55 and 211 DAP, respectively.

Table 34 Effect of tree population density and fertiliser levels on nutrient content (N, P, K) of ginger foliage and mature rhizomes

Treatments	GINGER FOLIAGE					
	55 days after planting (%)			116 days after planting (%)		
	N	P	K	N	P	K
Density (trees ha^{-1})						
3333	3.03	0.30	5.65	2.04	0.31*	5.60
2500	2.69*	0.30	5.73	2.23	0.31*	5.81*
1600	3.17	0.29	5.67	2.06	0.29	5.58
1111	3.04	0.28	5.52	1.91	0.28	5.31
F test	NS	NS	NS	<0.05	<0.01	NS
SEM (±)	0.102	0.006	0.165	0.057	0.003	0.123
CD (0.05)	-	-	-	0.20	0.01	-
Fertiliser levels ($N:P_2O_5:K_2O$ kg ha^{-1} yr^{-1})						
0:0:0	2.93	0.30	5.73	1.99	0.31	5.65
50:25:25	2.92	0.28	5.60	2.20	0.29	5.46
100:50:50	2.96	0.31	5.71	2.00	0.30	5.65
150:75:75	3.13	0.29	5.52	2.05	0.29	5.56
F test	NS	NS	NS	NS	NS	NS
SEM(±)	0.105	0.008	0.157	0.092	0.009	0.195
Density x fertiliser interaction						
F test	NS	NS	NS	NS	<0.05	NS
SEM(±)	0.210	0.017	0.315	0.184	0.017	0.390
Ginger monoculture	3.31	0.26	5.58	1.86	0.26	5.00

Contd....

Table 34 contd....

Treatments	GINGER FOLIAGE 211 days after planting (%)			MATURE RHIZOMES 234 days after planting (%)		
	N	P	K	N	P	K
Density (trees ha^{-1})						
3333	1.46	0.17	3.48	1.23	0.19	1.72
2500	1.42	0.16	3.56	1.31	0.20	1.47
1600	1.33	0.14	3.10*	1.21	0.18	1.59
1111	1.40	0.15	3.00**	1.34	0.19	1.50
F test	NS	NS	NS	NS	NS	<0.05
SEM (±)	0.047	0.007	0.167	0.043	0.006	0.036
CD (0.05)	-	-	-	-	-	0.10
Fertiliser levels ($N:P_2O_5:K_2O$ kg ha^{-1} yr^{-1})						
0:0:0	1.55	0.15	3.44	1.28	0.18	1.67
50:25:25	1.28	0.16	3.00	1.22	0.18	1.49
100:50:50	1.38	0.15	3.67	1.29	0.18	1.50
150:75:75	1.41	0.16	3.04	1.29	0.21	1.62
F test	NS	NS	NS	NS	NS	NS
SEM(±)	0.062	0.010	0.229	0.040	0.009	0.070
Density x fertiliser interation						
F test	<0.01	NS	NS	NS	NS	<0.01
SEM(±)	0.125	0.020	0.458	0.081	0.017	0.139
Ginger monoculture	1.19	0.16	3.92	1.24	0.19	1.47

* Paired 't' values comparing treatment with ginger monoculture, significant at 5% level
** Paired 't' values comparing treatment with ginger monoculture, significant at 1% level

Table 35 Two-way tables showing combined effects of tree population density and fertiliser levels on nutrient content of understorey ginger foliage and mature rhizomes

	% P in foliage (116 DAP)				% N in foliage (211 DAP)				% K in rhizome (234 DAP)			
	3333	2500	1600	1111	3333	2500	1600	1111	3333	2500	1600	1111
0 : 0 : 0	0.29**	0.33**	0.32**	0.30**	1.45**	2.03**	1.33	1.38*	1.76	1.84	1.32	1.76
50 : 25 : 25	0.31**	0.33**	0.26	0.26	1.42**	1.26	1.28	1.17	1.83	1.20	1.80	1.12
100 : 50 : 50	0.32**	0.28	0.32**	0.29**	1.42**	1.05	1.49**	1.56**	1.78	1.33	1.35	1.54
150 : 75 : 75	0.34**	0.31**	0.25	0.28	1.56**	1.35*	1.21	1.49**	1.50	1.52	1.88	1.58
CD for fertiliser levels within density	→ 0.05				→ 0.36				→ 0.41			
CD for densities at each fertiliser level	→ 0.06				→ 0.36				→ 0.37			
Ginger monoculture	→ 0.26				→ 1.19				→ 1.47			

* Paired 't' values comparing treatment with ginger monoculture, significant at 5% level
** Paired 't' values comparing treatment with ginger monoculture, significant at 1% level

Interaction effects (density x fertiliser) were significant with respect to nitrogen (211 DAP) and phosphorous contents (116 DAP) in ginger foliage and potassium content of the mature rhizomes (Table 35; Appendix XI). However, there was no predictable pattern available in this respect.

4.6 Root interactions

4.6.1 Foliar ^{32}P recovery by ginger as affected by tree population density and lateral distance of ^{32}P application

Tree population density and lateral distance of ^{32}P application did not exert any pronounced influence on the absorption of ^{32}P (Table 36; Appendix XIII), by either treated, or adjacent (25 cm apart) ginger clumps. Nonetheless, neighbouring plants at a distance of 50 cm, showed marked variability in this respect (between 10 and 20 cm lateral distance of ^{32}P application, at 45 days). Recovery was higher when ^{32}P was applied at a lateral distance of 20 cm.

Substantial quantities of the ^{32}P applied to the ginger plants were absorbed by the associated ailanthus trees (Table 37; Appendix XIV). In general, the rate of recovery increased over time. However, radioisotope recovery by adjacent ailanthus trees at 1.375 m (Table 37) was not greatly influenced by stand density.

Table 36 ^{32}p activity (log cpm g^{-1}) recovered in the leaves of ginger at 15, 30 and 45 days after application of ^{32}p to the soil as affected by tree population density and lateral distance

Treatments	15 days			30 days			45 days		
	Treated plants	Neighbouring plants (25 cm)	Neighbouring plants (50 cm)*	Treated plants	Neighbouring plants (25 cm)	Neighbouring plants (50 cm)	Treated plants	Neighbouring plants (25 cm)	Neighbouring plants (50 cm)
Density (trees ha^{-1})									
3333	2.72(524.8)	2.51(323.6)	1.52(33.1)	2.85(707.9)	3.08(1202.3)	1.96(91.2)	3.55(3548.1)	3.18(1513.6)	2.22(166.0)
1111	2.24(173.8)	2.46(288.4)	0.92(8.3)	2.98(955.0)	3.05(1122.0)	2.25(177.8)	3.16(1445.4)	3.27(1862.1)	2.28(190.5)
0	2.18(151.4)	(2.29(195.0)	1.64(43.6)	2.50(501.2)	2.54(346.7)	1.99(97.7)	3.30(1995.3)	3.31(2041.7)	2.50(316.2)
F test	NS	NS	NS	NS	NS	NS	NS	NS	NS
SEM(±)	0.227	0.201	0.319	0.197	0.235	0.310	0.137	0.264	0.215
Lateral distance (cm)									
10	2.52(331.1)	2.40(251.2)	1.30(19.9)	2.89(776.2)	3.00(1000)	2.02(104.7)	3.46(2884.0)	3.27(1862.1)	2.04(109.6)
20	2.24(173.8)	2.44(275.4)	1.42(26.3)	2.67(467.7)	2.78(602.5)	2.12(131.8)	3.22(1659.6)	3.23(1698.2)	2.63(426.6)
F test	NS	NS	NS	NS	NS	NS	NS	NS	<0.05
SEM(±)	0.169	0.155	0.237	0.180	0.083	0.122	0.119	0.084	0.166
CD(0.05)	-	-	-	-	-	-	-	-	0.53
Density x Lateral distance interaction									
F test	NS	NS	NS	NS	NS	<0.05	NS	NS	NS
SEM(±)	0.293	0.268	0.410	0.312	0.143	0.212	0.206	0.145	0.288

Figures in parentheses indicate retransformed values
NS - Not significant
* log cpm (x+1) g^{-1}

Table 37 Foliar radiophosphorus [log cpm (x+1) g^{-1}] concentration of adjacent trees in mixed cropping system with ginger as the treated plant, as affected by tree population density and lateral distance at 15, 30 and 45 days after application of ^{32}P

Treatments	Adjacent tree (1.375 m)			Adjacent tree (1.625 m)		
	15	30	45*	15	30	45
Density (trees ha^{-1})						
3333	1.49 (30.9)	2.31 (204.2)	2.66 (457.1)	1.37 (23.4)	1.39 (24.5)	1.87 (74.1)
1111	0.90 (7.9)	1.75 (56.2)	2.15 (141.2)	1.01 (10.2)	2.13 (134.9)	2.69 (469.8)
F test	NS	NS	NS	NS	NS	NS
SEM (±)	0.253	0.452	0.373	0.319	0.390	0.443
Lateral distance (cm)						
10	1.82 (66.1)	2.41 (257.0)	2.37 (234.4)	1.02 (10.5)	2.11 (128.8)	2.57 (371.5)
20	0.57 (3.7)	1.66 (45.7)	2.44 (275.4)	1.36 (22.9)	1.41 (25.7)	1.99 (97.7)
F test	<0.05	NS	NS	NS	NS	NS
SEM (±)	0.268	0.571	0.461	0.401	0.327	0.276
CD	0.93	-	-	-	-	-
Density x lateral distance						
F test	NS	NS	NS	NS	NS	NS
SEM (±)	0.389	0.807	0.652	0.567	0.462	0.390

Figures in parentheses indicate retransofrmed values
NS - Not significant
* (Log cpm g^{-1})

Table 38 Two-way table showing the combined effects of tree population density and lateral distance on ^{32}P recovered from ginger plants 50 cm apart at 30 days after application (Log cpm g^{-1})

Lateral distance (cm)	Trees ha^{-1}: 0	1111	3333
10	1.74 (54.95)	2.61 (407.38)	1.72 (52.48)
20	2.25 (177.83)	1.90 (79.43)	2.20 (158.49)

CD for lateral distance within density → 0.68

CD for densities at each lateral distance → 1.37

Figures in parentheses indicate retransformed values

The 10 cm lateral distance of ^{32}P application, enhanced foliar ^{32}P recovery at 15 days after isotope application (Table 37; Appendix XIV).

Interaction effects (density x lateral distance) were significant at 30 days, with respect to neighbouring plants (50 cm apart). Here again, higher recovery was observed at 10 cm lateral distance, in the treatment with 1111 TPHA (Table 38; Appendix XIV).

4.6.2 Foliar ^{32}P recovery by ailanthus as affected by tree population density, lateral distance of application and cropping situation

Recovery of ^{32}P in the foliage of treated ailanthus trees was found to be independent of tree population density, lateral distance of ^{32}P application and cropping situation, as the differences were not significant at any of the stages of observation (Table 39; Appendix XV). However, tree population density exerted a marked effect on the foliar recovery of ^{32}P by adjacent trees in the north south direction at 15, 30 and 45 days after application. Neighbouring trees in the high density stand (3333 TPHA), registered consistently higher values as compared to 1111 TPHA. Similar observations was also obtained from adjacent trees (east west direction) in the monocultural situation, at 30 days after ^{32}P application (Table 40; Appendix XVI).

Table 39 ^{32}p activity (log cpm g^{-1}) recovered in the leaves of *Ailanthus* trees at 15, 30 and 45 days after application of ^{32}p to the soil as affected by tree population density, cropping situation and lateral distance of ^{32}p application

Treatments	15 days		30 days		45 days	
	Treated tree	Adjacent trees*	Treated tree	Adjacent trees*	Treated tree	Adjacent trees*
Density (trees ha^{-1})						
3333	1.41(25.7)	1.17(14.8)	2.28(190.5)	1.93(85.1)	2.42(263.0)	2.09(123.0)
1111	1.77(58.9)	0.49(3.1)	2.47(295.1)	0.76(5.7)	2.97(933.2)	0.83(6.8)
F test	NS	<0.05	NS	<0.01	NS	<0.01
SEM(±)	0.285	0.134	0.245	0.065	0.221	0.088
CD (0.05)	-	0.60	-	0.29	-	0.40
Lateral distance (cm)						
20	1.53(33.9)	0.68(4.8)	2.36(229.1)	1.26(18.2)	2.73(537.0)	1.36(22.9)
40	1.65(44.7)	0.97(9.3)	2.39(245.5)	1.43(26.9)	2.66(457.1)	1.56(36.3)
F test	NS	NS	NS	NS	NS	NS
SEM(±)	0.206	0.159	0.135	0.134	0.144	0.135
Cropping situation						
Monoculture	1.46(28.8)	0.92(8.3)	2.20(162.2)	1.34(21.9)	2.66(457.1)	1.34(21.9)
Intercropping	1.72(52.5)	0.74(5.5)	2.54(354.8)	1.35(22.4)	2.73(537.0)	1.58(38.0)
F test	NS	NS	NS	NS	NS	NS
SEM(±)	0.177	0.098	0.112	0.153	0.171	0.154

Contd....

Table 39 contd.....

Tree population density x cropping situation						
F test	NS	<0.01	NS	NS	NS	NS
SEM(±)	0.251	0.139	0.159	0.217	0.242	0.217
Tree population density x lateral distance						
F test	NS	<0.05	NS	NS	NS	NS
SEM(±)	0.291	0.226	0.190	0.190	0.203	0.191
Cropping situation x lateral distance						
F test	NS	<0.05	NS	NS	NS	NS
SEM(±)	0.291	0.226	0.190	0.190	0.203	0.191
Tree population density x cropping situation x lateral distance						
F test	NS	NS	NS	NS	NS	NS
SEM(±)	0.411	0.319	0.269	0.268	0.287	0.271

Figures in parentheses indicate retransformed values

Adjacent trees in north south direction

NS - Not significant

* Log cpm (x+1) g^{-1}

Table 40 Radiophosphorus [Log cpm (x+1) g^{-1}] recovered from the foliage of adjacent trees in the east-west direction as affected by tree population density and lateral distance of application

Treatments	Adjacent trees 3 m apart (Tree monoculture)		
	15 D	30 D	45 D
3333	1.15 (14.1)	0.88 (7.6)	0.94 (8.7)
1111	0.70 (5.0)	0.42 (2.6)	0.80 (6.3)
F test	NS	<0.05	NS
SEM (±)	0.269	0.086	0.308
CD	-	0.39	-
Lateral distance (cm)			
20	0.73 (5.4)	0.48 (3.0)	0.42 (2.6)
40	1.12 (13.2)	0.82 (6.6)	1.32 (20.9)
F test	NS	NS	<0.05
SEM (±)	0.293	0.217	0.238
CD	-	-	0.82
Density x lateral distance			
F test	NS	NS	NS
SEM (±)	0.415	0.306	0.337

Figures in parentheses indicate retransformed values
NS - Not significant
D - Days after replication

The interaction effects (tree population density x lateral distance, tree population density x cropping situation and cropping situation x lateral distance) were significant with respect to ^{32}P uptake by the neighbouring plants at 15 days after application (Table 41; Appendix XV). Increasing lateral distance of application and ginger intercropping favoured ^{32}P recovery by adjacent ailanthus trees in the low density stand. Similarly in ginger intercropped plots, ^{32}P uptake by the adjacent ailanthus trees was higher at 40 cm lateral distance of application. As regards to treated plants, intercropping favoured ^{32}P recovery in the high density situation.

Data presented in Table 42 show the effect of tree population density and cropping situation on the root activity pattern of ailanthus trees. Ginger intercropping had only a modest influence on the root distribution pattern of ailanthus. Intercropped plots recorded 52-59% of the fine root activity at 20 cm lateral distance from the treated tree and 41-48% at 40 cm distance from the tree. The respective figures for ailanthus monoculture were 47-57% at 20 cm lateral distance and 43-53% at 40 cm lateral distance. As regards to tree population density, lower density (1111 TPHA) in general registered high root activity at 20 cm (57-59%), than high density

Table 41 Two-way tables showing the combined effects of tree population density, lateral distance and cropping situation on ^{32}p recovery in *Ailanthus* at 15 days after ^{32}p application [Log cpm (x+1) g^{-1}]

Tree population density (TPHA) x lateral distance (cm)

	TPHA	
	3333	1111
20 cm	0.78 (6.0)	0.59 (3.9)
40 cm	1.56 (36.3)	0.38 (2.4)

CD for lateral distance within density → 0.70
CD for densities at each lateral distance → 1.25

Tree population density (TPHA) x cropping situation

	TPHA	
	3333	1111
Monoculture	0.96 (9.1)	0.88 (7.6)
Intercropping	1.39 (24.5)	0.09 (1.2)

CD for cropping situation within density → 0.48
CD for densities at each cropping situation → 1.12

Cropping situation x lateral distance (cm)

	Monoculture	Intercropping
20 cm	1.08 (12.0)	0.29 (1.9)
40 cm	0.75 (5.6)	1.19 (15.5)

CD for lateral distance within cropping situation → 0.70
CD for cropping situation at each lateral distance → 0.97

Figures in parentheses indicate retransformed values

Table 42 Root activity (%) of *Ailanthus* as affected by stand density, lateral distance and cropping situation (monoculture/intercropping)

		3333 TPHA		1111 TPHA	
		Monoculture	Intercropping	Monoculture	Intercropping
Lateral distance (cm)	20	46.92	51.86	56.57	58.58
	40	53.08	48.14	43.43	41.42

stands (47-52%) at the same distance. In contrast to this, at 40 cm lateral distance, high density stands depicted higher root activity.

Recovery of ^{32}P by ginger clumps adjacent to treated ailanthus trees (Table 43; Appendix XVII) was modest and showed no significant difference with respect to tree population density and lateral distance of application. Interaction effects (density x lateral distance) were, however, significant with respect to ginger plants 1.625 m apart, at 30 days after application (Table 44; Appendix XVII). Ginger plants, in the low density stand (1111 TPHA) showed more recovery at the 40 cm lateral distance of ^{32}P application.

Table 43 Radiophosphorus [Log cpm (x+1) g^{-1}] recovered from ginger foliage, in the mixed cropping system, when ^{32}P was applied to *Ailanthus* as affected by the tree population density and lateral distance of application

Treatments	Ginger plants at											
	1.125 m			1.375 m			1.625 m			1.875 m		
	15 D	30 D	45 D*	15 D	30 D	45 D*	15 D	30 D	45 D*	15 D	30 D	45 D*
Density (trees ha^{-1})												
3333	0.64 (4.4)	1.12 (13.2)	1.23 (17.0)	0.33 (2.1)	0.92 (8.3)	1.17 (14.8)	0.23 (1.7)	0.71 (5.1)	1.05 (11.2)	0.47 (2.9)	0.88 (7.6)	1.09 (12.3)
1111	0.36 (2.3)	0.82 (6.6)	1.14 (13.8)	0.20 (1.0)	0.86 (7.2)	1.25 (17.8)	0.37 (2.3)	0.75 (5.6)	1.18 (15.1)	0.18 (1.5)	0.90 (7.9)	1.25 (17.8)
F test	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
SEM (±)	0.138	0.211	2.125	0.111	0.271	0.090	0.148	0.212	0.099	0.114	0.178	0.079
Lateral distance (cm)												
20	0.41 (2.6)	0.92 (8.3)	1.09 (12.3)	0.24 (1.7)	0.93 (8.5)	1.26 (18.2)	0.37 (2.3)	0.66 (4.6)	1.00 (10.0)	0.18 (1.5)	0.88 (7.6)	1.15 (14.1)
40	0.59 (3.9)	1.02 (10.5)	1.27 (18.6)	0.29 (1.9)	0.84 (6.9)	1.16 (14.4)	0.23 (1.7)	0.80 (6.3)	1.23 (17.0)	0.47 (2.9)	0.90 (7.9)	1.19 (15.5)
F test	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
SEM (±)	0.155	0.093	0.079	0.084	0.106	0.039	0.106	0.139	0.111	0.134	0.118	0.093
Density x lateral distance												
F test	NS	NS	NS	NS	NS	NS	NS	<0.05	NS	NS	NS	NS
SEM (±)	0.220	0.132	0.112	0.118	0.149	0.054	0.150	0.197	0.157	0.189	0.166	0.131

Figures in parentheses indicate retransformed values
NS - Not significant * (log cpm g^{-1})
D - Days after application

Table 44 Density x lateral distance means of radiophosphorus [Log cpm (x+1) g^{-1}] concentration in foliage of ginger plants (1.625 m apart) at 30 days after ^{32}P application

Lateral distance (cm)	Trees (ha^{-1}) 3333	1111
20	0.90 (7.9)	0.41 (2.6)
40	0.51 (3.2)	1.09 (12.3)

CD for lateral distance within density → 0.67

CD for densities at each lateral distance → 1.06

Figures in parentheses indicate retransformed values

Discussion

DISCUSSION

5.1 Growth of ailanthus as affected by tree population density and fertiliser regimes

Data on tree growth characteristics (Tables 1 and 2) suggest that mean annual increment for tree height ranges from 0.72 to 0.85 m yr^{-1} and that of DBH from 1.28 to 1.60 cm yr^{-1} at 48 months after planting. George (1993) and Jamaludheen (1994), however, reported much lower values. According to them, mean annual increment for tree height (ailanthus) ranged from 0.66 to 0.51 m yr^{-1}, and that of DBH from 0.96 to 0.51 cm yr^{-1}, at five and eight years of age respectively. The differences in site quality may provide a plausible explanation for such variations.

Growth rates of multipurpose tree species are generally dependent on genetic factors, besides inter and intraspecific competition and site characteristics. Tree population density and fertiliser regimes are cardinal factors in determining the magnitude of interspecific competition. Miller (1981), observed that fertiliser application to forest trees stimulate growth and shorten rotation length. Positive influences of fertiliser application on tree growth were also reported by Singh *et al.* (1991) and Cromer *et al.* (1993). However, in the present study neither tree population density nor fertiliser regimes exerted a dramatic influence on many of the growth parameters analysed (Tables 1 and 2). The lack of significant variation in respect of tree population density can be explained by the juvenile nature of the stand. Possibly the trees have not entered into the phase of competitive interaction.

The mean crown width is below 1.70 m (Table 2) implying that interlocking of ailanthus crowns has not yet taken place. The trees are perhaps still in stage 'A' of the stand development model (Long and Smith, 1984). Such non significant differences in tree growth as a function of tree spacing/density has been reported in *Prosopis juliflora* (Singh *et al.*, 1989a), *Gliricidia sepium* (Karim and Savill, 1991), *Ailanthus triphysa* and *Grevillea robusta* (KAU, 1992).

The only growth attribute that exhibited significant variation as a function of tree population density was, stand leaf area index. LAI increased as tree population density increased. Long and Smith (1984) reported that leaf area plateaus out earlier in high density stands than low density stands.

As regards to fertiliser regimes vis a vis tree growth characteristics, no clear trend was discernible. In general tree growth characteristics appeared to be independent of fertiliser regimes. Several workers have reported similar results. For instance, fertiliser application did not influence diameter growth and height increment of *Paraserianthes falcataria* at six years of age (Wan Rasidah and Sulaiman, 1992). Nitrogenous fertilisers also did not significantly effect height growth of *Acacia mangium*, *Eucalyptus camaldulensis* and *Paraserianthes falcataria* (Wan Rasidah *et al.*, 1988).

Response to fertiliser is generally observed when soil is deficient in nutrients (Chamshama and Hall, 1978; Cromer *et al.*, 1981; Wan Rasidah *et al.*, 1988). Lack of significant response to fertiliser application can be perhaps explained by the low recovery of applied nutrients by the tree crop. As fertilisers were applied in the present experiment in basins (50 cm radius) around the tree during the rainy season (August 1992 and September 1993), much of it might be lost, through leaching. Moreover, as trees did not reach canopy closure, weeds in the interspaces probably might have taken up a certain proportion of the applied nutrients, resulting low recovery of applied nutrients. Hence in juvenile stands of fast growing multipurpose tree species, it will not make much sense to apply high doses of chemical fertilisers, unless interspecific (weed growth) competition is checked.

5.1.1 Light interception by ailanthus crowns

Understorey light availability ranged from 35-72 per cent (50 cm) and 40-75 per cent (150 cm) of that in the open. Availability of photosynthetically active radiation (at 50 and 150 cm) was inversely related to tree population density (Table 19; Fig. 4-7) and can be explained by concomitant changes in LAI (Table 2).

The tree population density of 2500 trees per hectare recorded modestly higher (5%) understorey light availability, compared to 1600 TPHA (at 50 cm height). This can be attributed to planting geometry and width of inter-row spaces (2x2 m vs 3x2 m). Crown width also was greater in 1600 TPHA (Table 2).

Fertiliser levels also had only a modest influence in this respect. At 50 cm it ranged from 48-58 per cent, whereas at 150 cm, it ranged from 50-61 per cent.

Ailanthus owing to a compact and less spreading crown, intercepts relatively lower quantities of incoming solar radiation. Light interception of below 5 per cent have been reported by Mathew *et al.* (1992), for this species (at three years of age). Lower light interception in turn, facilitates growing other crops in association with ailanthus. Even a tree population density of 2500 TPHA intercepts only about 46-48 per cent of the total incoming solar radiation, thus making ailanthus an ideal species for agroforestry, which aims at optimising the production of both the tree and field crop components of the system. However, the light availability scenario may undergo drastic changes as stand age increase and it approaches crown closure.

5.1.2 Foliar nutrient concentration of ailanthus

Both tree population and fertiliser regimes had only a modest influence on foliar nutrient content (Tables 3-14). No clear trend also was discernible in this regard. Non-significant variations in foliar nitrogen content, in different row spacings in *Gliricidia sepium* has been reported by Karim and Savill (1991).

In almost all natural systems, however, young leaves with higher nitrogen content occupy the upper layers in a canopy and receive high photon flux densities (PFDs). This is considered to be favourable because leaves with a high nitrogen content can utilise high PFDs more efficiently for photosynthesis than those with a low nitrogen content

(Mooney and Gulmon, 1979; Field, 1983; Dejong and Doyle, 1985; Seeman *et al.*, 1987; Hirose, 1988). In the present study, however no strong relationship existed between foliar nitrogen concentration and light availability (r=0.102). Lack of clear stratification in crown architecture may perhaps explain this.

5.2 Growth and yield of ginger

5.2.1 Growth characteristics

Ginger emergence occurred between 12 and 14 days after planting. During the process of emergence, mitotic activity in the apical meristem of the buds on the rhizomes (seeds) is resumed and they elongate as sprouts. Experimental variables did not exert a marked effect on ginger emergence. Shoot elongation was curvilinear with time, initially being fast. Gradually, a point is reached when the main axis elongates no further (Tables 20, 21 and 23). Higher tree population densities in general stimulated shoot elongation. Ginger (cv. Kuruppampady), being a shade loving plant (Bai, 1981), low light intensities (54-35% PAR) may have a favourable effect on shoot growth. Several other workers also obtained similar results (Aclan and Quisumbing, 1976; Bai, 1981; Jayachandran *et al.*, 1991; Jaswal *et al.*, 1993).

Chemical fertilisers applied to the tree component of the agrisilviculture system did not show any consistent trends. Fertilisers applied to ailanthus can influence ginger growth in such polycultural systems only if they alter the growth pattern of the tree crop. In the present case, applied chemical fertilisers did not substantially modify the tree growth characteristics (Tables 1 and 2).

Tillering capacity is one of the most important characteristics of a variety. The high tree population densities in general favoured early high tillering (Tables 20, 21 and 23). However at the final stages of observation such differences were not discernible. Tillering potential of ginger was not influenced by fertiliser application to the tree crop component of the system also (Tables 20, 21 and 23).

Number of leaves per clump, leaf area, leaf area index (LAI) (Tables 20, 21 and 23) and foliar biomass (Tables 27, 29 and 31) were markedly influenced by tree population densities. In general presence of the tree component, in the system, favoured higher number of ginger leaves and LAI. Ginger monoculture consistently recorded the lowest values in this respect. Implicit in this stimulatory effect of tree population densities on leaf number and LAI is perhaps the shade-loving nature of the ginger crop

(Jaswal *et al.*, 1993). The increase in LAI is probably caused by two factors, increase in tiller number and in the size of successive tillers (Tables 20 and 21). Thus, leaf production, leaf retention and leaf size may be improved under moderate levels of shade (49-54% PAR). Furthermore, ginger grown in association with tree crop components presumably remained greener for a longer period of time. Fertiliser effects in this respect were not consistent.

Mean root length (Tables 20, 21 and 23), though initially high in tree population densities ≥ 1600 TPHA, did not follow a consistent trend. Fertiliser effect was also inconsistent in this respect.

5.2.2 Ginger dry matter production

Seasonal above ground dry matter accumulation (Haulm yield) exhibits essentially a curvilinear trend (Table 25) with maximum vegetative dry weight occurring at about four months after planting. The dry spell that followed this stage (Fig.1) may have caused senescence/mortality of older leaves and may account for the reduction in dry weight during the final stages of observation (211 DAP). Similar observations have been reported by Ravisankar and Muthuswamy (1986) also.

As regards to below ground biomass yield, over time it essentially followed a linear trend (Tables 25 and 27). Both above and below ground biomass accumulation were significantly influenced by tree population densities. Monoculture plots were characterised by relatively lower levels of productivity. With increasing tree population density, ginger biomass yield increased initially, followed by a marked reduction at the highest density of shade trees. Highest total biomass yield was registered at the tree population density of 2500 TPHA, implying the adequacy of shade level characterised by four year old ailanthus at this density (54% PAR). The precise density level at which such favourable effects can be observed is a function of tree age also. The present results suggest that at four years of age 2500 ailanthus trees per hectare is perhaps the best in terms of total below ground dry matter production.

Fertiliser application to the tree crop component did not exert any pronounced effect on any of the biomass fractions. Results of the ^{32}P experiments (Table 43) also corroborate this fact. Thus it can be surmised that fertilisers applied to the tree crop component (four years of age) of an agrisilviculture system like the present one, may not directly benefit the herbaceous crop. Owing to the restricted root system development of ginger grown on raised beds, it is perhaps incapable of competing with or sharing the nutrients applied to the tree component of the polycultural system. However, there may be indirect beneficial effects occurring from fertiliser application to the tree component of the system. Enrichment of the surface horizons of the soil profile through nutrient pumping (Nair, 1993) is cardinal in this context. Additionally the enhanced tree growth that may follow fertiliser application, may favour ginger growth and yield. However, in the present study no such favourable effects were noticed.

5.2.3 Nutrient uptake at different growth stages

The process of nutrient uptake at different growth stages is a function of climate, soil properties, amount and method of fertiliser application and variety of the ginger plant. It was observed that (Table 34), at the seedling stage the concentration of N, P and K increased as growth progressed and then decreased after reaching a maximum value around two months after planting. Presumably the time of maximum percentage nitrogen in the foliage differed with the tree population density. Initially highest nitrogen levels were encountered in the monoculture plots. However, shortly afterwards the situation changed. High tree population densities (1600 and 3333 TPHA) tallied higher nitrogen levels in the foliage, at the later stages of observation. Phosphorus and potassium also followed a similar trend.

Higher foliar nutrient concentrations observed in the high density treatments could be attributed to the fact that foliage remains greener and therefore physiologically active for a longer period of time in these treatments. This in turn, confirms the fact that optimal levels of shade may promote growth and development of the understorey ginger crop. Increases in foliar nutrient contents of ginger due to shade has been reported by Bai (1981). Fertiliser effects were however not quite explicit at any stages of observation in this regard.

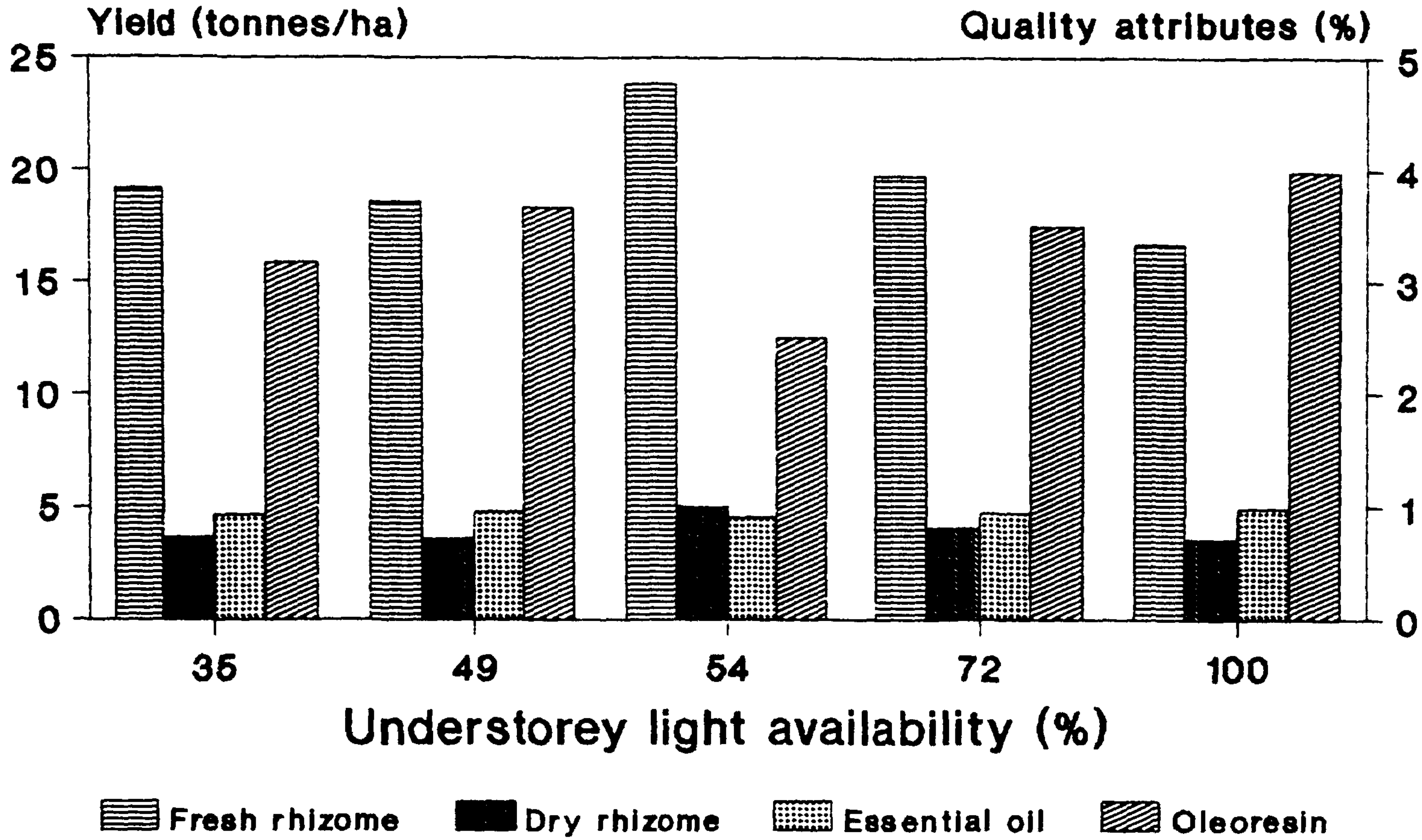
5.2.4 Rhizome yield of ginger

Rhizome initiation in ginger plants takes place under a wide range of developmental stages, varying from early in plants with well developed sprouts (two months after planting) to late in plants with excessive haulm growth. Environmental factors especially shade intensity, as influenced by differing population densities of the multipurpose tree component, may have a marked influence on rhizome initiation as apparent from the differential crop growth rates observed (Tables 25, 27, 29 and 31). There was a concomitant influence on ginger yield also. Tree population density significantly altered ginger rhizome yields (Tables 31 and 33).

The tree population density of 2500 TPHA recorded the highest dry weight of ginger rhizome. Such a favourable effect of 2500 TPHA on rhizome yield can be explained by the better growth of ginger plants observed in this treatment (Tables 20, 21 and 23). Although differences in dry rhizome yield of ginger at 234 DAP (Table 33) was not statistically significant, both fresh weight at this stage as well as dry weight at a previous stage (211 DAP) exhibited marked variability in this respect. Moreover, rhizome yield in the mixed-species system involving ailanthus was consistently higher than that of the sole crop situation (Tables 31, 33 and Fig.8). Dry rhizome yield of 2500 TPHA was about 42 per cent greater than that of the sole crop (Table 33).

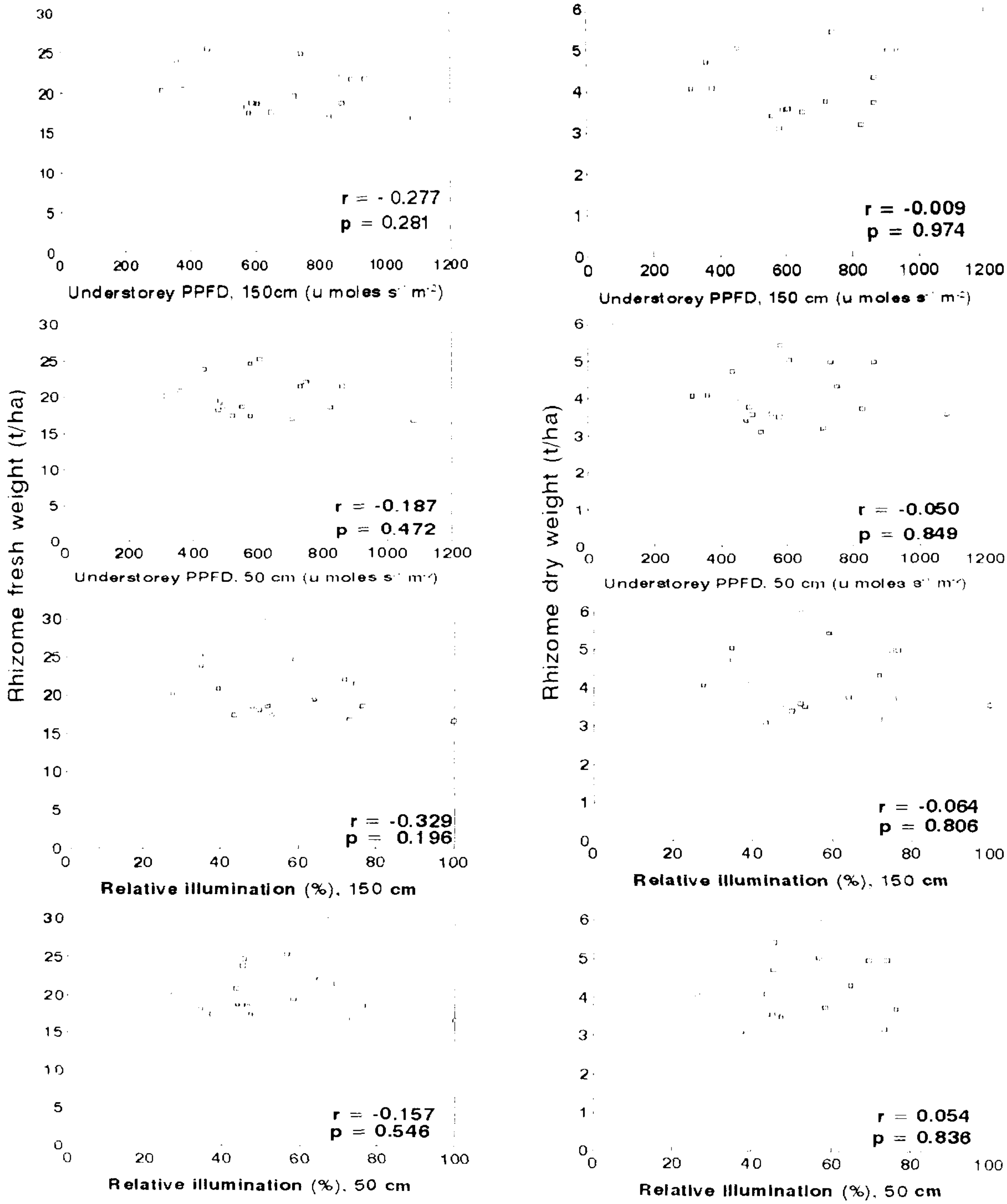
Higher fresh and dry rhizome yields of ginger when grown in association with ailanthus can be explained based on the shade-loving nature of the crop. When grown in association with a tree crop component, the ginger plants remain greener for a longer period of time, contain higher percentage of foliar nutrient levels, particularly N and therefore, higher photosynthetic potential resulting in

Fig.9 Yield and quality attributes of ginger as affected by light availability



better rhizome development and yields. Similar observations were made by other workers also (Bai, 1981; Ravisankar and Muthuswamy, 1986).

Correlation studies between rhizome yield and light availability did not reveal any strong association ('r' ranges from 0.005 to 0.226 at 211 DAP and -0.009 to -0.329 at 234 DAP and were statistically non significant). However, with increasing understorey light availability, apparently ginger yield increased initially, reached a maximum at around 60 per cent illumination (ratio of the PAR below and above tree canopy) or 600 µ moles s^{-1} m^{-2} (Fig.10) and then decreased. The tree population densities that correspond to these illumination levels are 2500 and 1111 TPHA. Earlier workers have, however, reported different values with respect to optimum shade requirement of ginger. For instance many workers have reported that inanimate shade of 25 per cent (illuminance level of 75%) promotes ginger yield (Bai, 1981; Jayachandran *et al.*, 1991; Varughese, 1989; George, 1992). A study conducted by Wilson and Ovid (1993) comparing inanimate shade (66% saran netting) with natural shade (mixed cropping system) however showed higher yields under inanimate shade (66%). In an intercropping study on ginger with poplar, Jaswal *et al.* (1993) observed maximum yield at 46 per cent light availability. Results of the present study, however, Fig 10. Relationships between ginger yield and photosynthetic photon flux densities at 50 and 150 cm above ground level



indicate modestly higher light requirement of ginger. This, inturn, can be explained by the varietal and/or spectral characteristics of below canopy light, which remain to be investigated.

Another aspect concerning polycultural systems, involving woody perennials is their potential for wood production. In this regard a higher tree population density in the range about 2500 TPHA, is preferable in view of its ability to yield a substantial quantity of timber. Two thousand five hundred trees per hectare, thus represents a typical trade-off between maximisation of timber yield and ensuring optimum yield levels.

Radioisotope studies also indicated that much of ailanthus roots are situated (41-53%) in a radius of about 40 cm from the tree base. Hence the competition for nutrients applied to the ginger crop (Tables 36 and 37) is modest at this density level. Therefore growing ginger as an intercrop in ailanthus plantations at a density of 2500 TPHA makes much practical sense. Nonetheless, shade tree density may be a function of tree age as the light interception of tree canopies is strongly influenced by crown development.

As regards to fertilisers applied to the tree component of the system, there was no pronounced effect of this on ginger productivity. Lack of significant response to fertiliser application has been reported by Wilson and Ovid (1993). These results are also consistent with the observations on ginger growth and nutrient concentration (Tables 20, 21, 23 and 34).

5.2.5 Quality attributes

Both essential oil and oleoresin contents of ginger were unaffected by tree population densities and fertiliser regimes (Table 34). However, a shade tree density of 2500 TPHA, recorded the lowest values in this respect albeit having registered the highest rhizome yield. Open grown ginger (Fig.9) registered the highest values with respect to both essential oil (0.983%) and oleoresin (3.98%) contents. Corroboratory results have been reported by Varughese (1989), although some workers (Ravisankar and Muthuswamy, 1987; Babu and Jayachandran, 1994), have observed that ginger grown under shade produces better quality rhizomes. Percentage of oleoresin and essential oil are primarily dependent on variety, maturity, environment and drying conditions (Nybe, 1978; Mathew *et al.*, 1975; Ravisankar and Muthuswamy, 1987; Jaswal *et al.*, 1993). Perhaps such factors may explain the observed variations.

5.3 Changes in soil fertility

Three years of ailanthus growth on the site has resulted in a noticeable reduction in the concentration of many nutrient elements and organic carbon (Table 15). Control plots recorded the highest values in respect of many of the observed parameters. In general soil nutrient availability declined as tree population density increased. The observed reduction in nutrients at higher tree population densities can be explained based on nutrient removal by trees. Ailanthus being a fast growing tree, may account for a substantial nutrient uptake, especially during the initial years. However, in later years, this may be compensated through the nutrient cycling process (Nair, 1993). The reduction in soil pH can be explained by litter decomposition and the consequent release of organic acids into the soil system.

Fertiliser application to ailanthus also altered the soil mineral nutrient status, except N, quite substantially. Increasing levels of applied mineral nutrients increased the organic carbon content, although it was significantly lower than that of the control. There was however no predictable pattern with respect to other nutrients. Raising a crop of ginger in the interspaces of ailanthus, also brought about an improvement in soil fertility, albeit feeble (Table 16). This may be due to fertilisers and green manure application to the ginger crop (KAU, 1993), which in turn may enhance the general fertility levels of soil. Tree population density and application of chemical fertilisers to the tree crop component also altered the nutrient capital of the site. Interestingly the monoculture in general registered higher values in this respect. Nutrient removal by the tree component, and addition of leaf litter, on decomposition of which may release organic acids, may provide a plausible explanation for this phenomenon (Negi and Sharma, 1984; Singh, 1984; Nair, 1989).

5.4 Root level interactions in agrisilvicultural systems involving ailanthus and ginger

Recovery of ^{32}P in ginger foliage, increased over time, irrespective of tree population density and lateral distance of ^{32}P application. Similar increases in ^{32}P recovery over time has been reported by Wahid *et al.* (1989a, 1989b) for cashew and cocoa and George *et al.* (1996) for acacia, casuarina, leucaena and ailanthus. Implicit in this increasing recovery of the radio-label from 15 to 45 days after application, is perhaps the active growth of ginger roots and also duration of absorption. Dry weight of ginger roots increased steadily until 211 DAP (Tables 27, 29 and 31). Application of radiophosphorus to ginger coincided with the grand growth phase of the crop

(116 DAP). Nutrients applied at the grand growth phase of the crop are absorbed quickly, especially when soil moisture is not a limiting factor. In the present experiment, ^{32}P was applied during the north east monsoon season. Since the experiment was conducted when soil moisture was not limiting, the extent of absorption of ^{32}P could be considered to reflect the amount of root activity (Wahid *et al.*, 1989b). Fine root activity of many tree species also have been reported to be high during the rainy season (Srivasthava *et al.*, 1986).

Lack of significant variations in ^{32}P recovery as a function of tree population density, suggests that tree population density or tree spacing is probably not a cardinal factor in determining the below ground interaction between the tree and field crop components in polycultural systems at this stage (four years after tree planting). Although tree population density did not influence ^{32}P recovery by ginger (Table 36), ailanthus trees in this polycultural system absorbed a substantial portion of the ^{32}P applied to the ginger crop (Table 37). This in turn, suggests that the effective rooting zones of ginger and ailanthus may overlap. Data on root activity (%) of ailanthus clearly indicate that 41-53 per cent of physiologically active roots are distributed at 40 cm lateral distance from the tree trunk (Table 42). As the ginger beds were located in the interspaces (2-3 m wide), there may be a substantial mixing up of the root systems of the component species.

This, in turn may have important managerial implications for silvoagricultural systems. Regardless of tree density the shade trees may compete with the herbaceous crop components for soil resources (water and nutrients). It is therefore important that tree management practises such as trenching, lopping/pollarding and other operations may be resorted to, for reducing the magnitude of interspecific competition. Deep rooted tree species may be ideally suited for this purpose. Furthermore, as lateral distance of ^{32}P application (10 and 20 cm) did not reveal any pronounced variations, placement of chemical fertiliser (either band/spot) may be at par with that of broadcast application of fertilisers for the ginger crop. Therefore, the present recommendation for broadcast application of fertilisers on ginger beds, evolved based on experiments conducted under sole crop situations might hold good for mixed-species agrisilvicultural systems as well.

As regards to fertilisers applied to the tree crop component of the system (three year old ailanthus), the present study reveals some interesting information.

Radiophosphorous recovery in ginger foliage was modest (Table 43). Implicit in this modest recovery of ^{32}P by the ginger when ^{32}P was applied to ailanthus is the lack of sharing or non-competitive nature of the herbaceous components with the tree species. Furthermore, experimental variables such as tree population density, lateral distance of ^{32}P application and cropping situation did not exert any discernible influence in this respect (Table 39).

To sum up although trees in polycultural systems may compete with the herbaceous crops for applied nutrients, the converse is perhaps not true. Hence, from a crop management point of view, it is better to fertilise adequately the herbaceous crop component of the system, as both components can benefit from such a practice. Consequently nutrient use efficiency (of applied nutrients) may be higher. In this context, Nair (1984a), suggested that loss of nutrients below the rooting zone can be considerably reduced in mixed species systems, where the total volume of root exploitation will be larger. This, however, is a function of the species, age, root spread and other related factors. Radiophosphorus recovery in ailanthus and acacia were not influenced by the associated forage grasses (George, 1996). Such a differential response in ^{32}P uptake depending on the growth habit of the component crops in an intercropping system was reported by Ashokan *et al.* (1988) also. They observed a decrease in ^{32}P uptake by elephant foot yam (*Amorphophallus compnulatus*) when it was grown in association with banana and/or cassava (*Manihot esculenta*). However, for banana an increase in ^{32}P uptake was observed when it was mixed with elephant foot yam or cassava, indicating competitive and or complementary interactions in ^{32}P uptake depending on the nature of the associated crop species.

Regarding the consistently high recovery of ^{32}P in the foliage of neighbouring ailanthus trees in the high density stand (Table 39), this may be due to the closer inter row spacing (1m vs 3m). Higher tree population density may concomitantly result in high root density and therefore increased plant uptake of applied nutrients.

Summary and Conclusion

SUMMARY AND CONCLUSIONS

Agrisilviculture, a type of agroforestry, in which field crops are grown in association with woody perennial species, is an important land use system in Kerala context. Ginger-shade tree system forms a prominent example in this respect. Although ginger (*Zingiber officinale* Roscoe) is grown in association with various trees under diverse cultural situations, only limited research has been conducted to standardise the shade levels and/or optimise the density of shade trees.

Ailanthus (*Ailanthus triphysa* (Dennst.) Alston.), is an important multipurpose tree, that is often used as a shade tree for ginger cultivation, owing to its compact crown, relatively lower lateral root spread and deep rooting nature. However, many aspects of the functional dynamics of ailanthus agroforestry involving ginger, such as competition for site resources and partitioning of nutrients and light between the tree and ginger remain uninvestigated.

In this context, a field experiment involving ginger as an understorey crop was superimposed in an ongoing split plot experiment, with *Ailanthus triphysa*, at three years of age. The treatments included four population densities (3333, 2500, 1600 and 1111 TPHA) and four fertiliser levels (0:0:0, 50:25:25, 100:50:50 and 150:75:75; kg $N:P_2O_5:K_2O$ $ha^{-1}yr^{-1}$), besides their monocultures. The study was conducted at the instructional farm, College of Forestry, Vellanikkara during the period from May 1994 to June 1995. The objectives included assessing productivity of ginger as a component of an agrisilviculture system involving ailanthus, besides analysing the partitioning of solar radiation among the different components of the system and characterising the nature of below ground interactions between the field and tree crop components. Salient results are summarised below:

1. Tree population densities did not influence ailanthus growth during the 36-48 months period after planting. Implicit in this lack of difference is perhaps the juvenile nature of the stand, characterised by non-competitive nature. Early tree growth appeared to be independent of fertiliser application also.

2. Both tree population density and fertiliser regimes did not exert any characteristic influence on the foliar nutrient content of ailanthus. Moreover, no strong relationships were observed between

photosynthetic photon flux density and foliar nitrogen content of ailanthus. Lack of stratification in crown architecture may probably explain this.

3. Tree population density significantly influenced understorey light availability, owing to changes in stand leaf area index. Light availability, ranged from 35-72 per cent and 40-75 per cent of that in the open, at 50 and 150 cm from the ground level respectively.

4. Ginger grown in the interspaces of ailanthus consistently recorded better growth as compared to open- grown ginger. Furthermore, ginger growth was profoundly influenced by tree population density. This may be attributed to the shade-loving nature of the crop. Ginger grown in the interspaces of the stand with 2500 TPHA showed better all round performance. Fertilisers applied to ailanthus however, did not exert a pronounced effect in this regard.

5. Tissue nutrient content of ginger foliage was highest at about two months after planting, after that it decreased. Initially nutrient content of open grown ginger was higher. However, the later stages showed

a reversal of this trend. Shade grown ginger recorded consistently higher foliar nutrient content. This could be attributed to the fact that ginger grown in the interspaces of ailanthus remains greener and therefore physiologically active for a longer period of time. It underscores the fact that optimal levels of shade may promote growth and development of the understorey ginger crop. Chemical fertilisers applied to ailanthus, however had no marked influence in this respect.

6. Rhizome yield of ginger was influenced by tree population density. Open-grown ginger recorded lower yield (fresh and dry rhizome) levels as compared to ginger in the mixed cropping situations.

7. As regards to interception of incoming solar radiation by the tree component, an understorey photosynthetic photon flux density (PPFD) level of 60 per cent of that in the open is considered favourable. This in turn, corresponds to a tree population density of 2500 TPHA, that represents a trade-off between, maximisation of timber volume production and ensuring optimum levels of understorey productivity. Shade tree density, however, may be a function of tree age,

as the light interception pattern of tree canopies is strongly influenced by crown development.

8. Open grown ginger recorded highest values with respect to essential oil and oleoresin. Ginger grown in the treatment with 2500 TPHA, recorded the lowest essential oil and oleoresin contents, albeit having registered the highest rhizome yield.

9. Three years of ailanthus growth on the site has resulted in a noticeable reduction in soil nutrient and organic carbon contents. Tree-less plots recorded higher values. Presumably nutrient removal by trees may explain such a reduction. The reduction in soil pH can be explained by litter decomposition and the consequent release of organic acids. With respect to fertilisers applied to the tree crop, no predictable pattern was discernible. Raising a crop of ginger in the interspaces of ailanthus, however, brought about a slight improvement in the nutrient capital of the site. This may be due to the fertilisers and green manure applied to the ginger crop.

10. Recovery of ^{32}P in ginger foliage, increased over time, irrespective of tree population density and lateral distance of isotope application. Lack of significant variations in ^{32}P recovery as a function of tree

population density, suggests that tree population density is probably not a strong determinant of below ground interaction between the tree and field crop components in polycultural systems (at least till four years after tree planting).

11. Although tree density did not influence ^{32}P recovery by ginger, trees in the polycultural system absorbed a substantial portion of the ^{32}P applied to the ginger crop. This in turn, suggests that the effective root zones of ginger and ailanthus may overlap. Hence management practices such as trenching may be resorted to reduce the intensity of root competition.

12. Data on root activity pattern of ailanthus suggest that about 41-53 per cent of physiologically active roots are concentrated at a distance of about 40 cm lateral distance from the tree trunk. Although trees in polycultural systems may compete with the herbaceous crops for applied nutrients, the converse is perhaps not true. Hence from a crop management perspective, it is better to fertilise adequately the herbaceous component of the system, as both components can benefit from such a practice. Nutrient use efficiency of applied nutrients may be higher under such situations owing to the associated complementary effects.

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* Original not seen

Appendix

APPENDIX I

Weather parameters during the experimental period (May 1994 - June 1995) recorded by the Department of Meteorology, College of Horticulture, Kerala Agricultural University

Months	Temperature (°C)		Rainfall (mm)
	Maximum	Minimum	
May	33.6	24.7	124.2
June	28.9	22.9	955.1
July	28.6	22.4	1002.1
August	30.0	22.8	509.2
September	31.8	23.2	240.5
October	32.3	22.7	358.2
November	31.8	23.3	125.3
December	32.2	22.2	0.0
January	32.9	22.4	0.0
February	35.4	23.4	0.5
March	37.6	23.8	2.8
April	36.6	24.9	118.7
May	33.5	23.9	370.5
June	31.6	23.1	500.4
Mean	32.63	23.26	307.68
Total rainfall (mm)			4307.50

APPENDIX II

Data-set used for establishing relationship between light availability and foliar nitrogen content

Treatment	μ mols $s^{-1}m^{-2}$ 1300 hr	% N (upper crown)	μ moles $s^{-1}m^{-2}$ 1300 hr	% N (lower crown)
D_1F_1	1768.0	2.127	1729.0	2.597
D_1F_2	763.3	2.333	907.0	1.943
D_1F_3	1014.0	2.017	1147.0	1.457
D_1F_4	1724.0	3.087	1590.0	1.867
D_2F_1	821.2	2.167	765.0	1.587
D_2F_2	1798	1.400	1747.0	1.587
D_2F_3	1485	2.353	1551.0	1.940
D_2F_4	1071.2	2.333	921.5	1.603
D_3F_1	1321.0	2.780	1342.0	2.163
D_3F_2	1576.0	2.467	1086.0	1.400
D_3F_3	1272.0	1.997	1169.0	1.550
D_3F_4	1660.0	2.597	1426.0	1.363
D_4F_1	1844.0	1.440	1759.0	1.307
D_4F_2	1913.0	1.820	1193.0	1.417
D_4F_3	1981.0	2.213	1480.0	2.167
D_4F_4	1910.0	2.017	1552.0	1.933

APPENDIX III

Data-set relating light availability and rhizome yield of ginger

Treatment	Below canopy mean PAR (μ moles $s^{-1}m^{-2}$)		Relative illumination (%) Below canopy		Rhizomze yield (Tonnes ha^{-1}) 211 DAP		234 DAP	
	50 cm	150 cm	50 cm	150 cm	Fresh	Dry	Fresh	Dry
D_1F_1	522.00	580.87	37.31	43.35	21.41	4.93	17.40	3.09
D_1F_2	359.01	376.89	43.49	39.38	23.98	5.33	20.85	4.08
D_1F_3	312.80	313.44	26.21	27.52	20.36	4.18	20.19	4.06
D_1F_4	477.78	557.59	34.36	49.87	27.09	5.47	18.12	3.38
D_2F_1	434.20	358.93	45.14	34.80	27.86	5.95	23.80	4.71
D_2F_2	861.77	936.05	69.20	74.82	22.73	4.92	21.49	4.96
D_2F_3	578.01	740.72	45.45	59.14	28.53	6.04	24.67	5.41
D_2F_4	606.73	454.09	56.65	34.67	34.48	7.48	25.30	5.02
D_3F_1	494.42	588.46	43.89	48.10	23.26	4.96	18.67	3.55
D_3F_2	552.23	607.30	46.28	52.03	27.06	5.15	18.60	3.57
D_3F_3	484.58	719.45	58.32	64.07	25.63	5.39	19.47	3.75
D_3F_4	577.69	648.62	47.22	53.06	23.48	4.94	17.45	3.49
D_4F_1	751.33	865.06	64.73	71.85	31.23	7.11	22.04	4.31
D_4F_2	731.66	895.74	73.90	76.57	30.29	6.76	21.50	4.96
D_4F_3	708.94	826.99	73.31	73.12	28.28	6.65	16.89	3.18
D_4F_4	825.37	865.70	76.24	76.49	27.41	5.65	18.55	3.71
Open	1083.66	1083.66	100.00	100.00	21.09	4.42	16.67	3.54

DAP - Days after planting

APPENDIX IV

Abstracts of ANOVA tables for tree growth characteristics of *Ailanthus* as affected by tree population density and fertiliser regimes

1. At three years of age

Source	df	Mean square		
		Growth characteristics		
		Height	Basal stem diameter	DBH
Density	3	2986.593	3.513	1.216
Error (A)	3	1645.443	0.764	0.494
Fertiliser	3	3098.862	2.892	0.922
Interaction	9	1199.351	0.992	0.242
Error (B)	12	1083.455	0.907	0.366

Contd...

Appendix IV contd....

2. At four years of age

Source	df	Mean square				
		Growth characteristics				
		Height	Basal stem diameter	DBH	Growth width	Pest incidence score
Density	3	5273.75	3.89	2.56	278.48	0.83
Error (A)	3	2866.09	0.99	0.69	318.17	0.90
Fertiliser	3	3514.06	3.10	1.31	452.76	1.13*
Interaction	9	1246.18	1.00	0.39	353.60	0.66
Error (B)	12	1679.87	1.64	0.53	217.58	0.26

3. Stand leaf area index

Source	df	Mean square
		LAI
Density	3	8.17**
Error (A)	6	0.37
Fertiliser	3	0.09
Interaction	9	0.41
Error (B)	24	0.29

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

APPENDIX V

Abstracts of ANOVA tables for foliar nutrient content of *Ailanthus* as affected by tree population density and fertiliser regimes

1. Nitrogen (upper crown)

Source	df	Mean square						
		JUN'94	JUL'94	AUG'94	SEP'94	OCT'94	NOV'94	DEC'94
Density	3	0.12	0.10	0.16	0.14	0.13	0.05	0.06
Error (A)	6	0.09	0.05	0.06	0.04	0.08	0.01	0.02
Fertiliser	3	0.02	0.07	0.06	0.29	0.16*	0.08*	0.01
Interaction	9	0.34**	0.12	0.09	0.22	0.08	0.08**	0.03
Error (B)	24	0.07	0.11	0.10	0.11	0.05	0.02	0.01

Source	df	Mean square					
		JAN'95	FEB'95	MAR'95	APR'95	MAY'95	JUN'95
Density	3	0.03	0.02	0.35	0.36	0.09	0.00
Error (A)	6	0.08	0.01	0.35	0.28	0.06	0.10
Fertiliser	3	0.03	0.26*	0.34	0.48	0.20**	0.04
Interaction	9	0.10	0.04	0.19	0.27	0.11**	0.08
Error (B)	24	0.05	0.06	0.14	0.31	0.02	0.11

Contd....

Appendix V contd....

2. Nitrogen (lower crown)

Source	df	Mean square						
		JUN'94	JUL'94	AUG'94	SEP'94	OCT'94	NOV'94	DEC'94
Density	3	0.38**	0.03	0.21	0.46	0.39**	0.34*	0.03*
Error (A)	6	0.03	0.03	0.11	0.17	0.02	0.06	0.004
Fertiliser	3	0.14	0.27	0.09	0.55**	0.18*	0.45**	0.11**
Interaction	9	0.07	0.12	0.15	0.07	0.06	0.06*	0.06**
Error (B)	24	0.06	0.10	0.10	0.09	0.04	0.03	0.01

Source	df	Mean square					
		JAN'95	FEB'95	MAR'95	APR'95	MAY'95	JUN'95
Density	3	0.14	0.04	0.06	0.44	0.01	0.04
Error (A)	6	0.03	0.06	0.02	0.14	0.04	0.04
Fertiliser	3	0.25**	0.03	0.23*	0.09	0.67**	0.08
Interaction	9	0.05	0.10	0.08	0.70	0.13*	0.06
Error (B)	24	0.03	0.06	0.05	0.32	0.04	0.06

Contd....

Appendix V contd....

3. Phosphorus (upper crown)

Source	df	Mean square						
		JUN'94	JUL'94	AUG'94	SEP'94	OCT'94	NOV'94	DEC'94
Density	3	0.001	0.0003	0.003*	0.0003	0.001**	0.0001	0.001*
Error (A)	6	0.0003	0.0002	0.0005	0.0002	0.0001	0.0003	0.0002
Fertiliser	3	0.001	0.001*	0.002	0.001	0.0003	0.0001	0.001**
Interaction	9	0.0002	0.001**	0.002*	0.001	0.0001	0.0004	0.002**
Error (B)	24	0.0004	0.0002	0.001	0.0003	0.0001	0.0002	0.0001

Source	df	Mean square					
		JAN'95	FEB'95	MAR'95	APR'95	MAY'95	JUN'95
Density	3	0.0003*	0.0001	0.003	0.002	0.0003	0.001**
Error (A)	6	0.0001	0.0002	0.002	0.001	0.001	0.0002
Fertiliser	3	0.0003	0.001**	0.003**	0.002	0.002*	0.0003*
Interaction	9	0.001**	0.0001	0.002*	0.001	0.001*	0.0003
Error (B)	24	0.0001	0.0002	0.001	0.001	0.0004	0.0002

Contd....

Appendix V contd....

4. Phosphorus (lower crown)

Source	df	Mean square						
		JUN'94	JUL'94	AUG'94	SEP'94	OCT'94	NOV'94	DEC'94
Density	3	0.001	0.001**	0.002	0.001*	0.0001	0.001	0.0003
Error (A)	6	0.0003	0.0001	0.001	0.0002	0.0003	0.0003	0.0001
Fertiliser	3	0.0003	0.0001	0.001	0.001*	0.001**	0.0001	0.001*
Interaction	9	0.001*	0.001**	0.001	0.0004	0.0002**	0.001**	0.002**
Error (B)	24	0.002	0.0002	0.001	0.0003	0.0001	0.0002	0.0003

Source	df	Mean square					
		JAN'95	FEB'95	MAR'95	APR'95	MAY'95	JUN'95
Density	3	0.0001	0.0001	0.0003*	0.004**	0.0001	0.0003
Error (A)	6	0.0002	0.0002	0.00003	0.0002	0.001	0.0002
Fertiliser	3	0.0003	0.0003	0.0003**	0.002	0.002**	0.0003
Interaction	9	0.0001	0.0001	0.0002**	0.003*	0.001**	0.0003
Error (B)	24	0.0001	0.0001	0.00004	0.001	0.0002	0.0002

Contd....

Appendix V contd....

5. Potassium (upper crown)

Source	df	Mean square						
		JUN'94	JUL'94	AUG'94	SEP'94	OCT'94	NOV'94	DEC'94
Density	3	0.02	0.01	0.01	0.01	0.02	0.05	0.79
Error (A)	6	0.01	0.01	0.03	0.01	0.02	0.03	0.65
Fertiliser	3	0.02	0.02	0.02	0.03*	0.09*	0.005	0.87
Interaction	9	0.02	0.06**	0.03	0.03**	0.07*	0.03	0.74
Error (B)	24	0.01	0.02	0.02	0.01	0.02	0.02	0.73

Source	df	Mean square					
		JAN'95	FEB'95	MAR'95	APR'95	MAY'95	JUN'95
Density	3	0.01	0.02	0.01	0.04	0.01	0.02
Error (A)	6	0.02	0.01	0.01	0.01	0.03	0.03
Fertiliser	3	0.01	0.10*	0.03	0.01	0.10*	0.02
Interaction	9	0.05	0.02	0.01	0.02*	0.06*	0.03**
Error (B)	24	0.02	0.02	0.01	0.01	0.02	0.01

Contd....

Appendix V contd....

6. Potassium (lower crown)

Source	df	Mean square						
		JUN'94	JUL'94	AUG'94	SEP'94	OCT'94	NOV'94	DEC'94
Density	3	0.07**	0.11**	0.01	0.01	0.01	0.01	0.03
Error (A)	6	0.01	0.01	0.01	0.02	0.01	0.03	0.02
Fertiliser	3	0.005	0.03	0.02	0.02	0.01	0.01	0.001
Interaction	9	0.01*	0.02	0.03	0.05**	0.07**	0.01	0.03*
Error (B)	24	0.004	0.01	0.02	0.01	0.01	0.02	0.01

Source	df	Mean square					
		JAN'95	FEB'95	MAR'95	APR'95	MAY'95	JUN'95
Density	3	0.00	0.02	0.03	0.07**	0.02	0.08
Error (A)	6	0.01	0.01	0.01	0.005	0.01	0.02
Fertiliser	3	0.02	0.02	0.02**	0.09*	0.18**	0.002
Interaction	9	0.02*	0.02	0.03**	0.13**	0.05**	0.02
Error (B)	24	0.01	0.02	0.00	0.02	0.01	0.02

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

APPENDIX VI

Abstracts of ANOVA tables for soil chemical properties before and after the ginger experiment as affected by tree population density and fertiliser regimes

1. Before the ginger experiment (Tree age - 3 years)

Source	df	Mean square						
		Total N	Available P	Available K	Organic carbon	Organic matter	C:N ratio	Soil pH
Density	3	0.005**	7.585	1231.727**	1.080**	3.023**	41.361**	0.035**
Error (A)	6	0.00004	4.798	1.519	0.042	0.125	2.465	0.0002
Fertiliser	3	0.0003	59.241**	5198.394**	1.016**	3.010**	44.028**	0.033**
Interaction	9	0.001**	29.476**	4827.561**	0.891**	2.640**	26.120**	0.014**
Error (B)	24	0.0002	4.116	5.556	0.091	0.271	2.514	0.0002

2. After the ginger experiment (Tree age - 4 years)

Source	df	Mean square						
		Total N	Available P	Available K	Organic carbon	Organic matter	C:N ratio	Soil pH
Density	3	0.0003	20.253*	885.764**	0.831**	2.462**	24.917**	0.007**
Error (A)	6	0.0002	2.235	44.618	0.031	0.091	0.750	0.0001
Fertiliser	3	0.0003	4.582	1898.264**	0.821**	2.420**	44.472**	0.021**
Interaction	9	0.0001	8.953**	1964.815**	0.751**	2.218**	35.009**	0.016**
Error (B)	24	0.00008	1.841	16.927	0.067	0.199	2.333	0.0001

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

APPENDIX VII

Abstracts of ANOVA tables for biometric/biomass observations of ginger as an understorey crop in a three year old *Ailanthus* stand at 55 days after planting

1. Biometric

Source	df	Mean square					
		Average tiller height	Number of tillers/clump	Number of leaves/clump	Leaf area/clump	LAI	Root length
Density	3	60.203	0.073*	3.711**	6123.842**	0.017**	32.884**
Error (A)	6	14.785	0.015	0.298	519.699	0.002	1.661
Fertiliser	3	18.247	0.002	0.126	844.762	0.003	7.445
Interaction	9	17.769	0.010	1.053	2486.061	0.006	3.802
Error (B)	24	12.961	0.021	1.347	1072.682	0.003	4.327

2. Biomass

Source	df	Mean square					
		Fresh weight			Dry weight		
		Culm	Leaf	Below ground	Culm	Leaf	Below ground
Density	3	439541.1**	85077.1**	9261978.0**	2023.2**	1127.3	85460.6**
Error (A)	6	38113.2	3964.6	430164.6	92.2	60.3	4097.7
Fertiliser	3	28599.4	17729.2	2753839.0**	71.0	204.7	28926.8**
Interaction	9	169185.8	49859.4	2497848.1**	819.4	718.8	24803.3**
Error (B)	24	120348.6	24941.0	561383.2	364.7	361.2	5569.7

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

APPENDIX VIII

Abstracts of ANOVA tables for biometric/biomass observations of ginger as an understorey crop in a three year old *Ailanthus* stand at 116 days after planting

1. Biometric

Source	df	Mean square					
		Average tiller height	Number of tillers/clump	Number of leaves/clump	Leaf area/clump	LAI	Root length
Density	3	187.834**	5.477*	1584.352**	1911767.276**	4.445**	25.553**
Error (A)	6	9.303	0.567	104.683	107952.216	0.319	2.503
Fertiliser	3	79.213**	0.782	131.047	639685.110**	1.685**	27.447*
Interaction	9	31.773*	1.932*	221.221	352573.386**	0.827*	12.601
Error (B)	24	12.983	0.746	108.160	98896.869	0.255	6.873

Contd....

2(a) Biomass (Fresh weight)

Source	df	Mean square				
		Culm	Leaf	Root	Rhizome	Residual rhizome
Density	3	54163128.7**	18352911.6**	534630.5	32292926.8**	910607.6*
Error (A)	6	3083389.7	1543600.9	315980.5	2291743.8	163432.6
Fertiliser	3	7715381.5	3455729.9*	951536.0*	985763.9	187974.3
Interaction	9	20092928.7**	3029521.6*	479573.0	11763992.9*	394215.0
Error (B)	24	5214475.8	990417.9	290576.3	4101495.2	300315.3

2(b) Biomass (dry weight) kg ha^{-1}

Source	df	Mean square				
		Culm	Leaf	Root	Rhizome	Residual rhizome
Density	3	171539.8*	188120.7**	34255.2	325893.9*	13502.8*
Error (A)	6	19498.6	17140.7	9648.7	37691.5	1442.8
Fertiliser	3	33647.7	46944.4*	8683.6	843.6	4205.4
Interaction	9	87706.8**	34217.1	13493.5	140952.4*	5076.2
Error (B)	24	26324.7	14985.9	11901.8	60944.7	3763.0

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

APPENDIX IX

Abstracts of ANOVA tables for biometric/biomass observations of ginger as an understorey crop in a three year old *Ailanthus* stand at 211 days after planting

1. Biometric

Source	df	Mean squares			
		Average tiller height	Number of tillers/clump	Number of leaves/clump	Root length
Density	3	166.166*	2.092	429.312*	10.655*
Error (A)	6	34.133	0.527	51.271	1.568
Fertiliser	3	35.712	2.793**	311.518*	10.698
Interaction	9	81.990*	2.364**	258.138*	8.632
Error (B)	24	30.722	0.495	82.320	3.818

Source	df	Mean square							
		Fresh weight				Dry weight			
		Culm	Leaf	Root	Rhizome	Culm	Leaf	Root	Rhizome
Density	3	6970763.3*	2676666.9*	395833.3	99853680.6	91732.6	113739.3	19789.4	6947054.4*
Error (A)	6	1329461.7	531822.9	384531.3	37115607.6	35604.6	33702.0	16413.0	1099345.6
Fertiliser	3	5382846.9*	600416.7	413194.5	15145208.3	54878.8	64825.0*	32483.0	314634.4
Interaction	9	4064328.3**	1289120.4**	264953.7	33508310.2	93185.4*	90862.0**	24322.3	1771087.6
Error (B)	24	1167916.5	337256.9	263993.1	18423211.8	31269.1	20788.6	20588.3	1323776.8

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

APPENDIX X

Abstracts of ANOVA tables for rhizome yield and quality of ginger as an understorey crop in a three year old *Ailanthus* stand at 234 days after planting

Source	df	Mean square			
		Rhizome yield		Quality attributes	
		Fresh	Dry	Essential oil	Oleoresin
Density	3	68.310*	5.274	0.005	3.194
Error (A)	6	14.055	1.213	0.002	0.694
Fertiliser	3	1.296	0.628	0.005	1.639
Interaction	9	11.719	0.723	0.001	0.824
Error (B)	24	7.081	0.358	0.002	0.778

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

APPENDIX XI

Abstracts of ANOVA tables for the nutrient content of ginger foliage and mature rhizomes

Source	df	Mean square											
		Ginger foliage									Rhizome		
		55 DAP			116 DAP			211 DAP			234 DAP		
		N	P	K	N	P	K	N	P	K	N	P	K
Density	3	0.49	0.001	0.09	0.22*	0.004**	0.50	0.04	0.001	0.91	0.04	0.001	0.15*
Error (A)	6	0.12	0.0005	0.32	0.04	0.001	0.18	0.03	0.001	0.33	0.02	0.003	0.02
Ferti-liser	3	0.11	0.001	0.11	0.11	0.0001	0.09	0.14	0.0001	1.24	0.01	0.008	0.10
Inter-action	9	0.04	0.001	0.13	0.23	0.002*	0.48	0.18**	0.002	1.04	0.03	0.004	0.23**
Error (B)	24	0.13	0.001	0.30	0.10	0.001	0.46	0.05	0.001	0.63	0.02	0.021	0.06

* Significant at 5% level

** Significant at 1% level

APPENDIX XII

Abstracts of ANOVA tables for the total above and below ground biomass of understorey ginger crop as affected by tree population density and fertiliser regimes

Source	df	Mean square									
		Total above ground biomass						Total below ground biomass			
		Fresh weight			Dry weight			Fresh weight		Dry weight	
		55	116	211	55	116	211	116	211	116	211
Density	3	0.91**	135.06**	17.83*	0.01**	0.86**	0.37	27.70*	111.27	0.28	7.12*
Error (A)	6	0.04	6.23	3.51	0.002	0.04	0.12	4.53	42.92	0.06	1.28
Fertiliser	3	0.05	20.28	9.49*	0.0003	0.10	0.23	4.05	19.70	0.01	0.47
Interaction	9	0.38	33.78**	9.32**	0.003*	0.20**	0.35**	19.23*	34.49	0.19*	0.76
Error (B)	24	0.22	9.29	2.43	0.001	0.05	0.08	5.96	21.19	0.07	1.40

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

APPENDIX XIII

Abstracts of ANOVA tables for the recovery of ^{32}P activity in the leaves of ginger at 15, 30 and 45 days after isotope application to the soil as affected by tree population density and lateral distance

Source	df	Mean square								
		15 DAA			30 DAA			45 DAA		
		Treated plants	Neigh-bouring 25 cm	Plants 50 cm	Treated plants	Neigh-bouring 25 cm	Plants 50 cm	Treated plants	Neigh-bouring 25 cm	Plants 50 cm
Density	2	0.696	0.109	1.161	0.493	0.722	0.209	0.323	0.035	0.168
Error (A)	6	0.412	0.324	0.816	0.312	0.442	0.770	0.151	0.559	0.372
Lateral distance	1	0.465	0.007	0.086	0.296	0.291	0.057	0.349	0.007	2.080*
Interaction	2	0.056	0.422	0.061	0.055	0.071	0.964*	0.485	0.037	0.392
Error (B)	9	0.343	0.288	0.671	0.390	0.082	0.179	0.170	0.084	0.331

* Significant at 5% level
** Significant at 1% level
DAA - days after application

APPENDIX XIV

Abstracts of ANOVA tables for the recovery of ^{32}P activity in the foliage of adjacent trees in the mixed cropping system with ginger as the treated plant, as affected by tree population density and lateral distance at 15, 30 and 45 days after application of ^{32}P

Source	df	Mean square					
		Adjacent tree (1.375 m)			Adjacent tree (1.625 m)		
		15	30	45	15	30	45
Density	1	1.355	1.267	1.038	0.524	2.196	2.649
Error (A)	3	0.512	1.632	1.112	0.816	1.215	1.573
Lateral distance	1	6.190*	2.219	0.015	0.458	1.958	1.344
Interaction	1	0.174	0.283	0.942	2.023	0.103	0.237
Error (B)	6	0.574	2.607	1.701	1.288	0.854	0.608

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

APPENDIX XV

Abstracts of ANOVA tables for the recovery of ^{32}P activity in the leaves of *Ailanthus* at 15, 30 and 45 days after isotope application to the soil as affected by tree population density, cropping situation and lateral distance of ^{32}P application

Source	df	Mean square					
		15 DAA		30 DAA		45 DAA	
		Treated tree	Adjacent trees	Treated tree	Adjacent trees	Treated tree	Adjacent trees
1. Density	1	0.986	3.748*	0.301	11.028**	2.398	12.852**
Error (A)	3	1.302	0.288	0.958	0.068	0.782	0.125
2. Cropping situation	1	0.532	0.249	0.935	0.001	0.029	0.446
Interaction							
1 x 2	1	1.214	2.943**	1.203	1.325	0.015	1.436
Error (B)	6	0.503	0.154	0.202	0.375	0.469	0.378
3. Lateral distance	1	0.118	0.661	0.009	0.246	0.051	0.312
Interaction							
1 x 3	1	0.167	1.994*	0.250	0.020	0.182	0.010
2 x 3	1	0.108	3.035*	0.001	0.508	0.236	0.411
1 x 2 x 3	1	0.004	0.364	0.003	0.448	0.506	0.563
Error (C)	12	0.676	0.408	0.290	0.288	0.330	0.293

* Significant at 5% level
** Significant at 1% level
DAA - Days after application
Adjacent trees in the North South direction

APPENDIX XVI

Abstracts of ANOVA tables for the recovery of ^{32}P from the foliage of adjacent trees in the east west direction as affected by tree population density and lateral distance of application

Source	df	Mean square		
		Adjacent trees 3 m apart (Tree monoculture)		
		15 DAA	30 DAA	45 DAA
Density	1	0.817	0.829*	0.077
Error (A)	3	0.577	0.059	0.760
Lateral distance	1	0.597	0.459	3.024*
Interaction	1	0.897	0.971	0.597
Error (B)	6	0.689	0.376	0.454

* Significant at 5% level
** Significant at 1% level
DAA - Days after application

APPENDIX XVII

Abstracts of ANOVA tables for the recovery of ^{32}P activity from ginger foliage, in the mixed cropping system, when ^{32}P was applied to *Ailanthus* as affected by tree population density and lateral distance of application

Source	df	Mean square											
		Ginger plants at											
		1.125 m			1.375 m			1.625 m			1.875 m		
		15 D	30 D	45 D	15 D	30 D	45 D	15 D	30 D	45 D	15 D	30 D	45 D
Density	1	0.31	0.35	0.03	0.37	0.01	0.03	0.09	0.01	0.06	0.35	0.001	0.11
Error (A)	3	0.15	0.36	0.13	0.10	0.59	0.06	0.17	0.36	0.08	0.10	0.25	0.05
Lateral distance	1	0.13	0.04	0.13	0.01	0.03	0.04	0.09	0.08	0.22	0.34	0.003	0.01
Interaction	1	0.04	0.03	0.11	0.09	0.23	0.0003	0.001	1.15*	0.01	0.01	0.03	0.12
Error (B)	6	0.19	0.07	0.05	0.06	0.09	0.012	0.09	0.15	0.10	0.14	0.11	0.07

* Significant at 5% level
** Significant at 1% level
D - Days after application

APPENDIX XVIII

Photosynthetically active radiation (μ moles $s^{-1}m^{-2}$) in the open (P.Q.) and under *Ailanthus* canopy (L.Q.) at different heights above the ground level during the period from 17th March to 27th April 1995

Local solar hour	PAR (μ moles $s^{-1}m^{-2}$)															
	Height above ground level															
	Treatment : D_1F_1				Treatment : D_1F_2				Treatment : D_1F_3				Treatment : D_1F_4			
	50 cm		150 cm		50 cm		150 cm		50 cm		150 cm		50 cm		150 cm	
	P.Q.	L.Q.	P.Q.	L.Q.	P.Q.	L.Q.	P.Q.	L.Q.	P.Q.	L.Q.	P.Q.	L.Q.	P.Q.	L.Q.	P.Q.	L.Q.
7 am	40	12	30	12	27	12	30	12	39	12	48	15	71	18	73	27
8	279	72	289	80	157	98	216	147	331	72	307	90	512	80	500	92
9	1008	179	992	168	398	248	634	418	948	165	732	183	973	130	1007	192
10	1525	671	1460	329	790	462	1069	682	1462	372	1012	278	1560	358	1048	367
11	1855	414	1771	885	1003	485	1477	271	1805	174	1209	309	1633	420	1506	534
12	2038	1391	1939	1523	1037	476	1851	669	1973	444	1580	685	1985	1375	1361	930
1 pm	2014	1729	1909	1768	1644	907	1392	763	2039	1147	1752	1014	1938	1590	1912	1724
2	1908	604	1744	1242	1818	546	1169	561	1770	438	1436	481	1653	940	1768	1613
3	1463	256	1464	503	1446	373	1435	309	1474	230	1762	261	1232	343	966	703
4	1308	215	1017	228	1294	353	1610	290	1174	330	1543	220	941	246	432	215
5	861	359	604	140	939	238	1221	315	746	272	1079	151	688	165	470	214
6	462	162	223	93	321	110	635	85	367	97	493	71	293	67	226	80

Contd.....

APPENDIX XVIII contd....

Local solar hour	PAR (μ moles $s^{-1}m^{-2}$) Height above ground level: Treatment : D_2F_1 50 cm P.Q.	L.Q.	D_2F_1 150 cm P.Q.	L.Q.	Treatment : D_2F_2 50 cm P.Q.	L.Q.	D_2F_2 150 cm P.Q.	L.Q.	Treatment : D_2F_3 50 cm P.Q.	L.Q.	D_2F_3 150 cm P.Q.	L.Q.	Treatment : D_2F_4 50 cm P.Q.	L.Q.	D_2F_4 150 cm P.Q.	L.Q.
7 am	35	14	48	17	30	20	23	16	18	9	20	13	16	8	20	8
8	262	100	309	75	318	207	276	200	342	111	304	191	196	124	252	118
9	790	286	916	323	776	546	834	583	959	414	853	633	744	589	828	401
10	1391	640	952	324	1186	930	1311	815	1471	654	1436	1204	1314	1140	1595	333
11	1857	570	1436	328	1814	1335	1708	1368	1811	943	1612	1546	1647	1103	1916	389
12	1230	563	1709	545	1949	1576	1924	1754	2017	1293	1991	1595	1881	532	2031	831
1 pm	1419	765	1755	821	1987	1747	1964	1798	1999	1551	2054	1485	1903	921	1339	1071
2	1901	572	1844	714	1331	1628	1955	1817	1924	902	1967	1083	1701	719	1303	1094
3	1238	539	1522	388	1739	1261	1690	1489	1511	334	1743	541	1248	535	1580	628
4	1035	618	1174	400	1286	623	1203	884	1183	368	1234	285	1397	754	1723	260
5	638	401	599	255	769	262	598	344	692	217	688	202	951	680	1593	196
6	300	141	252	117	300	205	327	163	268	141	227	110	395	175	1027	113

Contd.....

APPENDIX XVIII contd.....

Local solar hour	PAR (μ moles $s^{-1}m^{-2}$)															
	Height above ground level															
	Treatment : D_3F_1				Treatment : D_3F_2				Treatment : D_3F_3				Treatment : D_3F_4			
	50 cm		150 cm		50 cm		150 cm		50 cm		150 cm		50 cm		150 cm	
	P.Q.	L.Q.	P.Q.	L.Q.	P.Q.	L.Q.	P.Q.	L.Q.	P.Q.	L.Q.	P.Q.	L.Q.	P.Q.	L.Q.	P.Q.	L.Q.
7 am	46	24	37	17	67	28	52	26	18	11	33	21	97	39	54	29
8	216	103	291	86	252	110	264	118	194	92	204	121	508	172	310	101
9	559	217	852	177	695	246	721	229	724	189	771	360	1035	306	818	227
10	1257	314	1350	241	1224	289	1062	392	1499	636	1022	524	1542	330	1125	397
11	1520	424	1744	848	1723	575	1417	951	1497	652	1449	849	1939	852	1404	885
12	1916	597	1597	1125	1799	1161	1692	1480	1978	1427	1497	1124	2014	1608	1899	1639
1 pm	2054	1342	1638	1329	1470	1086	1842	1576	1406	1169	1502	1272	1809	1426	1915	1660
2	1624	1075	1782	1418	1829	1171	1649	1265	456	308	1725	1525	1557	838	1604	1229
3	1741	637	1568	859	1691	973	1086	474	1321	820	1687	1410	1234	455	1434	862
4	1380	565	1290	410	1257	733	1106	452	445	303	1310	888	1071	604	1235	437
5	846	489	834	365	771	184	845	233	149	93	867	373	561	201	507	212
6	394	145	349	186	203	70	290	91	178	114	351	165	180	100	273	104

Contd.......

APPENDIX XVIII contd....

Local solar hour	PAR (μ moles $s^{-1}m^{-2}$)															
	Height above ground level															
	Treatment : D_4F_1				Treatment : D_4F_2				Treatment : D_4F_3				Treatment : D_4F_4			
	50 cm		150 cm		50 cm		150 cm		50 cm		150 cm		50 cm		150 cm	
	P.Q.	L.Q.	P.Q.	L.Q.	P.Q.	L.Q.	P.Q.	L.Q.	P.Q.	L.Q.	P.Q.	L.Q.	P.Q.	L.Q.	P.Q.	L.Q.
7 am	34	24	21	16	16	12	23	17	13	10	22	18	28	18	33	23
8	271	169	188	170	278	154	316	186	144	110	195	159	216	134	313	170
9	718	390	534	472	774	459	916	432	658	412	537	419	952	483	599	359
10	1207	788	1024	699	896	541	1386	703	911	645	1166	782	1385	711	665	523
11	1573	811	1426	781	1522	964	1793	1338	1360	883	1172	1126	1699	1069	1219	982
12	1890	1204	1767	1427	1503	1271	1952	1748	1479	1291	1478	1447	1732	1484	1867	1609
1 pm	1938	1759	1924	1844	1315	1193	1997	1913	1633	1480	2063	1981	1694	1552	1992	1910
2	1816	1572	1978	1810	1729	1646	1776	1757	1549	1310	1818	1650	1494	1413	1872	1801
3	1681	1023	1896	1578	1541	1177	1358	1276	1424	833	1585	1121	1418	1288	1583	1360
4	1282	565	1585	978	1136	527	1013	749	1186	624	1556	592	1070	919	1207	918
5	830	452	1160	396	681	618	616	412	793	561	1109	416	615	516	739	505
6	352	257	579	209	250	217	233	216	421	348	500	213	347	317	335	227

P.Q. - Point Quantum Sesor
L.Q. - Line Quantum Sesor

UNDERSTOREY PRODUCTIVITY OF AGRISILVICULTURAL SYSTEMS AS AFFECTED BY TREE POPULATION DENSITY AND FERTILISER REGIMES

BY

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ABSTRACT OF A THESIS

Submitted in partial fulfilment of the requirement for the degree

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1996

ABSTRACT

A split plot experiment, involving ailanthus (*Ailanthus triphysa* (Dennst.) Alston.) at various population densities (3333, 2500, 1600 and 1111 TPHA) and fertiliser regimes (0:0:0, 50:25:25, 100:50:50 and 150:75:75; kg $N:P_2O_5:K_2O$ $ha^{-1}yr^{-1}$), initiated in June, 1991 was intercropped with ginger (*Zingiber officinale* Roscoe). Additional treatments included monocultures of ginger and ailanthus. Objectives were to assess the productivity of ginger as a component of an agrisilviculture system involving ailanthus, besides analysing the partitioning of solar radiation among the different components of the system and characterising the nature of below ground interactions between the field and tree crop components.

Ailanthus growth and its foliar chemical composition was not influenced by tree population density and fertiliser regimes. Light availability below the canopy was, however, strongly altered by tree population density. Availability of photosynthetically active radiation (PAR) was inversely proportional to stand density. Available PAR ranged from 35-72 per cent and 40-75 per cent of that in the open, at 50 and 150 cm above the ground level respectively. A strong relationship however, could not be established between light availability and foliar nitrogen content of the tree.

Ginger grown in the interspaces of ailanthus exhibited better growth as compared to the sole crop situation. Tissue nutrient content of ginger in the later stages were higher when grown as mixed crop. The tree population density of 2500 trees per hectare (TPHA) registered better growth of understorey ginger. Fresh and dry rhizome yield of ginger also was maximum at this density. However, no strong relationship could be established between light availability and rhizome yield of ginger. Fertilisers applied to the tree component of the system, did not influence the growth, yield and quality of ginger.

Three years of tree growth significantly reduced soil nutrient status below trees. A reduction in soil pH also was observed. Radiophosphorus recovery by ginger and ailanthus were not substantially altered by tree population density, lateral distance of application and cropping situation. However, ailanthus absorbed a substantial portion of the fertilisers applied to the ginger crop. Root activity of ailanthus suggests that 41-53 per cent of active roots are situated at about 40 cm from the tree trunk. Neighbouring trees in the high density stand registered a high recovery of ^{32}P as compared to the low density stand, which may have important management implications.