PRODUCTIVITY OF AILANTHUS (*Ailanthus triphysa*) UNDER DIFFERENT FERTILISER REGIMES AND POPULATION DENSITIES

By

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THESIS

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DECLARATION

I hereby declare that this thesis entitled "**Productivity of ailanthus (*Ailanthus triphysa*) under different fertiliser regimes and population densities**" is a bonafide record of research work done by me during the course of research and that the 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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We, the undersigned members of the Advisory Committee of **Mr.Naveed Shujauddin,** a candidate for the degree of **Master of Science in Forestry** agree that the thesis entitled "**Productivity of ailanthus (*Ailanthus triphysa*) under different fertiliser regimes and population densities**" may be submitted by Mr.Naveed Shujauddin, in partial fulfilment of the requirements for the degree.

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NAVEED SHUJAUDDIN

DEDICATED TO MY

Grand Mother

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Introduction

INTRODUCTION

Augmenting forest plantations to meet the ever-increasing demand for tropical tree products has become fashionable in recent decades. Up to 1997, the state forest departments in India have established a total of 153.4 lakh hectares of plantations (FSI, 1999). These man-made forests are expected to ease the pressure on natural forests in the humid tropical region which disappear at an estimated annual rate of 0.8 per cent (FAO, 1993). Furthermore, the recent Kyoto protocol (1997) reiterated the need for raising forest plantations to mitigate global warming (Clean Development Mechanism). It also implied that carbon credits generated from planted forests will be the main commodity for sale in the futuristic trading process (Asumadu, 1999).

A wide spectrum of trees is often involved in tropical plantation programmes. Important attributes include rapid juvenile growth, efficient dry matter production in terms of water and nutrient inputs, crown characteristics to maximise interception of solar radiation and ease or regeneration (Kumar *et al.*, 1998). Objectives of tree plantings are also variable. It includes development of high yielding and sustainable industrial plantations for wood production, control of land degradation besides agroforestry. In addition, MPT woodlots may have a facilitative or catalytic role in promoting native vegetation succession too (Parrotta, 1999).

Ailanthus triphysa (Dennst) Alston., locally known as Matti, is a prominent multipurpose tree in the traditional homegardens of Kerala. It is a fast growing tree with a mean biomass MAI of approximately 14 Mg ha^{-1} yr^{-1}. The wood is used for plywood, packing cases, toys, match industry and many other uses. The tree is also popular as a support tree for trailing black pepper vines.

However, comparatively little is known about the silvicultural techniques for multiple objective ailanthus stand management. The biomass productivity of the MPTs differs enormously with site and stand management practices (Deans *et al.*, 1996). Fertilisation and stand density manipulation are two major considerations in this regard, although literature on silvicultural manipulation of tropical trees in general and ailanthus in particular is scarce. Hence a study was carried out on ailanthus to evaluate it's biomass production potential when grown under graded levels of fertiliser and population densities. Additional objectives included estimating the nutrient characteristics of the species and evaluating nutrient export from the site through whole tree harvesting.

Review of Literature

2. REVIEW OF LITERATURE

Ailanthus triphysa (Dennst.) Alston (ailanthus) belongs to the family Simaroubaceae. The genus *Ailanthus* is having five species of deciduous trees occurring in Southern Asia, Malaya, China and Australia of which four species occur in India. Ailanthus is a prominent multipurpose tree (MPT) in the traditional homegardens of Kerala (Kumar *et al.*, 1994) and the natural evergreen forests of Western Ghats (PID, 1948). It is found in the Western Ghats from Konkan through Karnataka to Travancore up to 1500 m elevation. In Kerala, *A. triphysa* perhaps occur in all the physiographic provinces except the high hills and it tolerates a wide range of soils. But higher frequencies are found in places with very deep, well drained, gravelly clay soils on gently sloping coastal laterites (clayey - skeletal, kaolinitic, Typic kandiustults/kanhaplustults) and very deep, well drained, gravelly clay soils with moderate surface gravelliness on gently sloping midland laterites (clayey, kaolinitic, Ustic kandihumults/kanhaplohumults) (Kumar, 2001).

Ailanthus (locally known as *Matti*) is a prominent matchwood species used both for splints and boxes. The very light and soft wood is also utilised for plywood, for making packing cases, catamarans, fishing floats, sword handles, toys, drums etc. The bark, gum roots and leaves are used medicinally (Indira, 1996). The tree yields a highly viscous aromatic resin that is widely used as incense and in indigenous medicines (PID, 1948). Ailanthus is a popular support tree for pepper vines and is an important component of silvipastoral and agrisilvicultural systems in Kerala (Kumar *et al.*, 1994; Kumar, 2001). A survey conducted in 17 thaluks of the Kerala state to determine the floristic structure and composition of homegardens revealed that relative frequency of ailanthus was the highest (13.2%) among the homegarden tree components (Kumar *et al.*, 1994). The average commercial standing stock of Kerala homesteads ranged from 6.6 to 50.8 m^3 ha^{-1} and fuelwood volume is of the order of 23 to 86 m^3 ha^{-1} (Kumar *et al.*, 1994). Although ailanthus is extensively grown on a plantation scale and agroforestry, scientific information on its management is seldom available. The available literature on ailanthus, specially on its silvicultural management, suitability as a component of mixed species systems, implication for sustainable production and effects on soil nutrient capital are renewed here.

2.1 General description and suitability for mixed species stands

Ailanthus, a deciduous tree with a tall cylindrical trunk attaining a height of about 30 m is characterised by small compact crown. Considering the crown architecture, growth, leaf phenology and branching pattern, ailanthus could be classified into the KORIBA's architectural model (Chandrashekara, 1996). Owing to the small crown, moderate root spread and deep rooting tendency, ailanthus is thought to be less competitive with associated crops (Mathew *et al.*, 1992; Thomas *et al.*, 1998). Consequently many field/tree crops such as ginger are frequently grown in association with ailanthus (Kumar *et al.*, 2001).

Due to its quick rate of growth, it is recommended as a plantation species for producing matchwood over shorter rotations. Although the demand for ailanthus timber is very high from the industrial sector of Kerala, supply is limited only 10 per cent of the demand is met from the Kerala forests (Nair *et al.*, 1984). The tree is prone to attack by insect pests such as *Atteva fabriciella* (Ailanthus webworm) and *Eligma narcissus* (Ailanthus defoliator) and the potential for insect damage is greater in the monospecific stands. However, ailanthus is often considered promising under polycultural systems (Kumar *et al.*, 1998).

Although ailanthus is regarded as a promising multipurpose tree with high potential for wood production over short rotations, silvicultural research on this species has been mostly anecdotal. No attempts were made hitherto to evaluate the stand/tree management practices for ailanthus.

2.2 Tree/stand management practices

2.2.1 Ailanthus

There are relatively few reports of experimental manipulation of tree density and/or fertiliser levels in tropical tree species and in particular very few such studies have been conducted on ailanthus. Sojak and Loffler (1988) found that two year old, NPK fertilised ailanthus seedlings showed an average height and diameter growth of 303 cm and 49.3 mm respectively compared with 185 cm and 31.7 mm for control plants. N and P applications improved the branching of roots and root length considerably and enhanced root biomass by two-three fold in three year old ailanthus seedlings. Also, in a study on two year old ailanthus saplings in Rajasthan, N application improved tree height by 15-25 per cent and total biomass by 30 per cent (Gupta, 1994).

Kumar *et al.* (2001) however did not observe any significant effect of fertilisation (0:0:0, 50:25:25, 100:50:50 and 150:75:75 of kg N, P_2O_5 and K_2O ha^{-1} yr^{-1}) on tree height and diameter at breast height (dbh) in four year old saplings. In another study, Kumar *et al.* (1998) evaluated ailanthus productivity under two planting programmes and reported that biomass varies from MAI (mean annual increment) 3.96 to 4.61 Mg ha^{-1}. In a study involving four spacing treatments (3 x 1 m, 2 x 2 m, 3 x 2 m and 3 x 3 m). Kumar *et al.* (2001) found that although stand LAI (leaf area index) increased as tree population density increased there was no effect of population density on tree height and diameter growth. Overall, fertiliser application and density regulation in ailanthus stands are unresolved issues.

2.2.2 Other tropical hardwoods

2.2.2.1 Effect of stand density on tree growth

Several workers have reported that stand density exerts a pronounced effect on crown diameter, diameter at breast height (dbh) and biomass production of trees (Wang, 1987; Okario and Maghembe, 1994). For instance, Bernardo *et al.* (1998) reported that individual stems increased in diameter growth with increased spacing in *Eucalyptus camaldulensis, E. pellita* and *E. urophylla*. Diameter and height growth increased with spacing in *Leucaena leucocephala* and *Terminalia arjuna* also (Maghembe *et al.*, 1986; Jain and Singh, 1998). An increase in height and basal stem diameter of *Vateria indica* seedlings with increasing plant density also has been reported (KAU, 1992). Sahoo *et al.* (1996) observed that diameter at breast height (dbh) increased linearly whereas height declined with increased spacing in *Leucaena leucocephala*. Similar observations were reported for *Ricinus communis* (Poma *et al.*, 1996).

Many workers have also shown that stand density has little effect on growth in height, except where the stand is extremely dense or so open that the trees are distinctly isolated (Smith, 1962; Lanner, 1985). Among the tropical species *Leucaena leucocephala* and *Grevillea robusta* did not show much difference in height, collar and crown diameter when grown at various spacings (Gill *et al.*, 1991; KAU, 1992).

2.2.2.2 Effect of density on stand growth/productivity

Productivity of a stand is a function of tree growth rate and number of trees per unit area (DeBell *et al.*, 1989). Tree density influences the time required for canopy closure in forest stands. Denser stands may attain canopy closure sooner than sparse stands. This in turn implies better site resource utilization and/or earlier onset of competitive interactions (Long and Smith, 1984). Many authors have reported higher initial productivity in dense stands. For example, Jain and Singh (1998) reported an increase in growth and biomass production of *Terminalia arjuna* from lower (10,000 plants ha^{-1}) to higher (30,000 plants ha^{-1}) plant density. Total dry matter yield was higher at the high plant density (5000 plants ha^{-1}) in *Gliricidia sepium* at cutting intervals of 6, 9 and 12 weeks (Clavero and Razz, 1997). Keerthisena (1995) observed a decrease in shoot biomass yield with increasing alley width (spacing) in *Gliricidia sepium*. Bernardo *et al.* (1998) reported that total biomass production per hectare decreased with increasing spacing in three species of eucalyptus (*E. camaldulensis*, *E. pellita* and *E. urophylla*). For *Leucaena leucocephala* fuel and fodder yields have been reported to be negatively correlated with spacing and total volume and biomass per hectare increased under closer spacing (Laeeq and Hussain, 1990).

Some studies, however, suggest that spacing always does not have a significant effect on growth and development of tropical hardwoods. For instance, although Srivastava *et al.* (1999) observed an increase in mean stand basal area and volume with increasing plant density of *Terminalia arjuna* in the initial years, at a later age differences in basal area were nonsignificant. Although there are contradictory trends on the effects of spacing on growth and yield of tropical hardwood species, higher population density in general may favour early crown closure but may depress individual tree growth subsequently.

2.3 Fertilisers

Judicious nutritional management is a powerful tool to ensure not only increased productivity of forests but also to sustain productivity over many relations (Nambiar, 1984). Fertilisation is the most important single treatment that can be applied to the crop to accelerate growth, shorten the time in which a yield might be obtained and to increase the financial returns (Ford, 1984). Fertilisation causes an array of shifts in tree physiological processes that result in increased stem growth. Leaves may increase their photosynthetic activity by raising levels of chlorophyll, trees may expand their canopies or the allocation of photosynthetic products may change (Binkley, 1986).

Many authors have, however, reported varying effects of fertilisations in forest trees - significantly positive, nonsignificant and significantly negative. Average stem height and diameter were significantly increased by fertilisation in one year old *Eucalyptus saligna* seedlings (Walters, 1982). In Eucalypts (a hybrid of *E. grandis* and *E. camaldulensis*) fertilising rates had a positive effect on volume and dry matter production (Miranda *et al.*, 1998). Chaves and De Loma (1974) reported that MAI of unfertilised trees of *Eucalyptus globulus* was 3.3 m^3 ha^{-1} as against 12, 15, 20 and 27 m^3 ha^{-1} for trees fertilised with NPK (20:10:10) at the rate of 200, 400, 600 and 800 kg ha^{-1} respectively. Cromer and Williams (1982) showed that net primary production of *Eucalyptus globulus* between ages 6 and 9.5 years increased from 7.2 to 15.4 Mg ha^{-1} yr^{-1} as a result of N and P fertilisation.

However, height and basal diameter in *Grevillea robusta* remained uninfluenced by fertilisation (KAU, 1992). Ranwell (1975) studying the response of one year old *E. grandis* and *E. saligna* seedlings to fertilisation found that there was no increase in growth, due to high rates of fertiliser application at one of the two sties in South Africa. Binkley (1986) found that age, size, stocking and vigor responsible to difference in fertilisation responses. Barros and Pritchett (1979) reported that ammonium sulphate significantly reduced seedling growth of *Eucalyptus grandis*.

2.4 Nutrient export through harvest and nutrient use efficiency (NUE)

Amounts of nutrients removed during harvest depends on utilization standards, tree species, stand development and site quality (McGoll and Powers, 1984). Nutrient removals are increased as more biomass is harvested and the loss per unit biomass is much higher in leaves, branches and bark than for stemwood (Binkley, 1986).

Nutrient content of bark in Eucalyptus was high compared to stemwood and hence debarking logs onsite significantly reduced nutrient export (Hopman *et al.*, 1993). Whole tree harvesting can increase biomass removal over stem harvesting by 30 per cent and nutrient removal i.e., NPK by 65, 45 and 44 per cent respectively in *Casuarina equisetifolia* (Wang *et al.*, 1991). Rotation length is an important factor determining nutrient removal even under low utilization (Webber, 1978). Nutrient retention in perennial tree parts parallels the trend in biomass growth, peaking around crown closure and decreasing with time. Thus, more nutrients will be removed in several short rotations than in an equivalent harvest in a longer rotation (Madgwick *et al.*, 1977).

The potential nutrient export, especially with whole tree harvesting may deplete the site nutrient capital (Jorgensen and Wells, 1986). Altering the rate of nutrient removal in products, is therefore an important design criterion in intensive short rotation silvicultural systems.

Nutrient accumulation rates are generally higher if the biomass is high. Comparing the nutrient use efficiency (NUE) of nine multipurpose trees, Kumar *et al.* (1998) showed that NUE of tropical species is tremendously variable. They reported nitrogen use efficiency (NUE, Kg biomass per g of N) values of 0.1841, 0.1026 and 0.1772 respectively for 8.8 yr, 7 yr and 5 yr old ailanthus stands. The corresponding figures for phosphorus use efficiency (PUE, Kg biomass per g of P) were 3.032, 0.904 and 1.159 and that of potassium use efficiency (KUE, kg biomass per g K) were 0.566, 0.137 and 0.496. Wang *et al.* (1991) also found large differences in nutrient use efficiency of five tropical tree species (*Casuarina equisetifolia, Albizia procera, E. robusta, L. Leucocephala* K8 and *L. leucocephala* P.R) with casuarina showing the highest efficiency for N, P, K and Mg and Leucaena K8 the least efficient.

2.5 Effect of quick growing trees on soil properties

The promotion of short rotation plantations to resolve the chronic wood shortages in tropical regions (FAO, 1981) has raised doubts about their sustainability owing to the threat that frequent harvest related nutrient exports could result in soil fertility deprivation and productivity declines, even on good sites (Goncalves *et al.*, 1997; Kumar *et al.*, 1998). The harvest of forest products represents a significant nutrient "cost" to the site (Nykvist, 1997; Kumar *et al.*, 1998). Loss of nutrients during harvest may far exceed the rate of their replenishment by weathering of minerals in soils when rotations are short (Folster and Khanna, 1997). In many cases it is best not to remove some tissues, such as small branches and leaves, which can be more valuable as nutrient stores than as forest products. Some rather dramatic effects of trees on soils have been noted where trees are very old (Alban, 1969). Over shorter time spans smaller changes might be anticipated.

A study conducted to determine the effects of immediate (1 year), short term (3 years), mid-term (9 years) and long-term (45 years) planting of leucaena on soil nutrients showed that available N, P, and K were higher in soils under the long-term planting followed by mid-term planting, short term and immediate plantings (Jha *et al.*, 1991). Malik *et al.* (1996) comparing soil properties under tree species and adjacent open agricultural fields, however, found a decrease of 3-5 per cent in soil pH, available plant nutrients by 8-30 per cent and exchangeable bases by 7-83 per cent under tree species.

Total organic matter accumulated in soils constitutes a major portion of the world's fixed carbon reserves. Bohn (1976) estimated that the soils contain about 30 x 10^{14} kg organic carbon. Soil organic matter also is the largest pool of plant nutrients. According to MacDicken and Vergara (1990), micro-site enrichment through improvement in the soil organic matter and mineral nutrient pools form an important attribute of woody perennials. Several workers have reported corroborating results. Jha *et al.* (1991) found a 10 per cent increase in soil organic matter in top soil in short-term plantings, 33 per cent in the mid-term planting and 135 per cent in the long term planting in comparison to immediate planting of *Leucaena leucocephala*.

To manage short and long term nutrient availability, we need to understand nutrient mineralisation and immobilization patterns in relation to chemical composition of the residues. Furthermore, in order for these managed forest systems to continue to provide social, economic and environmental benefits over successive harvests, a better understanding of the tree specie's impact on various aspects of soil fertility, including nutrient cycling process is essential. Thus, it is critical to understand the ecological properties of these ecosystems to avoid failures, minimise ecological damage and optimise the use of soil, water and energy resources (Cuevas and Lugo, 1998). Recently, there have been significant international efforts (e.g. Montreal Process, 1995) to define social, economic and environmental criteria for ecologically sustainable forest management and the indicators to evaluate these criteria. But such efforts are rare in the Indian context.

Materials and Methods

3. MATERIALS AND METHODS

The present investigation was carried out at the Instructional Farm, College of Forestry, Kerala Agricultural University, Vellanikkara, Thrissur district, Kerala in an 8.8 year-old ailanthus stand. The details about the experimental site, materials used and methodology adopted are as follows.

3.1 Location

The experimental site has an elevation of 40.29m above sea level and located at 10^0 13^1 N latitude and 76^0 13^1 E longitude.

3.1.1 Climate

Vellanikkara experiences a warm humid climate, having a mean annual rainfall of 2899 mm (mean corresponding to the ten year period from 1991 to 2000), most of which is received during the South-West monsoon (June to August). The mean maximum temperature ranges from 28.9°C (July) to 36.2°C (March) and the mean minimum temperature varies from 22°C (January) to 24.6°C (May) (Temperature means corresponding to the ten-year period from 1991 to 2000) (Fig.1.).

3.1.2 Soil

The soil of the experimental site is an Ultisol (Typic Plinthustult - Vellanikkara Series midland laterite – Ustic moisture regimes and Isohyperthermic temperature regimes) having a pH of 5.19.

3.2 Experimental design and treatments.

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

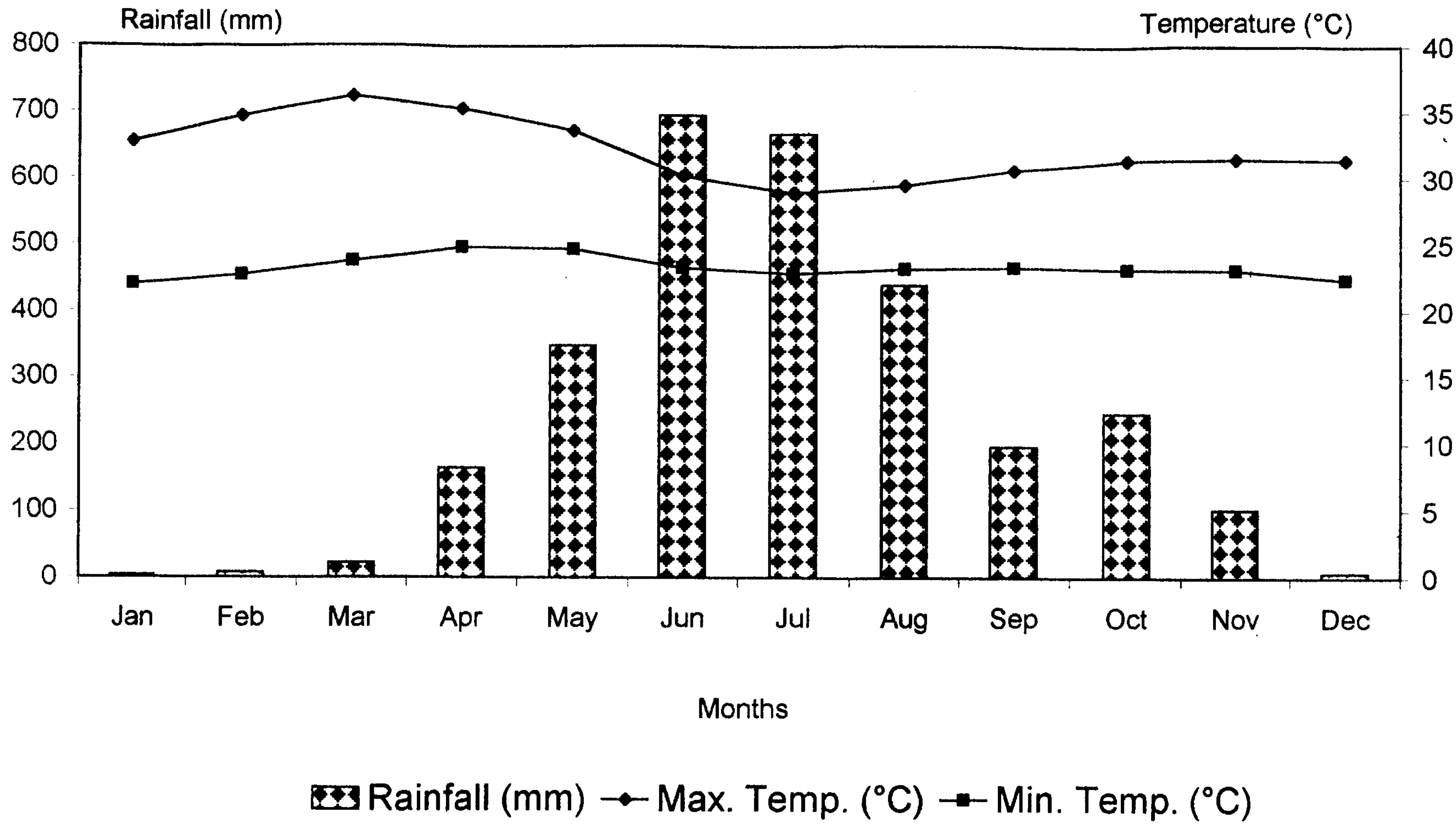


Fig. 1. Mean weather parameters during the experimental period (Jan. 1991 - Dec. 2000)

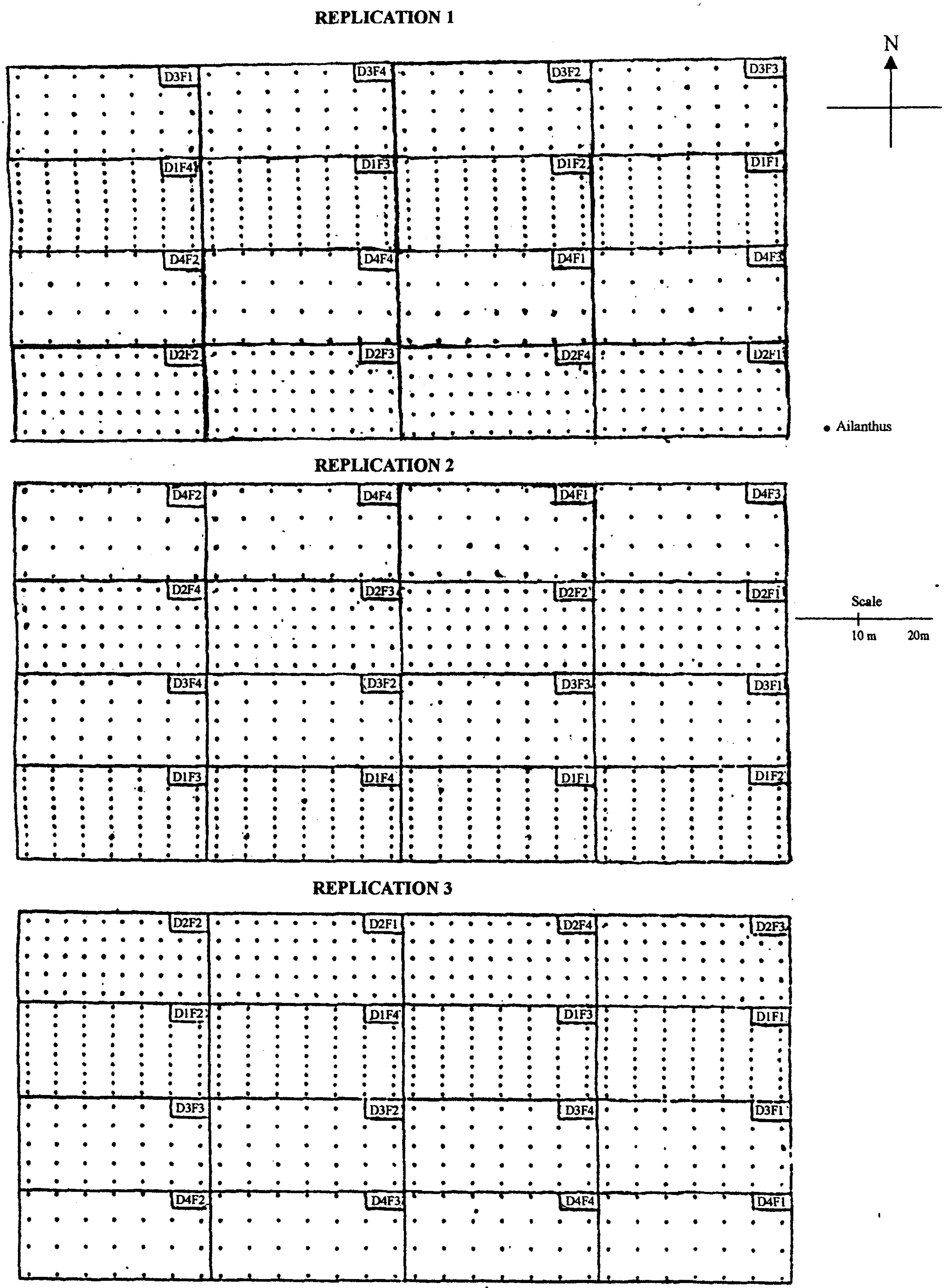


Fig. 2. SCHEMATIC LAYOUT PLAN OF THE FIELD EXPERIMENT

excluded from the investigation because of poor growth resulting from fire outbreak.

A. Main plot treatments

Tree population densities.

D_1 – 3333 trees ha^{-1} (3x1 m spacing)

D_2 – 2500 trees ha^{-1} (2x2 m spacing)

D_3 – 1600 trees ha^{-1} (3x2 m spacing)

D_4 – 1111 trees ha^{-1} (3x3 m spacing)

(Plate 1)

B. Sub plot treatments

Fertiliser treatments

	(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

(Trees were fertilised as per the treatment protocol, thrice during August 1992, Sept 1993 and Sept 1996).

3.3 Observations on tree growth characteristics

Height and diameter at breast height (dbh) of all trees (excluding border trees) were measured at six monthly intervals from planting with a graduated pole and measuring tape respectively. Additionally, stand leaf area index was estimated using a plant canopy Analyser (LAI 2000, Li-COR Inc., Lincoln, Nebraska) A single measurement of LAI was accomplished by taking the LAI 2000 unit outside the plot (in the open) to record an above canopy reading of sky brightness and then sampling five random locations in the central region of each plot (Height 1.5 m above ground). Care was taken to ensure that the unit was facing the same direction both outside and inside the stand. A sunlit canopy was avoided by taking

Plate 1. Experimental plots of varying tree population densities

a) At 1111 trees per hectare

b) At 1600 trees per hectare


←3m→
←2m→


←3m→
←3m→

c) At 2500 trees per hectare

d) At 3333 trees per hectare


← 3m →
← 1m →


← 2m →

measurements just after sunrise and just before sunset when the solar radiation is low (February, 2000).

3.4 Destructive sampling

From a frequency distribution of the dbh of trees in the net plot (excluding border trees), three mean trees were randomly selected from each plot. The selected trees were felled at the ground level using a handsaw taking care not to disturb the surviving trees, during March 2000 (8 year 8 months).
Felling resulted in the following population densities.

Spacing – Initial nos. – After thinning

D_1 - 3333 - 3190 trees/ha

D_2 - 2500 - 2350 trees/ha

D_3 - 1600 - 1462 trees/ha

D4 - 1100 - 991 trees/ha

The following observations were recorded on the felled trees.

1. Total height
2. Height upto first crown forming branch
3. Girth at breast height

Above ground portions of all felled trees were separated into stemwood (main shoot, if the main shoot is forked below breast height level (1.37m), then such branches were also treated as stem wood), branch wood (all branches differentiating above BH level) and foliage. Using appropriate spring scales, fresh weights of all the above components were recorded immediately after felling (to either nearest 0.1 kg or 10 mg).

3.4.1 Biomass sampling

Representative foliage and branch wood samples (ca 500g each) were collected randomly (treatment-wise in triplicate) for moisture estimation and chemical analyses. Stem disks (ca 2cm thick) were cut at breast height and at the base of the crown from all felled trees for moisture determination and for phytochemical analyses.

For quantifying the coarse roots (>5 mm radius) one stump per plot was randomly selected and completely excavated (up to 1.4 cm thickness) (Plate 2) and their fresh weights recorded after thorough cleaning. Maximum root depth and spread were also noted. Triplicate samples (ca 500g each, covering medium and large roots, treatment-wise) were collected for estimating moisture content and for chemical analyses.

The samples were immediately transferred to the laboratory in double sealed polythene bags. After recording the fresh weights, they were oven dried to constant weights at 70°C and ground to pass through a 2mm sieve.

Estimates of dry weight biomass were obtained from the fresh weights of various tissues and their corresponding moisture contents. Dry : wet ratios from felled trees were used to correct the field weight determinations and obtain biomass on a per tree basis. The average biomass of component parts per tree was multiplied by the number of trees per plot and extrapolated to a hectare. Biomass of tree parts other than roots were summed to obtain the total above ground biomass per tree.

Representative leaf samples (ca 500 g) were collected from the felled trees and transported to the laboratory in an ice box for leaf area measurement. After recording the fresh weight of the samples, leaf area measurements were made using a Li-Cor Model 3100 Area Meter (Li-Cor, Lincoln, Nebraska, USA). Total leaf area for individual trees was calculated by multiplying the total fresh weight of foliage with the leaf area-fresh weight ratio. Individual tree leaf area multiplied by the number of trees per plot yielded stand leaf area on per hectare basis.

Plate 2. Complete tree excavation

3.5 Phytochemical analyses

Triplicate samples were analysed for N, P and K (three sub-samples were drawn from the tissue samples for this purpose). Nitrogen was estimated following the micro-kjeldahl method, phosphorus and potassium were estimated after digesting the samples in a diacid mixture (HNO_3 and $HClO_4$ in 10:3 ratio). Phosphorus was determined following the vanado – molybdo phosphoric yellow colour method using Milton Roy spectronic 1001 plus (Milton Roy, Rochester, New York) and potassium by flame photometry (Jackson, 1958) using Elico flame photometer (Model Cl-22D). Total nutrients for whole trees were obtained by summing results for component parts. Nutrient use efficiency was estimated by dividing component-wise biomass accumulation with the corresponding nutrient accumulation values.

3.6 Soil chemical analyses.

Soil samples were collected from the interspaces between rows of trees at nine random points per plot after removing the litter layer and made into three composite samples representing the top 0-15 cm soil layer. Samples were air dried and ground to pass through a 2-mm sieve and analysed for N, P, K, org C and pH as described below.

Soil pH was determined using an aqueous suspension of soil and water (1:5) using an 'Elico' pH meter (Model Li 613). Organic carbon by the walkley–Black method, total nitrogen by micro-kjeldahl method, available P by ascorbic acid reduced molybdo phosphoric blue colour method (Watnabe and Olsen, 1965) using a Milton Roy Spectronic 1001 plus and available K by flame photometry following extraction with normal neutral ammonium acetate (Jackson, 1958).

3.7 Statistical analyses

Data pertaining to tree biomass and chemical composition of soil and plant parts were analysed following the ANOVA technique (using MSTAT) for split plot design. LSD was used to compare mean biomass yield, nutrient concentration, nutrient content of tree parts and whole trees and the soil parameters.

Results

4. RESULTS

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

Data on plot means of ailanthus growth parameters at 8.3 years of age and the growth data on three mean trees felled at 8.7 years after planting are given in Tables 1 and 2 and Figures 3 and 4 respectively. Appendices 2 and 3 give the summary of ANOVA results. Although tree height growth was not significantly altered by either stand density or fertiliser treatments at 8.3 years of age (Fig. 3), the differences were significant in respect of the felled trees at 8.7 years. A population density of 2500 trees per hectare (tpha) showed the highest value in this respect (9, 7 and 16% more height than stands of 3333, 1600 and 1111 tpha respectively). Low density stands also had shorter clean bole lengths. Interaction effects (density x fertiliser) were significant for height. The combination of 3333 tpha and 50:25:25 N:P_2O_5: K_2O kg ha^{-1} yr^{-1} showed the maximum height of 11.45 m.

Tree population density exerted only a modest influence on radial growth of trees at 8.3 years (Fig.4). But the differences were significant at 8.7 year (felled trees). Stand density of 2500 tpha showed the highest diameter growth (12% more radial growth than 3333 tpha).

Fertiliser levels exerted only a non-significant influence on height and diameter growth of trees both at 8.3 and 8.7 years of age. Interaction effects (density x fertiliser) were significant for radial growth at 8.7 years. A combination of 2500 tpha at 100:50:50 N:P_2O_5: K_2O kg ha^{-1} yr^{-1} showed the maximum diameter growth (Table 3, Appendix 3).

Data presented in Table 4 and Appendix 4 show that stand density had a significant effect on per tree leaf area and stand leaf area. Stands with 1111 tpha and 3333 tpha showed maximum per tree leaf area and the stand area respectively.

Table 1. Effect of tree population density and fertiliser levels on tree height and radial growth of 8.3 year old *Ailanthus triphysa* trees

Treatments	Height (m)	Diameter at breast height (cm)
Density (trees ha^{-1})		
3333	7.098	10.093^{c}
2500	7.921	11.898^{b}
1600	7.856	12.711^{a}
1111	6.905	12.380^{ab}
F test	NS	<0.05
SEm(±)	0.3865	0.1699
LSD(0.05)	-	0.7648
Fertiliser levels ($N:P_2O_5:K_2O$ kg ha^{-1} yr^{-1})		
0:0:0	7.678	11.914
50:25:25	7.101	11.234
100:50:50	7.708	12.121
150:75:75	7.292	11.813
F test	NS	NS
SEm(±)	0.3838	0.6149
LSD (0.05)	-	-
Density x fertiliser interaction		
F test	NS	NS
SEm(±)	0.7679	1.2298

Table 2. Allometric data for 8.7 year old destructively sampled ailanthus trees as influenced by tree population density and fertiliser levels

Treatments	Total height (m)	Clear bole height (m)	~~DBH (cm)~~
Density (trees ha^{-1})			
3333	9.604^{b}	6.367^{a}	13.899^{b}
2500	10.524^{a}	6.047^{a}	15.739^{a}
1600	9.742^{b}	5.773^{a}	14.965^{ab}
1111	8.870^{c}	4.989^{b}	14.729^{ab}
F test	<0.01	<0.01	<0.05
SEm(±)	0.2398	0.2402	0.4003
LSD(0.05)	0.7228	0.7241	1.207
Fertiliser level ($N:P_2O_5:K_2O$ kg ha^{-1} yr^{-1})			
0:0:0	9.605	5.923	14.358
50:25:25	9.854	5.920	15.021
100:50:50	9.722	5.626	14.812
150:75:75	9.558	5.707	15.141
F test	NS	NS	NS
SEm(±)	0.2744	0.2272	0.5321
LSD (0.05)	-	-	-
Density x fertiliser interation			
F test	<0.01	<0.01	<0.05
SEm(±)	0.5488	0.4545	0.0641

Table 3. Combined effects of tree population density and fertiliser levels on tree height, bole height and diameter growth

Total tree height (m)

Fertiliser levels ($N:P_2O_5:K_2O$ kg ha^{-1} yr^{-1})	3333	2500	1600	1111
0:0:0	9.767 ^{abcde}	10.35 ^{abcd}	8.992 ^{cde}	9.308 ^{bcde}
50:25:25	11.450 ^{a}	10.22 ^{abcde}	10.650 ^{abc}	7.100 ^{f}
100:50:50	8.717 ^{def}	11.01 ^{ab}	9.808 ^{abcde}	9.357 ^{bcde}
150:75:75	8.483 ^{ef}	10.52 ^{abcd}	9.517 ^{bcde}	9.717 ^{abcde}

LSD(0.05) = 1.552

ClearBole height (m)

Fertiliser levels ($N:P_2O_5:K_2O$ kg ha^{-1} yr^{-1})	3333	2500	1600	1111
0:0:0	6.900 ^{ab}	6.383 ^{abc}	5.250 ^{cd}	5.158 ^{cd}
50:25:25	7.508 ^{a}	5.413 ^{bcd}	6.525 ^{abc}	4.233 ^{d}
100:50:50	5.630 ^{bcd}	6.383 ^{abc}	5.483 ^{bcd}	5.007 ^{cd}
150:75:75	5.428 ^{bcd}	6.008 ^{bc}	5.833 ^{bc}	5.558 ^{bcd}

LSD(0.05) = 1.285

DBH (cm)

Fertiliser levels ($N:P_2O_5:K_2O$ kg ha^{-1} yr^{-1})	3333	2500	1600	1111
0:0:0	13.850 ^{ab}	15.14 ^{ab}	12.78 ^{b}	15.67 ^{ab}
50:25:25	15.720 ^{ab}	15.89 ^{ab}	15.72 ^{ab}	12.75 ^{b}
100:50:50	13.580 ^{ab}	16.72 ^{a}	14.92 ^{ab}	14.03 ^{ab}
150:75:75	12.440 ^{b}	15.20 ^{ab}	16.44 ^{a}	16.47 ^{a}

LSD(0.05) = 3.010

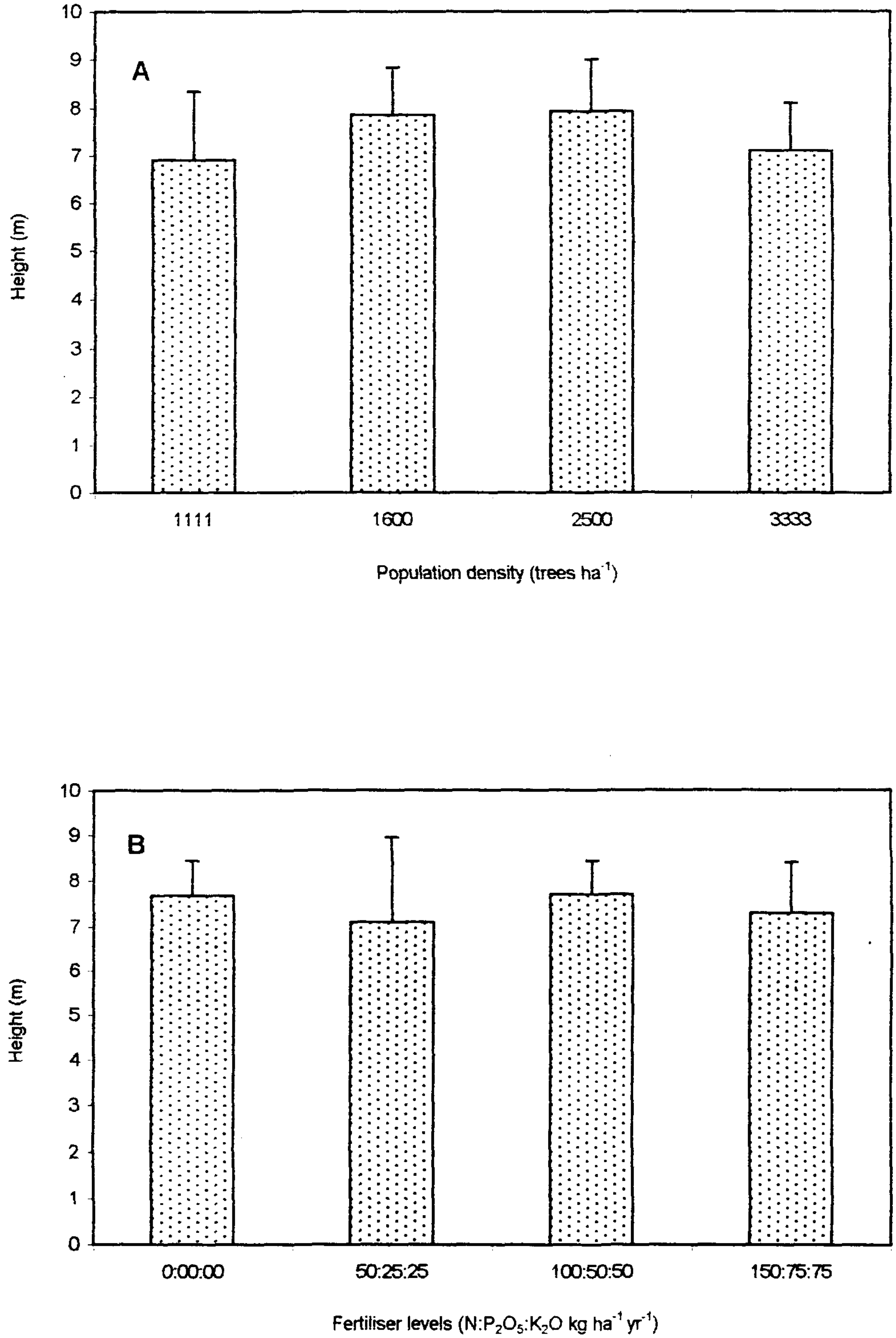


Fig. 3. Height growth of 8.3 year old ailanthus trees as influenced by tree population density (A) and fertiliser levels (B)

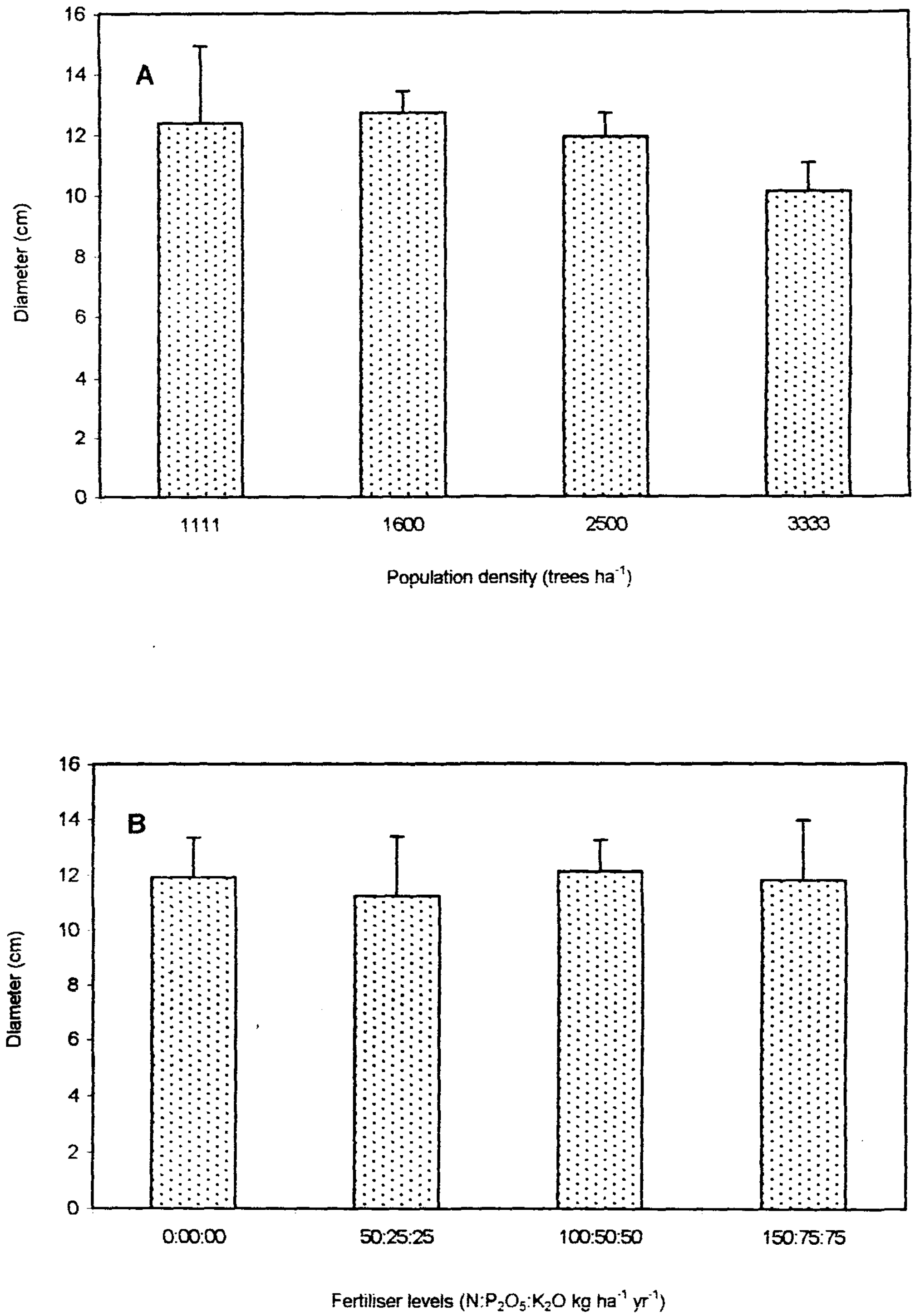


Fig. 4. Diameter growth of 8.3 year old ailanthus trees as influenced by tree population density (A) and fertiliser levels (B)

Table 4. Effect of tree population density and fertiliser levels on leaf area, root depth and root spread of 8.7 year old *Ailanthus triphysa* trees

Treatments	Mean leaf area/tree (m^2)	Leaf area ha^{-1} (m^2)	Leaf area index (LAI)	Root Depth (m)	Root Spread (m)
Density (trees ha^{-1})					
3333	12.752^{c}	42502.69^{a}	3.679	1.063	1.556
2500	20.194^{ab}	50484.60^{a}	4.289	1.119	1.575
1600	16.807^{bc}	26891.73^{b}	3.543	1.181	1.669
1111	24.387^{a}	27093.60^{a}	3.460	1.056	1.625
F test	<0.01	<0.01	NS	NS	NS
SEm(±)	2.0616	3952.62	0.4350	0.0.463	0.1263
LSD(0.05)	6.214	11900.10	-	-	-
Fertiliser level ($N:P_2O_5:K_2O$ kg ha^{-1} y^{-1})					
0:0:0	18.474	36429.85	3.400	1.113	1.681
50:25:25	19.979	41727.66	4.046	1.100	1.519
100:50:50	18.606	37674.52	3.982	1.131	1.625
150:75:75	17.080	31140.51	3.541	1.075	1.600
F test	NS	NS	NS	NS	NS
SEm(±)	2.1051	4328.164	0.2337	0.0426	0.0481
LSD (0.05)	-	-	-	-	-
Density x Fertiliser Interaction					
F test	NS	NS	NS	NS	NS
SEm(±)	4.2102	8656.34	0.4673	0.0852	0.0961

However, neither population density nor fertiliser regimes seemed to influence the stand leaf area index (LAI) significantly. Furthermore, differences in root depth and lateral spread were not statistically significant either in terms of density or fertiliser regimes.

4.2 Biomass accumulation

Clearly, the most important component of biomass yield in all density and fertiliser treatments was stemwood (range: 70.8 to 71.6% and 71.5 to 71.9% of total biomass for tree density and fertiliser treatments respectively). The contribution of branches ranged from 11.2 to 11.8 per cent and 10.6 to 11.9 per cent respectively of the total biomass in tree density and fertiliser treatments. Percentage contribution of roots was modest (range: 10.5 to 12.2% and 11.1 to 12.2% of the total tree biomass in stand density and fertiliser treatments respectively). Foliage invariably had the least biomass yield (5 to 7% in tree density treatments and 5.3 to 6.3% of the total tree biomass in fertiliser treatments).

Although differences in total biomass (dry weight) on a per tree basis was not statistically significant (Table 5, Appendix 5), stand density exerted a perceptible influence on dry weight of branchwood and foliar dry weight on a per tree basis. In general, the lower densities recorded higher values. Interaction effects (density x fertiliser) were also significant with respect to root biomass and the combination of 1600 tpha with 100:50:50 N:P_2O_5: K_2O kg ha^{-1} yr^{-1} fertiliser dose showed the maximum biomass of 8.79 kg $tree^{-1}$ (Table 6, Appendix 5).

Stand biomass was, however, significantly affected by density (Fig. 5, Table 7 and Appendix 6). The stands with 3333 tpha showed the highest total biomass of 135 Mg ha^{-1}. Lower density stands of 2500, 1600 and 1111 tpha produced correspondingly lower biomass: 2.6, 40 and 56 per cent less biomass than the high density stand. Significant differences in biomass yield on a per hectare basis owing to differences in population density were noted in different tissue

Table 5. Effect of tree population density and fertiliser levels on mean biomass accumulation of 8.7 year old *Ailanthus triphysa* trees

Treatments	Stem wood	Branch wood	Foliage	Above ground	Roots	Total
	Mean Biomass (kg $tree^{-1}$)					
Density (trees ha^{-1})						
3333	29.041	4.512^{b}	2.050^{b}	35.603	4.985	40.587
2500	38.317	5.487^{a}	2.910^{ab}	46.887	5.815	52.701
1600	35.847	5.802^{a}	2.818^{ab}	44.513	6.081	50.594
1111	37.810	6.263^{a}	3.776^{a}	47.848	5.610	53.458
F test	NS	<0.05	<0.05	NS	NS	NS
SEm (±)	3.3914	0.3695	0.3167	3.7423	0.4903	4.112
LSD (0.05)	-	1.114	0.9548	-	-	-
Fertiliser level ($N:P_2O_5:K_2O$ kg ha^{-1} yr^{-1})						
0:0:0	35.694	5.552	2.993	44.239	5.553	49.792
50:25:25	34.795	5.499	3.197	43.492	5.672	49.163
100:50:50	35.251	5.504	2.454	43.429	5.875	49.302
150:75:75	35.275	5.508	2.910	43.693	5.391	49.083
F test	NS	NS	NS	NS	NS	NS
SEm (±)	2.6332	0.5013	0.3253	3.2026	0.4903	4.445
LSD (0.05)	-	-	-	-	-	-
Density x Fertiliser Interaction						
F test	NS	NS	NS	NS	<0.05	NS
SEm (±)	5.2663	1.0026	0.6506	6.4052	0.9806	8.8907

Table 6. Combined effects of tree population density and fertiliser levels on root biomass

Fertiliser levels ($N:P_2O_5:K_2O$ kg ha^{-1} yr^{-1})	Root biomass (kg tree^{-1}) 3333	2500	1600	1111
0:0:0	7.280 ^{ab}	5.533 ^{abc}	3.552 ^{c}	5.849 ^{abc}
50:25:25	5.161 ^{bc}	7.194 ^{ab}	5.677 ^{abc}	4.655 ^{bc}
100:50:50	3.898 ^{bc}	4.951 ^{bc}	8.791 ^{a}	5.858 ^{abc}
150:75:75	3.600 ^{c}	5.582 ^{abc}	6.302 ^{abc}	6.079 ^{abc}

LSD (0.05) = 2.956

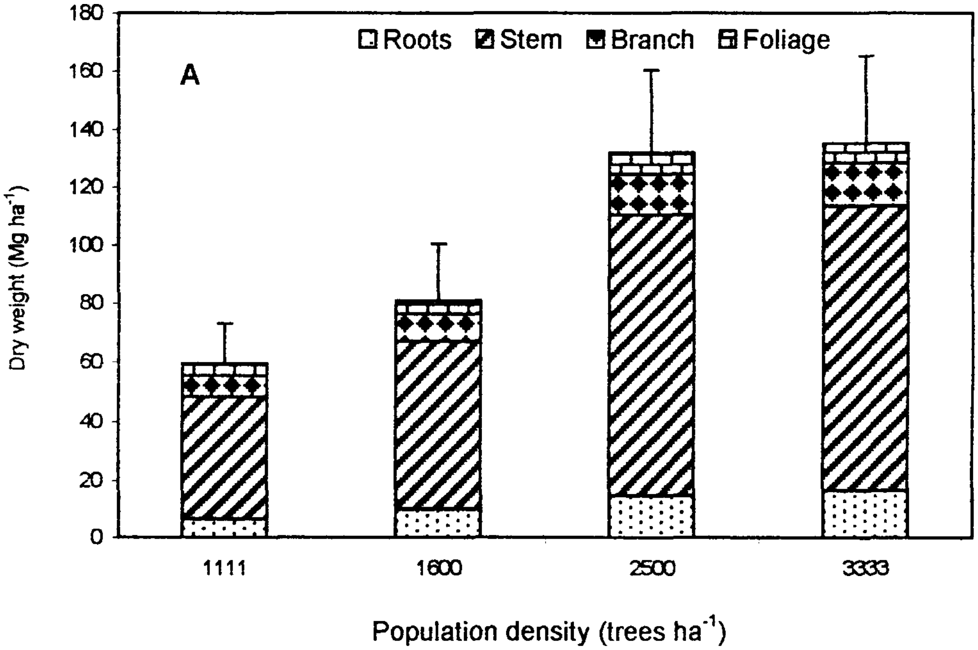
Table 7. Effect of tree population density and fertiliser levels on mean biomass accumulation of 8.7 year old *Ailanthus triphysa* trees

Treatments	Stem wood	Branch wood	Foliage	Above ground	Roots	Total	MAI (Mg ha^{-1} yr^{-1})
	Biomass accumulation (Mg ha^{-1})						
Density (trees ha^{-1})							
3333	96.794[a]	15.038[a]	6.834[a]	118.666[a]	16.614[a]	135.280[a]	13.638[a]
2500	95.793[a]	14.093[a]	7.676[a]	117.217[a]	14.537[a]	131.754[a]	13.473[a]
1600	57.355[b]	9.281[b]	4.508[b]	71.222[b]	9.722[b]	80.950[b]	8.186[b]
1111	42.007[b]	6.958[b]	4.194[b]	53.159[b]	5.232[c]	59.301[b]	6.110[b]
F test	<0.01	<0.01	<0.01	<0.01	<0.01	<0.05	<0.01
SEm(±)	7.8349	1.0372	0.6109	8.6392	0.701	9.5477	0.9929
LSD(0.05)	23.62	3.127	1.841	26.04	3.156	42.97	2.993
Fertiliser level ($N:P_2O_5:K_2O$ kg ha^{-1} yr^{-1})							
0:0:0	73.833	11.077	5.918	90.829	12.570	103.308	10.439
50:25:25	77.130	11.355	6.748	95.235	12.360	107.595	10.947
100:50:50	71.761	11.455	5.253	88.574	11.486	100.060	10.181
150:75:75	69.225	11.482	5.294	85.626	10.697	96.323	9.842
F test	NS	NS	NS	NS	NS	NS	NS
SEm(±)	5.5821	1.0353	0.6705	6.7526	1.1538	10.315	0.7763
LSD(0.05)	-	-	-	-	-	-	-
Density x Fertiliser Interaction							
F test	NS	NS	NS	NS	<0.05	NS	NS
SEm(±)	11.1641	2.0706	1.3410	13.505	2.1572	20.630	1.5526

Table 8. Combined effects of tree population density and fertiliser levels on root biomass

Fertiliser levels ($N:P_2O_5:K_2O$ kg ha^{-1} yr^{-1})	Root biomass (Mg ha^{-1}) 3333	2500	1600	1111
0:0:0	24.27 ^{a}	13.83 ^{bcde}	5.684 ^{fg}	6.497 ^{efg}
50:25:25	17.20 ^{bc}	17.98 ^{ab}	9.083 ^{defg}	5.171 ^{g}
100:50:50	12.99 ^{bcdef}	12.38 ^{bcdefg}	14.06 ^{bcd}	6.508 ^{efg}
150:75:75	12.00 ^{bcdefg}	13.95 ^{bcd}	10.08 ^{cdefg}	6.753 ^{defg}

LSD(0.05) = 6.502



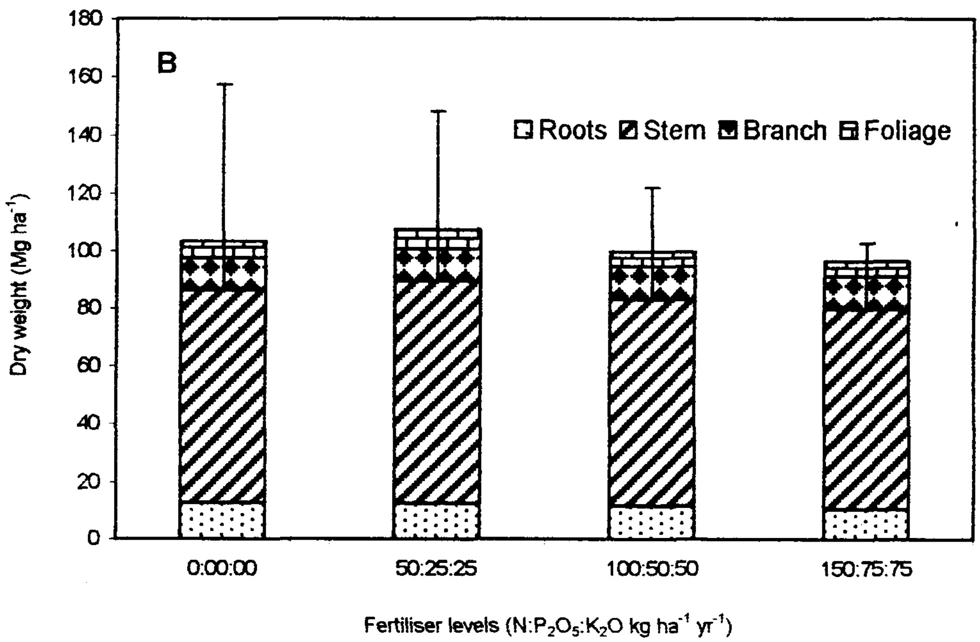


Fig. 5. Biomass accumulation of 8.7 year old ailanthus trees as influenced by tree population density (A) and fertiliser levels (B)

fractions such as: stemwood, branchwood, foliage and roots ($p<0.01$) also. Population densities of 3333 and 2500 tpha were significantly superior to the densities of 1600 and 1111 tpha.

Fertiliser levels did not seem to substantially alter the biomass accumulation pattern. All the three fertiliser doses were statistically at par with that of the control (no fertiliser). However, density x fertiliser interaction was significant in respect of root biomass. The combination of 3333 tpha and unfertilised control showed the maximum biomass accumulation of 24.3 Mg ha^{-1} (Table 8, Appendix 6).

Stand density had a significant effect on mean annual biomass increment (MAI). With increasing density, MAI increased (13.64, 13.47, 8.2 and 6.1 Mg ha^{-1} yr^{-1} for stands of 3333, 2500, 1600 and 1111 tpha respectively). The stand with 3333 tpha registered highest MAI but was statistically at par with stand of 2500 tpha (Table 7, Appendix 6). Fertiliser levels had no significant influence on stand biomass MAI.

4.3 Tissue nutrient concentration

4.3.1 Nitrogen

Nitrogen content of tissue fractions decreased in the order: foliage> branchwood> roots> stemwood. The percentage of N in foliage ranged from 2.7 to 2.8, branchwood: 0.86 to 0.97, roots: 0.75 to 0.77 and stemwood: 0.67 to 0.72. Stand density exerted a perceptible influence on stemwood N content. Highest N concentration was observed in the stand of 2500 tpha, which was statistically at par with that of the 3333 tpha. Elemental concentrations of N in branchwood, foliage and roots were, however, not significantly different (Table 9, Appendix 7). Regarding fertiliser regimes, only the branchwood N concentration was significantly influenced by the addition of chemical fertilisers. Maximum branchwood N concentration was observed in the medium dose of fertiliser

Table 9. Effect of tree population density and fertiliser levels on N concentration of 8.7 year old *Ailanthus triphysa* trees

Treatments	Stemwood	Branchwood	Foliage	Roots
	N (%)			
Density (trees ha^{-1})				
3333	0.702^{ab}	0.950	2.807	0.746
2500	0.718^{a}	0.919	2.802	0.750
1600	0.666^{c}	0.942	2.760	0.753
1111	0.682^{c}	0.934	2.739	0.771
F test	<0.05	NS	NS	NS
SEm (±)	0.0119	0.0307	0.0349	0.0061
LSD (0.05)	0.0337	-	-	-
Fertiliser levels ($N:P_2O_5:K_2O$ kg ha^{-1} yr^{-1})				
0:0:0	0.695	0.859^{b}	2.759	0.753
50:25:25	0.685	0.969^{a}	2.813	0.764
100:50:50	0.669	0.967^{a}	2.756	0.748
150:75:75	0.718	0.950^{a}	2.778	0.755
F test	NS	<0.01	NS	NS
SEm (±)	0.0174	0.0249	0.026	0.0108
LSD (0.05)	-	0.07072	-	-
Density x Fertiliser interaction				
F test	NS	<0.01	NS	NS
SEm (±)	0.0347	0.0499	0.052	0.0216

Table 10. Combined effects of tree population density and fertiliser levels on branch wood nitrogen concentration.

Fertiliser levels ($N:P_2O_5:K_2O$ kg ha^{-1} yr^{-1})	Branch wood N (%) 3333	2500	1600	1111
0:0:0	0.861 bcde	0.712 e	1.004 abc	0.858 cde
50:25:25	1.043 a	1.034 a	0.797 de	1.004 abc
100:50:50	0.949 abcd	0.931 abcd	1.028 ab	0.962 abcd
150:75:75	0.947 abcd	1.000 abc	0.940 abcd	0.913 abcd

LSD(0.05) = 0.1414

(50:25:25 $N:P_2O_5:K_2O$ $kgha^{-1}yr^{-1}$). This, however, was statistically at par with that of higher fertiliser levels (100:50:50 and 150:75:75 N: $P_2O_5:K_2O$ kg ha^{-1} yr^{-1}). Interaction effects (density x fertiliser) were significant in respect of branchwood N concentration. Population density of 3333 tpha at 50:25:25 $N:P_2O_5:K_2O$ kg ha^{-1} yr^{-1} showed the highest value (Table 10, Appendix 7).

4.3.2 Phosphorus

The concentration of P in different biomass fractions showed marked variability. P concentration of tree parts decreased in the order: foliage (0.10-0.15%) > Branchwood (0.09-0.11%) > Roots (0.06-0.07%) > Stemwood (0.03-0.05%). Population density influenced the P content of stemwood and roots (Table 11, Appendix 8). In general, lower densities recorded higher P concentrations. Branchwood and foliage P concentrations were, however, not significantly influenced by stand density. Fertiliser levels had a significant influence on P concentration of different tissue fractions. The fertiliser levels of 100:50:50 and 150:75:75 $N:P_2O_5:K_2O$ kg ha^{-1} yr^{-1} were significantly superior to the unfertilised control (27, 20, 19 and 29% more P concentration for stemwood, branchwood, roots and foliage than control). Interaction effects (density x fertiliser) were significant with respect to foliage and stemwood. But a clear trend was not discernible (Table 12, Appendix 8).

4.3.3 Potassium

There was marked variation in K concentration of different biomass fractions. K concentration of different biomass fractions followed the order: foliage > branchwood > stemwood > roots. Stand density affected the K concentration of stemwood and roots. Stands with 2500 tpha showed the highest concentration of stemwood K (0.42%). For roots, the lowest density of 1111 tpha showed the highest K concentration of 0.37%. Fertiliser regimes seemed to influence the K Concentration of stemwood, branchwood, foliage and roots ($p<0.01$). Greater K

Table 11. Effect of tree population density and fertiliser levels on P concentration of 8.7 year old *Ailanthus triphysa* trees

Treatments	Foliage	Branch wood	Stem wood	Root
	P (%)			
Density (trees ha^{-1})				
3333	0.123	0.102	0.036 ^{b}	0.058 ^{b}
2500	0.124	0.102	0.039 ^{a}	0.065 ^{ab}
1600	0.127	0.099	0.041 ^{a}	0.060 ^{b}
1111	0.132	0.099	0.041 ^{a}	0.069 ^{a}
F test	NS	NS	<0.01	<0.05
SEm (±)	0.0026	0.0011	0.0005	0.024
LSD (0.05)	-	-	0.001946	0.007096
Fertiliser level ($N:P_2O_5:K_2O$ kg ha^{-1} yr^{-1})				
0:0:0	0.103 ^{d}	0.089 ^{b}	0.033 ^{b}	0.055 ^{b}
50:25:25	0.116 ^{c}	0.092 ^{b}	0.035 ^{b}	0.068 ^{a}
100:50:50	0.146 ^{a}	0.110 ^{a}	0.044 ^{a}	0.066 ^{a}
150:75:75	0.140 ^{b}	0.111 ^{a}	0.045 ^{a}	0.063 ^{ab}
F test	<0.01	<0.01	<0.01	<0.05
SEm (±)	0.0019	0.0014	0.0007	0.0031
LSD (0.05)	0.00527	0.004083	0.002353	0.008498
Density x Fertiliser interaction				
F test	<0.01	NS	NS	<0.01
SEm (±)	0.0038	0.0028	0.0014	0.0061

Table 12.Combined effects of tree population density and fertiliser levels on foliar and root P concentration.

Fertiliser levels ($N:P_2O_5:K_2O$ kg ha^{-1} yr^{-1})	Foliar P (%)				Root P (%)			
	3333	2500	1600	1111	3333	2500	1600	1111
0:0:0	0.093 ^{h}	0.102 ^{gh}	0.108 ^{fg}	0.112 ^{fg}	0.053 ^{cde}	0.051 ^{cde}	0.057 ^{bcde}	0.058 ^{bcde}
50:25:25	1.108 ^{fg}	0.112 ^{fg}	0.117 ^{ef}	0.127 ^{de}	0.069 ^{abcd}	0.063 ^{bcde}	0.058 ^{bcde}	0.084 ^{a}
100:50:50	0.146 ^{abc}	0.156 ^{a}	0.136 ^{cd}	0.146 ^{abc}	0.044 ^{e}	0.070 ^{abc}	0.067 ^{abcd}	0.086 ^{a}
150:75:75	0.144 ^{bc}	0.127 ^{de}	0.148 ^{ab}	0.143 ^{bc}	0.067 ^{abcd}	0.075 ^{ab}	0.059 ^{bcde}	0.049 ^{de}

LSD(0.05) = 0.01054

LSD(0.05) = 0.0170

Table 13. Effect of tree population density and fertiliser levels on K concentration of 8.7 year old *Ailanthus triphysa* trees

Treatments	Stem wood	Branch wood	Foliage	Root
	K (%)			
Density (trees ha^{-1})				
3333	0.390 ^{b}	0.758	0.958	0.323 ^{c}
2500	0.423 ^{a}	0.778	0.986	0.360 ^{ab}
1600	0.392 ^{b}	0.755	0.947	0.333 ^{bc}
1111	0.383 ^{b}	0.740	1.002	0.369 ^{a}
F test	<0.05	NS	NS	<0.05
SEm (±)	0.0095	0.0228	0.0271	0.0115
LSD (0.05)	0.02752	-	-	0.0337
Fertiliser level ($N:P_2O_5:K_2O$ kg ha^{-1} yr^{-1})				
0:0:0	0.351 ^{b}	0.727 ^{bc}	0.854 ^{c}	0.277 ^{c}
50:25:25	0.380 ^{b}	0.713 ^{c}	0.879 ^{c}	0.321 ^{b}
100:50:50	0.434 ^{a}	0.778 ^{ab}	1.016 ^{b}	0.396 ^{a}
150:75:75	0.423 ^{a}	0.812 ^{a}	1.143 ^{a}	0.392 ^{a}
F test	<0.01	<0.01	<0.01	<0.01
SEm (±)	0.0109	0.0179	0.020	0.0092
LSD (0.05)	0.03163	0.05165	0.05774	0.02582
Density x Fertiliser interaction				
F test	<0.01	NS	NS	<0.01
SEm (±)	0.0217	0.0358	0.0401	0.0184

Table 14. Combined effects of tree population density and fertiliser levels on stem wood and root K concentration

Fertiliser levels ($N:P_2O_5:K_2O$ kg ha^{-1} yr^{-1})	Stem wood K (%)				Root K (%)			
	3333	2500	1600	1111	3333	2500	1600	1111
0:0:0	0.325^{d}	0.374^{bcd}	0.381^{bcd}	0.324^{d}	0.2670^{g}	0.300^{fg}	0.275^{g}	0.267^{g}
50:25:25	0.380^{bcd}	0.372^{bcd}	0.405^{bc}	0.363^{cd}	0.300^{fg}	0.317^{efg}	0.358^{def}	0.308^{efg}
100:50:50	0.441^{b}	0.514^{a}	0.361^{cd}	0.419^{bc}	0.383^{cd}	0.367^{cde}	0.350^{def}	0.483^{a}
150:75:75	0.414^{bc}	0.433^{bc}	0.422^{bc}	0.425^{bc}	0.342^{def}	0.458^{ab}	0.350^{def}	0.417^{bc}

Stem wood K: LSD(0.05) = 0.0633

Root K: LSD(0.05)0 = 0.0516

values were observed at higher fertiliser levels (19, 10.5, 25 and 30% more K in stemwood, branchwood, foliage and roots than the unfertilised control; Table 13, Appendix 9. In addition, the interaction effects (density x fertiliser) were significant in respect of K concentration in the stemwood and roots. The levels of 2500 tpha at 100:50:50 $N:P_2O_5:K_2O$ kg ha^{-1} yr^{-1} of applied fertiliser and 1111 tpha at 100:50:50 $N:P_2O_5:K_2O$ kg ha^{-1} yr^{-1} fertiliser level showed higher values for K concentration in case of stemwood (0.51%) and roots (0.48%) respectively than other combinations. But a clear trend was not discernible (Table 14, Appendix 9).

4.3.4 Nutrient accumulation

4.3.4.1 Nitrogen

Data on N accumulation of ailanthus on per tree and stand basis are given in Tables 15 and 17 and Fig.6. Summary of ANOVA results are given in Appendices 10 and 11. Differences in N content of total biomass on a per tree basis were not statistically significant both in respect of stand density and fertiliser regimes. Stand density, however, had a significant effect on the foliar N content. Stands with 1111 tpha showed the highest accumulation of 0.102 kg N per tree but was statistically at par with that of 2500 tpha. Interaction effects (density x fertiliser) were significant in respect of the root N content (Table 16, Appendix 10). A tree density of 1600 tpha at 100:50:50 $N:P_2O_5:K_2O$ kg ha^{-1} yr^{-1} recorded the highest value. As regards to N accumulation on stand basis, data presented show significant variation on account of stand density (Fig. 6). N accumulation in total above ground biomass and different tissue fractions were significantly influenced by stand density ($p<0.01$). Stands with 3333 and 2500 tpha were significantly superior to the 1600 and 1111 tpha density stands for all tissue fractions. Fertiliser regimes, however, had no significant influence on N accumulation. But interaction effects (density x fertiliser) were significant in respect of roots N content. Unfertilised, 3333 tpha combination showed the highest N accumulation (Table 18, Appendix 11).

Table 15. Effect of tree population density and fertiliser levels on nitrogen accumulation of 8.7 year old *Ailanthus triphysa* trees

Treatments	Stem wood	Branch wood	Foliage	Roots	Above ground	Total
	N accumulation (kg tree^{-1})					
Density (trees ha^{-1})						
3333	0.208	0.041	0.057 [b]	0.037	0.306	0.343
2500	0.269	0.050	0.086 [a]	0.043	0.405	0.448
1600	0.237	0.055	0.078 [ab]	0.046	0.370	0.421
1111	0.257	0.057	0.102 [a]	0.043	0.416	0.459
F test	NS	NS	<0.05	NS	NS	NS
SEm (±)	0.025	0.0040	0.0085	0.0038	0.0326	0.0307
LSD (0.05)	-	-	0.02752	-	-	-
Fertiliser level ($N:P_2O_5:K_2O$ kg ha^{-1} yr^{-1})						
0:0:0	0.248	0.046	0.081	0.042	0.376	0.418
50:25:25	0.232	0.053	0.090	0.043	0.375	0.418
100:50:50	0.238	0.053	0.072	0.043	0.363	0.406
150:75:75	0.251	0.052	0.081	0.041	0.384	0.430
F test	NS	NS	NS	NS	NS	NS
SEm (±)	0.0180	0.0049	0.0093	0.0039	0.0284	0.038
LSD (0.05)	-	-	-	-	-	-
Density x Fertiliser interaction						
F test	NS	NS	NS	<0.05	NS	NS
SEm (±)	0.035	0.0098	0.0186	0.0064	0.0569	0.0759

Table 16. Combined effects of tree population density and fertiliser levels on root nitrogen accumulation

N accumulation (kg $tree^{-1}$)

Fertiliser levels ($N:P_2O_5:K_2O$ kg ha^{-1} yr^{-1})	3333	2500	1600	1111
0:0:0	0.053 ab	0.043 bcd	0.026 d	0.045 bcd
50:25:25	0.040 bcd	0.052 ab	0.045 bcd	0.036 bcd
100:50:50	0.029 cd	0.036 bcd	0.068 a	0.041 bcd
150:75:75	0.027 cd	0.042 bcd	0.046 bcd	0.049 abc

LSD(0.05) = 0.01985

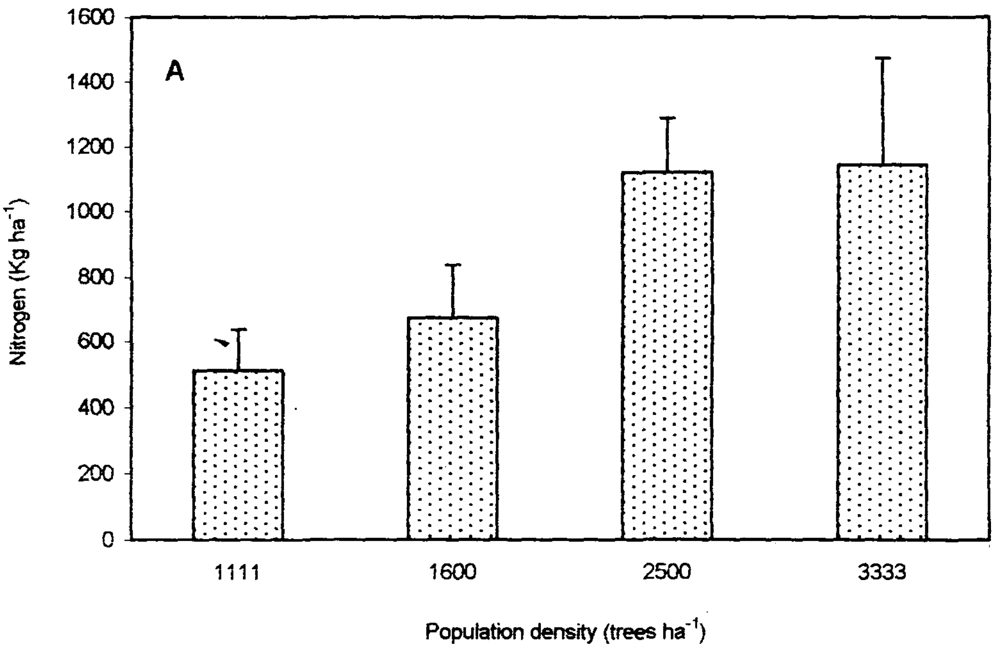
Table 17. Effect of tree population density and fertiliser levels on nitrogen accumulation of 8.7 year old *Ailanthus triphysa* stand

Treatments	Stem wood	Branch wood	Foliage	Root	Above ground	Total
	N accumulation (kg ha^{-1})					
Density (trees ha^{-1})						
3333	691.736^{a}	137.903^{a}	191.092^{a}	123.821^{a}	1020.731^{a}	1144.845^{a}
2500	672.396^{a}	125.135^{a}	215.938^{a}	108.594^{a}	1012.708^{a}	1121.203^{a}
1600	378.800^{b}	87.600^{b}	124.933^{b}	69.680^{b}	591.333^{b}	673.006^{b}
1111	284.972^{b}	63.557^{b}	113.830^{b}	47.273^{b}	462.360^{b}	509.531^{b}
F test	<0.01	<0.01	<0.01	<0.01	<0.01	<0.05
SEm (±)	59.458	9.2774	17.1208	6.464	75.25	70.37
LSD(0.05)	179.2	27.96	51.61	29.09	226.8	316.7
Fertiliser level ($N:P_2O_5:K_2O$ kg ha^{-1} yr^{-1})						
0:0:0	514.987	90.989	162.387	94.414	768.365	862.692
50:25:25	522.066	111.232	189.691	93.698	822.99	917.082
100:50:50	494.957	107.670	145.822	85.014	748.448	833.240
150:75:75	495.894	104.305	147.892	76.241	747.330	835.571
F test	NS	NS	NS	NS	NS	NS
SEm (±)	38.9235	9.557	18.882	8.3483	59.4584	86.497
LSD (0.05)	-	-	-	-	-	-
Density x Fertiliser interaction						
F test	NS	NS	NS	<0.05	NS	NS
SEm (±)	77.847	19.1147	37.764	16.6965	118	172.99

Table 18. Combined effects of tree population density and fertiliser levels on stand root nitrogen accumulation

Fertiliser levels ($N:P_2O_5:K_2O$ kg ha^{-1} yr^{-1})	Nitrogen (kg ha^{-1}) 3333	2500	1600	1111
0:0:0	178.1 ^{a}	107.1 ^{bcd}	42.0 ^{e}	50.38 ^{de}
50:25:25	132.8 ^{ab}	130.9 ^{ab}	71.6 ^{cde}	39.50 ^{e}
100:50:50	95.82 ^{bcde}	90.38 ^{bcde}	108.6 ^{bc}	45.22 ^{e}
150:75:75	88.49 ^{bcde}	106.0 ^{bcd}	56.48 ^{cde}	53.99 ^{cde}

LSD(0.05) = 51.45



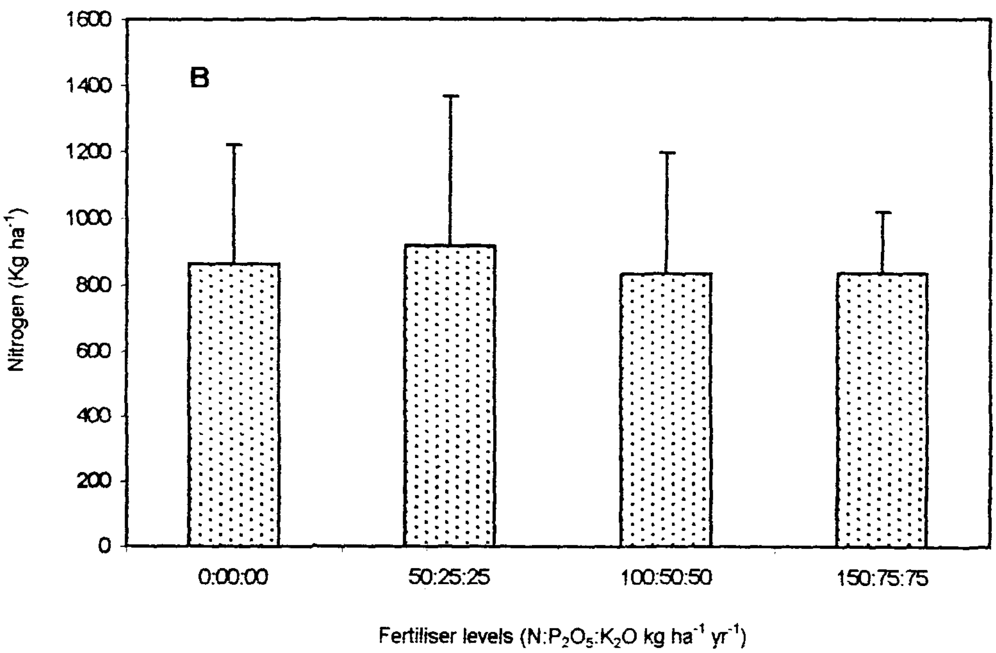


Fig. 6. Nitrogen removal of 8.7 year old ailanthus trees through harvest as influenced by tree population density (A) and fertiliser levels (B)

4.3.4.2 Phosphorus

Although stand density had no significant influence on P accumulated in the biomass on an individual tree basis, a profound influence was noted on the above ground, stemwood and foliar P contents (Table 19, Appendix 12). The lowest density stands of 1111 tpha showed the highest P accumulation of 0.016, 0.005 and 0.027 kg $tree^{-1}$ for stemwood, foliage and above ground biomass respectively, whereas stands with 3333 tpha registered the lowest values. Fertiliser regimes seemed to have a significant effect on stemwood P accumulation only. The higher dose of fertilisers recorded 25 per cent more P accumulation than the unfertilised control. Data on P accumulation on stand basis is given in Table 20, Appendix 13. P accumulation in total biomass and different tissue fractions were significantly altered by stand density. Stands with 2500 and 3333 tpha in general recorded higher values of 33 to 49 per cent than stands of 1600 and 1111 tpha (Fig.7). Significant fertiliser and interaction effects on P accumulation were absent (Table 20, Appendix 13).

4.3.4.3 Potassium

Total K accumulation per tree was not significantly influenced by stand density and fertiliser regimes. However, total above ground biomass, branchwood and foliar K accumulation were significantly affected by stand density. The lowest density stand of 1111 tpha exhibited 20, 50 and 28 per cent higher values for branchwood, foliage and above ground biomass respectively over 3333 tpha (Table 21, Appendix 14). Fertiliser effect was significant in the case of roots. The dose of 100:50:50 $N:P_2O_5:K_2O$ kg ha^{-1} yr^{-1} showed 34 per cent more K accumulation than that of the control (no fertiliser). Density x fertiliser interaction effect was significant in respect of roots K accumulation. The combination of 1600 tpha at 100:50:50 $N:P_2O_5:K_2O$ kg ha^{-1} yr^{-1} registered the highest value of 0.031 kg $tree^{-1}$ (Table 22, Appendix 14). K accumulation in overall stand biomass (Fig.8) and different tissue fractions (stemwood, branchwood and foliage) were significantly

Table 19. Effect of tree population density and fertiliser levels on phosphorus accumulation of 8.7 year old *Ailanthus triphysa* trees

Treatments	Stem wood	Branch wood	Foliage	Roots	Above ground	Total
	P accumulation (kg tree^{-1})					
Density (trees ha^{-1})						
3333	0.010 ^{a}	0.005	0.003 ^{b}	0.003	0.017 ^{b}	0.020
2500	0.015 ^{ab}	0.006	0.004 ^{ab}	0.004	0.024 ^{a}	0.028
1600	0.015 ^{ab}	0.006	0.004 ^{ab}	0.004	0.024 ^{a}	0.028
1111	0.016 ^{a}	0.006	0.005 ^{a}	0.004	0.027 ^{a}	0.031
F test	<0.05	NS	<0.05	NS	<0.05	NS
SEm (±)	0.0013	0.004	0.0005	0.0005	0.001581	0.0018
LSD (0.05)	0.00504	-	0.00180	-	0.00477	-
Fertiliser level ($N:P_2O_5:K_2O$ kg ha^{-1} yr^{-1})						
0:0:0	0.012 ^{b}	0.005	0.004	0.003	0.020	0.023
50:25:25	0.013 ^{ab}	0.005	0.004	0.004	0.021	0.025
100:50:50	0.016 ^{a}	0.006	0.004	0.004	0.025	0.030
150:75:75	0.016 ^{a}	0.006	0.004	0.003	0.026	0.029
F test	<0.05	NS	NS	NS	NS	NS
SEm (±)	0.0012	0.005	0.0005	0.0005	0.0019	0.0027
LSD (0.05)	0.00332	-	-	-	-	-
Density x Fertiliser interaction						
F test	NS	NS	NS	NS	NS	NS
SEm (±)	0.0024	0.0010	0.0009	0.0009	0.0038	0.0054

Table 20. Effect of tree population density and fertiliser levels on phosphorus accumulation of 8.7 year old *Ailanthus triphys* stand

Treatments	Stem wood	Branch wood	Foliage	Roots	Above ground	Total
	Phosphorus accumulation (kg ha^{-1})					
Density (trees ha^{-1})						
3333	34.632^{a}	15.429^{a}	8.096^{ab}	9.624^{a}	58.160^{a}	67.423^{a}
2500	37.854^{a}	13.781^{a}	9.494^{a}	9.094^{a}	61.116^{a}	70.159^{a}
1600	23.920^{b}	9.173^{b}	5.883^{bc}	5.860^{b}	38.977^{b}	44.842^{b}
1111	17.427^{b}	6.860^{b}	5.476^{c}	4.361^{b}	29.574^{b}	34.094^{b}
F test	<0.01	<0.01	<0.01	<0.05	<0.01	<0.05
SEm (±)	2.9326	1.0245	0.8048	0.5312	3.906	3.755
LSD (0.05)	8.840	3.088	2.426	2.391	11.78	16.90
Fertiliser level ($N:P_2O_5:K_2O$ kg ha^{-1} yr^{-1})						
0:0:0	24.496	9.813	6.094	6.701	40.389	47.073
50:25:25	26.932	10.405	7.726	8.074	45.063	52.833
100:50:50	31.237	12.607	7.734	7.479	51.578	59.027
150:75:75	31.169	12.419	7.395	6.685	50.798	57.586
F test	NS	NS	NS	NS	NS	NS
SEm (±)	2.3872	1.1111	0.8299	0.9726	3.8249	5.993
LSD (0.05)	-	-	-	-	-	-
Density x Fertiliser interaction						
F test	NS	NS	NS	NS	NS	NS
SEm (±)	4.7745	2.2222	1.6599	1.9451	7.6497	11.986

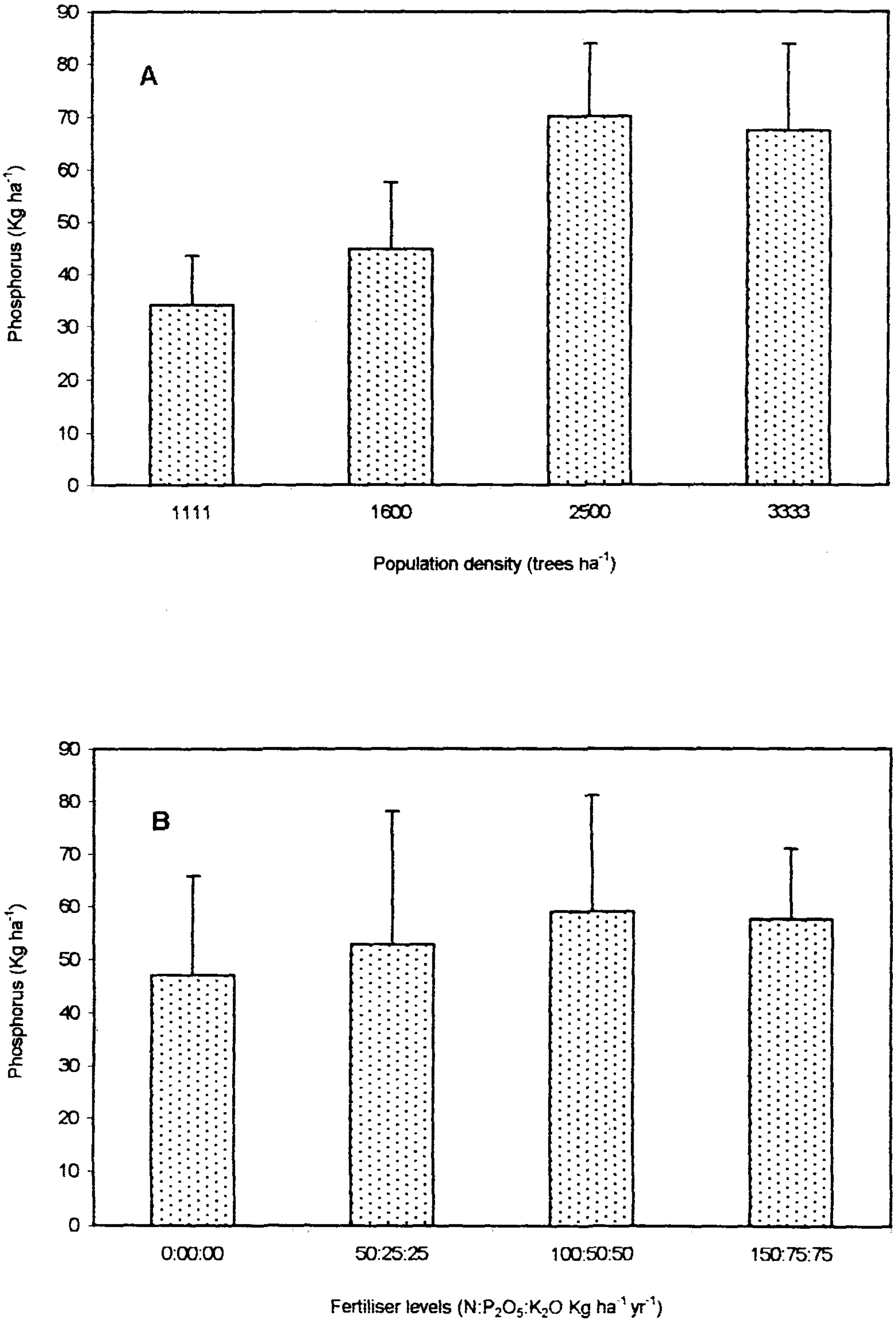


Fig. 7. Phosphorus removal of 8.7 year old ailanthus trees through harvest as influenced by tree population density (A) and fertiliser levels (B)

Table 21. Effect of tree population density and fertiliser levels on potassium accumulation of 8.7 year old *Ailanthus triphysa* trees

Treatments	Stem wood	Branch wood	Foliage	Roots	Above ground	Total
	K accumulation (kg tree^{-1})					
Density (trees ha^{-1})						
3333	0.113	0.034^{b}	0.019^{b}	0.0153	0.166^{b}	0.182
2500	0.163	0.042^{ab}	0.029^{ab}	0.0205	0.233^{a}	0.252
1600	0.142	0.044^{a}	0.027^{a}	0.0205	0.212^{ab}	0.233
1111	0.147	0.046^{a}	0.038^{a}	0.0208	0.231^{a}	0.252
F test	NS	<0.05	<0.05	NS	<0.05	NS
SEm (±)	0.0134	0.0029	0.0032	0.0249	0.0162	0.016
LSD (0.05)	-	0.008702	0.009729	-	0.02400	-
Fertiliser level ($N:P_2O_5:K_2O$ kg ha^{-1} yr^{-1})						
0:0:0	0.126	0.040	0.024	0.0150^{b}	0.189	0.204
50:25:25	0.133	0.039	0.028	0.0181^{ab}	0.200	0.218
100:50:50	0.155	0.043	0.027	0.0229^{a}	0.225	0.246
150:75:75	0.150	0.045	0.034	0.0211^{a}	0.229	0.250
F test	NS	NS	NS	<0.05	NS	NS
SEm (±)	0.0116	0.0038	0.0032	0.0143	0.0163	0.022
LSD (0.05)	-	-	-	0.004872	-	-
Density x Fertiliser interaction						
F test	NS	NS	NS	<0.05	NS	NS
SEm (±)	0.0231	0.0076	0.0064	0.0287	0.0326	0.0439

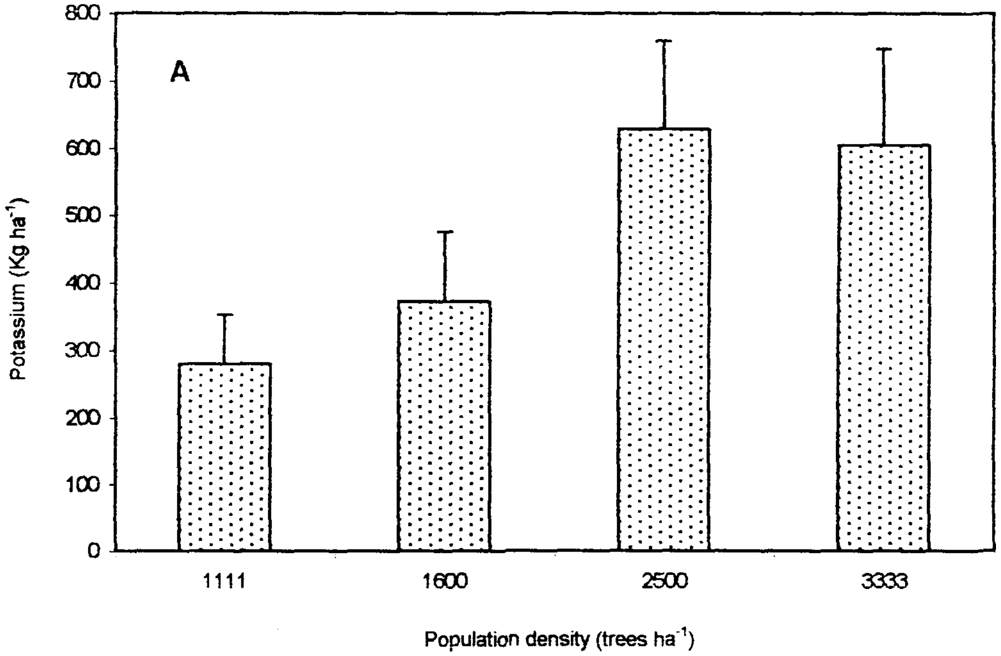
Table 22. Combined effects of tree population density and fertiliser levels on root potassium accumulation

Fertiliser levels ($N:P_2O_5:K_2O$ kg ha^{-1} yr^{-1})	Root K accumulation (kg $tree^{-1}$)			
	3333	2500	1600	1111
0:0:0	0.0185 ^{bcde}	0.0159 ^{cde}	0.0097 ^{c}	0.0158 ^{cde}
50:25:25	0.0152 ^{cde}	0.0229 ^{abcd}	0.0199 ^{bcde}	0.0146 ^{cde}
100:50:50	0.0153 ^{cde}	0.0179 ^{bcde}	0.0308 ^{a}	0.0276 ^{ab}
150:75:75	0.0122 ^{de}	0.0255 ^{abc}	0.0216 ^{abcd}	0.0253 ^{abc}

LSD(0.05) = 0.009744

Table 23. Effect of tree population density and fertiliser level on potassium accumulation of 8.7 year old *Ailanthus triphysa* stand

Treatments	Stem wood	Branch wood	Foliage	Root	Above ground	Total
	K accumulation (kg ha^{-1})					
Density (trees ha^{-1})						
3333	376.240 [a]	114.211 [a]	64.021 [a]	50.911	554.470 [a]	605.248 [a]
2500	406.333 [a]	105.083 [a]	72.323 [a]	51.344	583.740 [a]	629.188 [a]
1600	226.502 [b]	70.740 [b]	42.702 [b]	32.800	339.519 [b]	372.141 [b]
1111	163.150 [b]	51.407 [b]	42.024 [b]	23.150	256.577 [b]	279.185 [b]
F test	<0.01	<0.01	<0.01	NS	<0.01	<0.05
SEm (±)	30.8581	7.6578	5.5669	4.8332	36.36	40.7662
LSD (0.05)	93.02	23.08	16.78	-	109.6	183.5
Fertiliser level ($N:P_2O_5:K_2O$ kg ha^{-1} yr^{-1})						
0:0:0	258.233	80.734	47.382	33.615	386.347	419.743
50:25:25	293.155	80.179	59.346	38.951	432.271	470.507
100:50:50	327.100	90.335	54.307	43.922	471.723	509.881
150:75:75	293.738	90.193	60.034	41.717	443.965	485.631
F test	NS	NS	NS	NS	NS	NS
SEm (±)	24.2467	8.0088	6.5048	3.3298	34.1969	48.809
LSD (0.05)	-	-	-	-	-	-
Density x Fertiliser interaction						
F test	NS	NS	NS	NS	NS	NS
SEm (±)	48.4934	16.018	13.0097	6.6596	68.3938	97.619



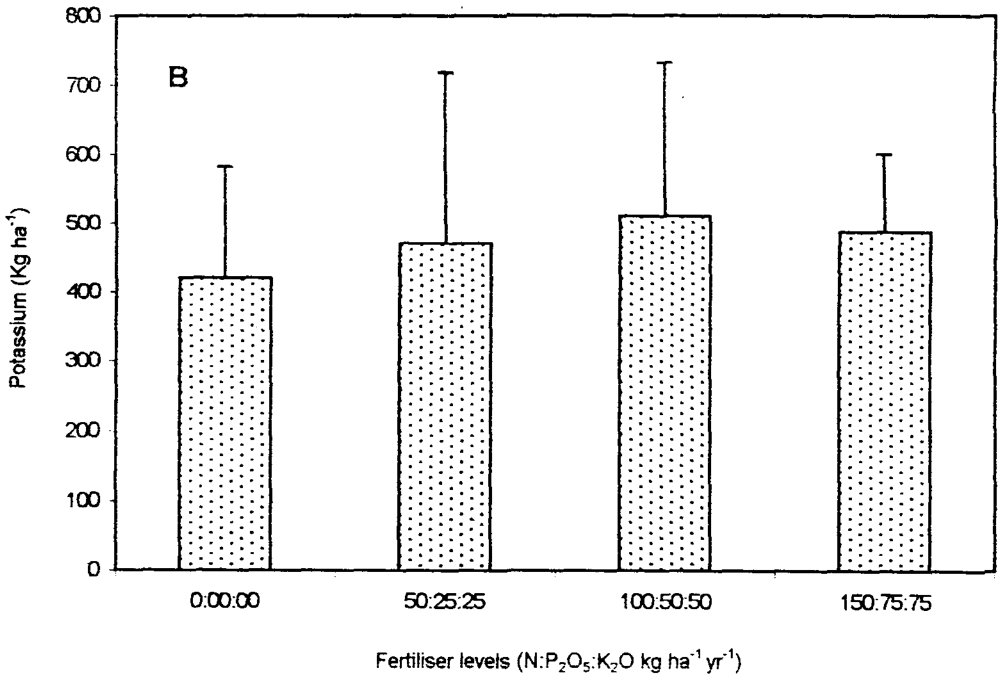


Fig. 8. Potassium removal of 8.7 year old ailanthus trees through harvest as influenced by tree population density (A) and fertiliser levels (B)

influenced by tree population density ($p<0.01$). Stands with 2500 tpha in general showed higher values but were statistically at par with 3333 tpha (Table 23, Appendix 15). Fertiliser regimes did not affect K accumulation. On stand basis also, interaction effect was lacking.

4.3.5 Nutrient use efficiency

4.3.5.1 Nitrogen

Neither population density nor fertiliser levels had a significant effect on the overall nitrogen use efficiency (NUE) and NUE of above ground parts (Table 24, Appendix 16). But a significant effect of stand density was noted on the stemwood NUE. Stands with 1600 tpha registered the highest efficiency (0.15 kg biomass g^{-1} of N). Nitrogen use efficiency of branchwood was significantly influenced by fertiliser levels. Trees in the control plot showed the highest NUE (10% more than the highest dose of fertiliser applied). Interaction effects (fertiliser x density) were also significant in respect of branchwood NUE (Table 25, Appendix 16). The combination of 2500 tpha and unfertilised control showed the highest NUE of 0.14 kg biomass g^{-1} of N.

4.3.5.2 Phosphorus

Phosphorus use efficiency (PUE) for aboveground biomass, stemwood and foliage was significantly affected by population density. The stand with 3333 tpha showed the highest PUE (2.84, 0.87 and 2.05 kg biomass g^{-1} of P for stemwood, foliage and above ground biomass respectively). In general, denser stands showed greater PUE (upto 12% more than that of the stands with 1111 tpha). Fertiliser regimes had a significant effect ($p<0.01$) on overall PUE. Greater efficiency was noted in the trees of the control plot (no fertiliser), with 24% higher PUE for control than that of the dose of 150:75:75 kg $N:P_2O_5:K_2O$ ha^{-1} yr^{-1} (Table 26, Appendix 17). Above ground biomass and foliage PUE also showed significant interaction effects (density x fertiliser). A combination of 3333 tpha and

Table 24. Effect of tree population density and fertiliser levels on nitrogen use efficiency of 8.7 year old *Ailanthus triphysa* trees

Treatments	Stem wood	Branch wood	Foliage	Roots	Above ground	Total
	NUE (kg biomass g^{-1} N)					
Density (trees ha^{-1})						
3333	0.144[b]	0.108	0.036	0.134	0.117	0.119
2500	0.142[b]	0.113	0.036	0.134	0.116	0.117
1600	0.152[a]	0.109	0.036	0.144	0.122	0.121
1111	0.149[ab]	0.111	0.037	0.134	0.116	0.117
F test	<0.05	NS	NS	NS	NS	NS
SEm (±)	0.0026	0.004	0.0004	0.0062	0.0029	0.0025
LSD (0.05)	0.007096	-	-	-	-	-
Fertiliser level ($N:P_2O_5:K_2O$ kg ha^{-1} yr^{-1})						
0:0:0	0.145	0.121[a]	0.036	0.133	0.120	0.120
50:25:25	0.149	0.106[b]	0.036	0.131	0.115	0.117
100:50:50	0.152	0104[b]	0.036	0.137	0.122	0.123
150:75:75	0.140	0.109[b]	0.036	0.143	0.115	0.115
F test	NS	<0.01	NS	NS	NS	NS
SEm (±)	0.0036	0.0032	0.0003	0.0049	0.0026	0.0036
LSD (0.05)	-	0.008757	-	-	-	-
Density x Fertiliser interaction						
F test	NS	<0.01	NS	NS	NS	NS
SEm (±)	0.0073	0.0063	0.0007	0.0099	0.0053	0.0072

Table 25. Combined effects of tree population density and fertiliser levels on branch wood NUE

Fertiliser levels ($N:P_2O_5:K_2O$ kg ha^{-1} yr^{-1})	NUE (kg biomass g^{-1} N) 3333	2500	1600	1111
0:0:0	0.119 ^{bcd}	0.143 ^{a}	0.100 ^{de}	0.122 ^{bc}
50:25:25	0.097 ^{e}	0.098 ^{e}	0.128 ^{ab}	0.101 ^{de}
100:50:50	0.107 ^{cde}	0.107 ^{cde}	0.098 ^{e}	0.105 ^{cde}
150:75:75	0.109 ^{bcde}	0.103 ^{cde}	0.109 ^{bcde}	0.116 ^{bcde}

LSD(0.05) = 0.01751

Table 26. Effect of tree population density and fertiliser levels on phosphorus use efficiency of 8.7 year old *Ailanthus triphysa* trees

Treatments	Stem wood	Branch wood	Foliage	Roots	Above ground	Total
	PUE (kg biomass g^{-1} P)					
Density (trees ha^{-1})						
3333	2.836[a]	1.010	0.872[a]	1.851	2.048[a]	2.027
2500	2.585[b]	0.996	0.847[ab]	1.619	1.939[ab]	1.890
1600	2.491[b]	1.025	0.805[ab]	1.702	1.882[b]	1.842
1111	2.520[b]	1.019	0.775[b]	1.591	1.809[b]	1.764
F test	<0.05	NS	<0.05	NS	<0.05	NS
SEm (±)	0.0354	0.0119	0.0236	0.0853	0.0511	0.0632
LSD (0.05)	0.1066	-	0.07015	-	0.1544	-
Fertiliser level ($N:P_2O_5:K_2O$ kg ha^{-1} yr^{-1})						
0:0:0	3.015[a]	1.138[a]	0.991[a]	1.915	2.243[a]	2.185[a]
50:25:25	2.882[a]	1.092[b]	0.882[b]	1.538	2.045[b]	1.972[b]
100:50:50	2.303[b]	0.917[c]	0.694[c]	1.619	1.728[c]	1.692[c]
150:75:75	2.231[b]	0.903[c]	0.732[c]	1.689	1.622[c]	1.674[c]
F test	<0.01	<0.01	<0.01	NS	<0.01	<0.01
SEm (±)	0.0507	0.0154	0.0190	0.1566	0.0334	0.0516
LSD (0.05)	0.1438	0.04473	0.05479	-	0.09488	0.2810
Density x Fertiliser interaction						
F test	NS	NS	<0.01	NS	<0.01	NS
SEm (±)	0.1013	0.0307	0.0380	0.3132	0.0668	0.1032

Table 27. Combined effects of tree population density and fertiliser levels on foliar and above ground phosphorus use efficiency

Fertiliser levels ($N:P_2O_5:K_2O$ kg ha^{-1} yr^{-1})	Foliar PUE (kg biomass g^{-1} P)				Above ground PUE (kg biomass g^{-1} P)			
	3333	2500	1600	1111	3333	2500	1600	1111
0:0:0	1.116 [a]	0.987 [b]	0.949 [bc]	0.911 [bcd]	2.519 [a]	2.164 [bc]	2.222 [bc]	2.069 [cd]
50:25:25	0.947 [bc]	0.924 [bc]	0.865 [bcd]	0.793 [def]	2.347 [ab]	2.037 [cde]	1.949 [def]	1.847 [efg]
100:50:50	0.708 [fg]	0.642 [g]	0.735 [efg]	0.692 [fg]	1.730 [gh]	1.756 [fgh]	1.765 [fgh]	1.659 [gh]
150:75:75	0.717 [fg]	0.836 [cde]	0.672 [fg]	0.704 [fg]	1.594 [h]	1.801 [fgh]	1.593 [h]	1.660 [gh]

LSD(0.05) = 0.1096

LSD(0.05) = 0.1898

Table 28. Effect of tree population density and fertiliser levels on potassium use efficiency of 8.7 year old *Ailanthus triphysa* trees

Treatments	Stem wood	Branch wood	Foliage	Roots	Above ground	Total
	KUE (kg biomass g^{-1} K)					
Density (trees ha^{-1})						
3333	0.259[ab]	0.133	0.106	0.330	0.215	0.182
2500	0.247[b]	0.130	0.108	0.294	0.203	0.240
1600	0.259[ab]	0.137	0.111	0.302	0.212	0.220
1111	0.268[a]	0.137	0.102	0.286	0.210	0.215
F test	<0.05	NS	NS	NS	NS	NS
SEm (±)	0.0045	0.0041	0.0042	0.0281	0.0043	0.0125
LSD (0.05)	0.0133	-	-	-	-	-
Fertiliser level ($N:P_2O_5:K_2O$ kg ha^{-1} yr^{-1})						
0:0:0	0.292[a]	0.141[a]	0.125[a]	0.371[a]	0.236[a]	0.215
50:25:25	0.268[b]	0.142[a]	0.115[a]	0.318[b]	0.215[b]	0.226
100:50:50	0.235[c]	0.130[b]	0.100[b]	0.260[c]	0.196[c]	0.228
150:75:75	0.238[c]	0.125[b]	0.088[b]	0.262[c]	0.194[c]	0.188
F test	<0.01	<0.01	<0.01	<0.01	<0.01	NS
SEm (±)	0.0068	0.0032	0.0045	0.01581	0.0042	0.0148
LSD (0.05)	0.01826	0.00913	0.01291	0.04872	0.01169	-
Density x Fertiliser interaction						
F test	<0.01	<0.05	NS	NS	<0.05	NS
SEm (±)	0.137	0.0064	0.0091	0.0305	0.0083	0.0296

Table 29. Combined effect of tree population density and fertiliser levels on stemwood, branch wood and above ground potassium use efficiency

Fertiliser levels ($N:P_2O_5:K_2O$ kg ha^{-1} yr^{-1})	Stem wood KUE (kg biomass g^{-1} K)				Branch wood KUE (kg biomass g^{-1} K)				Above ground KUE (kg biomass g^{-1} K)			
	3333	2500	1600	1111	3333	2500	1600	1111	3333	2500	1600	1111
0:0:0	0.311^{a}	0.218^{ab}	0.264^{bc}	0.313^{a}	0.134^{bcd}	0.129^{cd}	0.153^{ab}	0.147^{abc}	0.250^{a}	0.228^{abc}	0.227^{abc}	0.238^{ab}
50:25:25	0.265^{bc}	0.273^{abc}	0.253^{bcd}	0.279^{ab}	0.143^{abc}	0.134^{abcd}	0.155^{a}	0.135^{abcd}	0.227^{abc}	0.209^{cde}	0.217^{bcd}	0.208^{cde}
100:50:50	0.217^{de}	0.203^{e}	0.279^{ab}	0.242^{bcde}	0.131^{cd}	0.130^{cd}	0.120^{d}	0.139^{abcd}	0.184^{ef}	0.178^{f}	0.217^{bcd}	0.205^{cde}
150:75:75	0.244^{bcde}	0.232^{cde}	0.239^{bcde}	0.238^{bcde}	0.126^{cd}	0.127^{cd}	0.118^{d}	0.128^{cd}	0.201^{cdef}	0.197^{def}	0.188^{ef}	0.189^{ef}

LSD(0.05) = 0.03652 (stem wood); LSD(0.05)= 0.01826 (branch wood); LSD(0.05)= 0.02338 (above ground) unfertilised control had the highest efficiency in both cases (Table 27, Appendix 17).

4.3.5.3 Potassium

As regard to potassium use efficiency (KUE), data presented in Table 28 and Appendix 18 show that stand density had significant effect on stemwood KUE. The lowest density stand of 1111 tpha showed the highest efficiency (0.27 kg biomass g^{-1} of K). KUE of stemwood, branchwood, foliage and roots were significantly influenced by fertiliser regimes ($p<0.01$). Trees in the control plots exhibited the highest efficiencies (12-30% more) than the fertilised trees for different tissue fractions. Interaction effects (density x fertiliser) were also significant in respect of stemwood, branchwood and total aboveground KUE (Table 29, Appendix 18). But a clear trend was not discernible.

4.4 Soil physico-chemical properties

A comparison of the data on soil chemical analyses presented in Table 30, Fig. 9 and Appendix 19 show that stand density did not exert any profound effect on soil N, organic carbon and soil pH levels. However, density effects on soil available phosphorus and available potassium were significant. The low density (1111 tpha) stand showed 17 per cent higher value for available P when compared to stands with 3333 tpha but was statistically at par with stands of 2500 tpha. For available K, stands with 2500 tpha exhibited a higher value of 105.7 mg kg^{-1} compared to stands with 3333, 1600 and 1111 tpha.

Physico-chemical properties of the soil showed significant variations ($p<0.01$) with respect to fertiliser regimes except for soil pH. Increasing fertiliser levels in general increased the soil organic C, N, available P and available K levels. The fertiliser dose of 150:75:75 $N:P_2O_5:K_2O$ kg ha^{-1} yr^{-1} showed the highest concentration of organic carbon (1.43%), total N (0.18%), available P (8.498 mg kg^{-1} soil) and available K (104.3 mg kg^{-1} soil). Interaction effects (density x

Table 30. Effect of tree population density and fertiliser levels on soil chemical properties

Treatments	Total N (%)	Organic C (%)	Available P ($mg\ kg^{-1}$)	Available K ($mg\ kg^{-1}$)	Soil pH
Density (trees ha^{-1})					
3333	0.164	1.335	5.952 ^{b}	90.00 ^{b}	5.175
2500	0.162	1.341	6.812 ^{a}	105.70 ^{a}	5.233
1600	0.159	1.352	6.602 ^{ab}	92.60 ^{b}	5.209
1111	0.164	1.226	7.183 ^{a}	93.33 ^{b}	5.145
F test	NS	NS	<0.05	<0.05	NS
SEm (±)	0.0051	0.0395	0.2661	3.658	0.0466
LSD (0.05)	-	-	0.802	11.03	-
Fertiliser level ($N:P_2O_5:K_2O$ kg ha^{-1} yr^{-1})					
0:0:0	0.151 ^{bc}	1.155 ^{c}	6.064 ^{b}	88.72 ^{b}	5.272
50:25:25	0.148 ^{c}	1.315 ^{b}	6.232 ^{b}	87.99 ^{b}	5.173
100:50:50	0.168 ^{ab}	1.357 ^{ab}	5.758 ^{b}	100.6 ^{a}	5.160
150:75:75	0.181 ^{a}	1.427 ^{a}	8.498 ^{a}	104.3 ^{a}	5.157
F test	<0.01	<0.01	<0.01	<0.01	NS
SEm (±)	0.0067	0.0303	0.2508	3.146	0.0386
LSD (0.05)	0.01826	0.856	0.7096	8.898	-
Density x Fertiliser interaction					
F test	<0.05	NS	<0.01	NS	NS
SEm (±)	0.0134	0.0607	0.5017	0.0312	0.0773

Table 31.Combined effects of tree population density and fertiliser levels on soil N and P content.

N content (%)

Fertiliser levels ($N:P_2O_5:K_2O$ kg ha^{-1} yr^{-1})	3333	2500	1600	1111
0:0:0	0.146 cde	0.178 abcd	0.146 bcde	0.134 e
50:25:25	0.140 de	0.153 bcde	0.153 bcde	0.146 cde
100:50:50	0.190 ab	0.165 bcde	0.153 bcde	0.165 bcde
150:75:75	0.178 abcd	0.153 bcde	0.184 abc	0.209 a

LSD(0.05) = 0.03652

P content (mg kg^{-1})

Fertiliser levels ($N:P_2O_5:K_2O$ kg ha^{-1} yr^{-1})	3333	2500	1600	1111
0:0:0	4.798 e	6.115 cde	7.985 b	5.358 de
50:25:25	5.388 de	7.921 b	4.815 e	6.795 bcd
100:50:50	5.527 de	5.409 de	5.979 de	6.115 de
150:75:75	8.096 b	7.805 b	7.629 bc	10.46 a

LSD(0.05) = 1.419

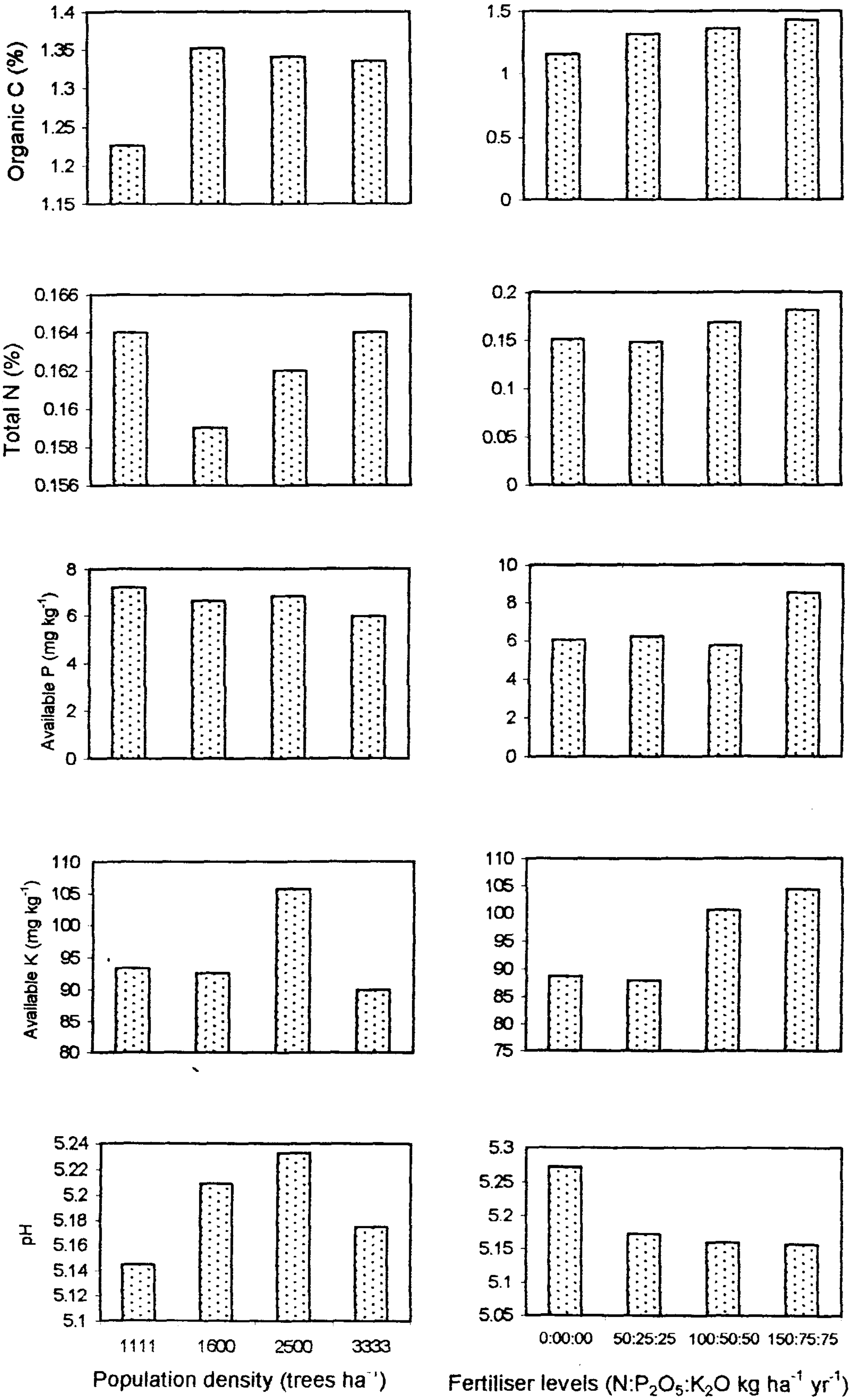


Fig. 9. Soil physico-chemical properties as influenced by ailanthus population density and fertiliser levels

fertiliser) were seen in case of total N and available P (Table 31, Appendix 19). A combination of 1111 tpha at 150:75:75 N:P_2O_5:K_2O kg ha^{-1} yr^{-1} showed highest value for both.

Discussion

5. DISCUSSION

5.1 Short rotation plantations as a source of tropical wood products

Establishing forest plantations to meet the ever increasing demand for tropical tree products has been a long-standing tradition (Evans, 1982), although it gained momentum only after the second World War. Thus, in the tropics by 1950, there were rather less than a million hectares of plantations as defined by FAO. However, by 1980 there were some 11.15 millions and by 1990 almost 44 million ha (FAO, 1995). In India up to 1997, a total of 15.3 million hectares of plantations were established (FSI, 1999). Most plantations are also distinct from the natural forests because of their orderliness and uniformity, being monospecific stands aimed at maximising wood production.

A wide spectrum of trees, usually described as multipurpose trees (MPTs) is involved in the tropical forest plantation programme. Important attributes of MPTs include rapid juvenile growth, efficient dry matter production in terms of water and nutrient inputs, crown characteristics to maximise interception of solar radiation and ease of regeneration (Kumar *et al.*, 1998). Objectives of tree planting are also correspondingly diverse, ranging from production of large diameter lumber over short rotations (maximising individual tree growth) to maximisation of stand volume production on a unit area basis. Although complex multi-use objectives are often proposed, appropriate silvicultural techniques are not available to meet these ends.

Ailanthus triphysa is an important multipurpose tree in the Peninsular Indian context, with high potential for rapid growth (Nair *et al.*, 1984). However, silvicultural manipulation of ailanthus stands has been seldom attempted in the past. The present experiment was designed to assess the influence of graded levels of stand density and fertilisation doses on growth and yield of ailanthus.

5.2 Ailanthus growth and yield as influenced by plant population density

In general, the silviculturist controls stand growth and yield through decisions regarding initial spacing and/or subsequent thinning. In the present study stand density seemed to alter the growth parameters such as total height, clear bole height, diameter at breast height and the biomass accumulation pattern (Tables 2, 4, 5 and 7). Overall, a density level of 2500 tpha showed more height and diameter growth than both higher and lower densities. Lowest mean DBH was observed in the densest stands, which in turn, showed the highest mean clear bole height also. Furthermore, lower branch wood and foliage biomass per tree were observed in this treatment (Table 5). In contrast, the low density stands showed higher branchwood and root biomass, besides greater leaf area and leaf biomass on a per tree basis.

Although, consistently lower values were observed in the densest treatment for various tissue fractions (Table 5), stand biomass, dry weights of various tissue fractions and biomass MAI were higher in the denser treatments (3333 and 2500 tpha; Table 7).

Experimental studies of the influence of initial spacing on tree growth and plantation development has a long history (Sjolte-Jorgensen, 1967), although few studies are reported in the case of ailanthus. It is evident from the data that initial spacing is a critical factor causing growth differences. Presumably trees in the high density stand are competitively stressed as exemplified by the lower mean tree biomass, DBH and other growth attributes. Competition may be for light and/or nutrients and water.

Kumar *et al.* (2001) at an earlier stage of the present experiment showed that in the 3333 tpha stands the understorey PAR transmittance was 40 per cent of the open as compared to 75 per cent in the 1111 tpha stands. Thus higher densities intercepted more of the incoming solar radiation. Reduced PAR transmittance in the understorey implies lower light availability especially in the lower region of the crown. Under "crown competition" of dense stands, branching complexity is less and less foliage is carried on a tree basis (Table 5). Furthermore, owing to earlier death of lower limbs due to mutual shading, lower foliage cover (Putz *et al.*, 1984) and the lower live crown ratio are probable in the denser stands.

Moreover, productivity of stemwood is linearly related to the amount of radiation intercepted (Cannel, 1989). Plants under stress produce less leaf area and therefore intercept less radiation and consequently produce less stemwood (Table 5: 29 kg $tree^{-1}$ at 3333 tpha and 38 kg $tree^{-1}$ at 1111 tpha).

5.3 Ailanthus growth and yield as influenced by fertiliser levels

Intensively managed fast-growing plantations are expected to place large demands on soil nutrient reserves as their nutritional requirements are closely related to growth rates. Most tropical soils are, however, highly weathered and predominantly consisting of kaolinite, iron and aluminium oxides and amorphous materials containing only a small fraction of 2:1 type clay minerals (Kitakawa and Moller, 1977; Lopes, 1977). Because of this mineralogical composition, the essential nutrient reserves are small, CEC is low and P-fixing capacity is high. The permeability of these soils and the potential to leach cations are high. The P, Ca, Mg, Zn, S, N, K, Cu and B levels in many tropical soils are considered to be low or very low and this has a major influence on the potential use and management of these soils (Goncalves *et al.*, 1997).

Seasonal deficiencies in nutrient availability are, therefore, probable in many tropical and subtropical sites. Silvicultural techniques such as application of chemical fertilisers (Binkley, 1986) and/or inter-cropping N-fixing plants (Kumar *et al.*, 1998; De Bell *et al.*, 1989) are often recommended to augment soil nutrient availability. Experience in fast-growing plantations in temperate regions shows that scientifically based, intensive management practices can increase and sustain productivity (Beets *et al.*, 1994; Nambiar, 1996). However, such reports are only rarely available in respect of ailanthus plantations.

Although fertiliser application was expected to promote ailanthus growth results of the present study suggest that fertiliser application at 1.2, 2.25 and 5.25 years after planting, had only a modest influence on growth and biomass accumulation of ailanthus trees in the humid tropical regions of central Kerala (Tables 1, 2, 4, 5 and 7). Surprisingly parameters such as clean bole height, mean tree biomass and stand biomass were slightly higher in the control plot as compared to the fertilised plots. This, however, is in contrast with the findings of Van Cleve and Oliver (1982) who observed that stand leaf area index doubled in N-fertilised quaking aspen (*Populus tremuloides*) and several other previous workers (Heliman and Xie, 1994; Miranda *et al.*, 1998) also reported similar observations.

Although fertiliser effects were generally not significant, density x fertiliser interaction effects were significant in several cases (Tables 3, 6 and 8) implying the necessity for chemical fertiliser application in conjunction with stand density manipulation. In general, the medium stocking level (2500 tpha) showed faster growth and higher biomass accumulation in association with moderate doses of chemical fertilisers (100:50:50 and 50:25:25 NPK kg ha^{-1} yr^{-1}). However, previous published evidences in support of this contention are only scarcely available.

While literature showing the interrelationships between initial stocking levels and fertiliser application is scarce, there is abundant literature on the interactions between thinning and fertilisation (Jacobson and Kukkola, 1999). The general consensus among the authors is that the value of responses in thinned stand is normally greater, as it goes to fewer, larger, selected stems (Ballard and Lea, 1981). Such considerations favour the coincidence of thinning and fertilisation operations.

Furthermore, on nutritionally poor sites, fertiliser response tends to occur irrespective of stocking, whereas on better sites thinning may be a pre-requisite for a response to fertiliser . A comparison of the data presented in Table 30 show that the present experimental site was moderately fertile with mean N, P, K and organic levels of 0.162 per cent, 6.65 mg kg^{-1}, 95.41 mg kg^{-1} and 1.314 per cent respectively.

Another plausible explanation for the lack of fertiliser response especially at the lower stocking levels is the potential competition from weeds. Fertilisation often enhance growth of competing and understorey vegetation especially in the young stands prior to crown closure, and can, therefore, limit response to fertilisation through limiting the availability of other site resources such as moisture or light. Similar effects of weeds on forest plantation have been reported by Kumar *et al.* (2001) and Woods *et al.* (1992) in case of ailanthus and pinus spp. respectively.

The rate of nutrient uptake by trees is also not constant with stand age. Miller (1984) described three general nutrition stages in the life of a plantation. During the first months after planting in the field the rates of nutrient accumulation is small. The length of this phase varies with site quality, which is strongly influenced by water availability also (Goncalves *et al.*, 1997). After establishment, the plants enter a stage of rapid growth and nutrient accumulation. The rate of nutrient absorption parallels the rate of biomass accumulation with age. When the canopy is closed and leaf area stabilises, nutrient accumulation becomes relatively greater in the stem, and the litter biomass accumulated steadily increases to a level determined by site and stand factors. Large variations among species in their ability to absorb nutrients under different conditions of nutrient supply are probable. Hence fertiliser application to forest plantations in the tropics should consider site nutrient supplying power, stocking levels and the magnitude of potential weed competition, besides soil moisture regimes, species and stage of growth.

5.4 Biomass production potential of ailanthus

High biomass production obviously is an important consideration in all tropical tree-planting programmes. Ailanthus is generally regarded as a quick growing tree species (Nair *et al.*, 1984), although Kumar *et al.* (1998) reported relatively lower biomass yield for this species (4.6 Mg ha^{-1}) in comparison to eight other tropical species, owing to the incidence of insect pests such as *Atteva fabriciella* and *Eligma narcissus*. In the present study, ailanthus biomass MAI (at 8.7 years of age) ranged from 6 to 14 Mg ha^{-1} yr^{-1} (Table 7). The growth rates presently observed are in agreement with the results of Lugo *et al.* (1988), who observed that most tropical species fall in the range of 6 to 15 Mg ha^{-1} yr^{-1} for total above ground biomass accumulation. Wang *et al.* (1991), nevertheless reported that the above ground biomass accumulation rates for five other tropical species were of the order of 6 to 36.2 Mg ha^{-1} yr^{-1} (age 5.5 years)implying greater variability in biomass production potential of tropical trees.

Biomass productivity of the multipurpose trees thus differs enormously with species, site characteristics and stand management practices (Kumar *et al.*, 1998). Among the stand management practices, probably manipulating the stocking levels is of utmost importance. A comparison of the data on biomass (Tables 5 and 7) show that biomass accumulation on stand basis has been greater at higher stocking levels, while on individual basis it was more at the low density levels. So if the stand management objective is to produce large biomass volumes on a unit area basis, it is probably better to follow closer spacings such as 2500 and 3333 tpha. On the contrary, if production of large-diameter lumber is the principal management objective, then it is better to adopt density levels such as 1600 and 1111 tpha. This, in turn, underscores the need for tailor-made silvicultural decisions, especially in respect of stocking levels, to meet specific stand management objectives. Although site quality is expected to have a profound impact on the biomass production potential of ailanthus, results of the present study do not portray any perceptible differences owing to the application of chemical fertilisers.

Furthermore, stocking levels are seen to influence the accumulation of stemwood significantly. Stemwood accounted for 82 per cent of the total above ground biomass in 2500 and 3333 tpha treatments, whereas it accounted for 81 and 79 percent of the total aboveground biomass in 1600 and 1111 tpha density levels. Since the accumulation of stemwood is usually the major interest in forestry programmes, results of the present study explains how manipulating ailanthus density would alter this parameter. At wider spacings, trees do not compete with one another atleast during the early years and can therefore extend their crowns. This crown extension is compensated by a smaller height growth (Cabannettes *et al.*, 1999), a higher percentage of branchwood and foliage and lower percentage of stemwood (Tables 2 and 7) in wider spaced stands.

5.5 Nutrient removal through biomass harvest in ailanthus plantation

The promotion of short rotation plantations to resolve the chronic wood shortage faced by hundreds of millions of people in the tropical regions (FAO, 1981) has raised doubts about their sustainability. The question is : can tree plantations be grown indefinitely for rotation after rotation on the same site without serious risk to their health and rate of growth? Of particular concern is the threat that frequent harvest related nutrient exports could result in soil fertility deprivation and productivity declines, even on good sites (Goncalves *et al.*, 1997; Kumar *et al.*, 1998).

Nutrient removal at harvest is a function of both nutrient concentrations of the different tissue fractions and biomass yield. Leaves were the most costly tissues to build registering the highest concentration of N, P and K followed by branchwood, roots and stemwood respectively. Significant variations were noticed in stemwood (for N%) and stemwood and roots (for P and K%) in response to tree population density (Tables 9, 11 and 13).

Elemental concentration in various tissue fraction was modestly higher than previously reported values of N, P and K at 8.8 years of age (Kumar *et al.*, 1998). Site and soil conditions may have a strong influence on tissue nutrient concentrations. Deviations in nutrient concentrations of tissue fractions are therefore not extraordinary.

As regards to nutrient accumulation on a tree basis, the lower density stands recorded higher values for N, P and K accumulation (Tables 15, 19 and 21) indicating greater availability of nutrient resources at low density and also high biomass accumulation rate may have resulted in the high nutrient accumulation rates. The stands with 3333 and 2500 tpha recorded higher nutrient accumulation rates on a hectare basis. Fertiliser response on nutrient accumulation was however, lacking both on a tree and stand basis. Most of the nutrients were concentrated in the stemwood, followed by branchwood, foliage and roots (Tables 17, 20, 23). Hence during harvesting operation, if the branches and stemwood alone are removed, leaving the foliage and other tissue fractions at the site itself, nutrient loss from the site could be substantially reduced.

5.5.1 Nutrient use efficiency

Sustainable production without adversely affecting site quality is a key design criteria in all short rotation intensive cultural systems. Such systems are, however, characterised by frequent removal of parts in pruning, lopping etc. or whole tree harvesting, which in turn may have the potential for high nutrient depletion. In this context, nutrient use efficiency (biomass to nutrient ratio) provides a good measure to evaluate large differences in nutrient 'costs' of biomass production (Wang *et al.*, 1991).

Significant effects of tree population density were seen on nitrogen use efficiency of stemwood, phosphorus use efficiency of stemwood and foliage and potassium use efficiency of stemwood. However, N, P and K efficiency (Tables 24, 26 and 28) did not follow a consistent pattern. For instance, lower densities were most efficient for N and K while higher densities were most efficient for P. Regarding fertiliser regimes, trees in the control plot exhibited higher efficiencies compared to the fertilised trees (Tables 24, 26 and 28). Interaction effects were also significant in several cases (Table 25, 27 and 29) and highest efficiencies were invariably seen in combinations that involved control (unfertilised) trees with varying tree population densities. Thus fertilisation generally depressed nutrient use.

5.6 Soil physico-chemical properties

Culture of short rotation forest (SRF) crops can have positive and negative impacts on productive capacity of soils. Positive impacts derive from several factors, including the high input or organic matter to the soil. The organic inputs are mainly from leaf fall and the turnover of fine roots within the soil. The deep and extensive root systems can also improve soil conditions. Negative impacts can be through soil erosion and the effects of harvesting and other operations on soil physical conditions (Heilman, 1992).

The data in Table 30 suggests that as tree population density increased, the available P, available K and organic C concentrations declined. Reduction in soil nutrient levels particularly at high densities can be explained based on accelerated nutrient removal by trees. Ailanthus being a fast growing tree may absorb nutrients rapidly. The magnitude of nutrient extraction is presumably a function of tree density. Similar results have been reported by Kumar *et al.* (2001) at an earlier stage of the present experiment. Soil pH was also lower in high density stands. Dense stands probably produce more litter and are expected to have relatively low pH values (Jamaludheen and Kumar, 1999). Fertiliser application also altered the soil nutrient status. Increased content of Total N, Organic C, available P and K were observed at higher dose of fertilisers.

Woody perennials may enrich soils through nutrient cycling, nutrient pumping etc. The higher content of total N and available K observed in the present study when compared to previous study (Kumar *et al.*, 2001) could be attributed to it. Also nutrient removal by tree component may have reduced the soil organic carbon content over the previous study.

Summary and Conclusion

6. SUMMARY AND CONCLUSION

Ailanthus (*Ailanthus triphysa* (Dennst) Alston.) is an important multipurpose tree in the peninsular Indian context. It shows high growth rates (biomass MAI up to 14 Mg ha^{-1} yr^{-1} over short rotations) and can be used for multiple purpose (eg: match industry, plywood making, medicinal uses besides a support tree for pepper vines). Comparatively little is known about the silvicultural manipulation of ailanthus, despite being a prominent component of tropical plantations and agroforestry. A split - plot experiment involving *Ailanthus triphysa* was initiated at Vellanikkara in June 1991. The objectives were to assess the productivity of ailanthus in relation to graded levels of fertilisers and plant population densities, besides estimating the nutrient characteristics of the species and evaluating nutrient export from the site through whole tree harvesting. 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}). Salient results are summarised below.

(1) Differing levels of stand densities had a marked effect on height, diameter and leaf area growth of ailanthus at 8.7 years of age. Stands with 2500 tpha consistently showed the highest values for height and diameter.

(2) Greater biomass accumulation on per tree basis was observed in the low density stands compared to the higher density stands. However, on stand basis, higher stocking levels showed substantially more biomass accumulation. Thus, lower planting densities can be adopted if production target is to obtain large diameter lumber over short rotations. On the other hand, if production of large biomass volumes is the stand management objective, clearly higher stand densities are preferable.

(3) Fertiliser application had only a modest influence on growth and biomass accumulation of ailanthus trees owing to moderate levels of native soil fertility. However, fertiliser responses are frequent on nutritionally poor sites.

Under moderate to high levels of soil fertility perhaps it makes little sense to apply chemical fertilisers to ailanthus plantations.

(4) Density x fertiliser interactions was significant in terms of growth and biomass accumulation of ailanthus. The medium stocking level (2500 tpha) showed faster growth and higher biomass accumulation when grown with moderate doses of chemical fertilisers. This, in turn, underscores the need for applying chemical fertilsers in conjunction with stand density manipulation.

(5) Nutrient removed through whole tree harvesting is a function of tissue nutrient concentrations and biomass accumulation. High density stands in general recorded greater potential for nutrient export from the site (1133, 68 and 617 kg of N, P and K).

(6) Leaves are the most costly tissues to build showing the highest concentration of N, P and K followed by branchwood, roots and stemwood respectively. The harvest of woody biomass (bolewood) account for only 56 per cent of the total site nutrient removed. Thus foliage and small branches which contain a large proportion of the nutrients if left at the site may reduce nutrient export associated with tree harvesting.

(7) Nutrient use efficiency indicates the ability of different organs / plants to accumulate biomass per unit of nutrients absorbed. Overall N and P use efficiency declined in the order: Stemwood > roots > branchwood > foliage whereas for KUE it is : roots > stemwood > brancwood > foliage. Although lower stand density provide greater root foraging zones for individual plants and hence potentially more nutrient availability, the present results do not show any perceptible variations in terms of nutrient use efficiency. Fertilisation, in general depressed nutrient use efficiency (N, P and K).

(8) Tree population density did not influence the soil physico-chemical parameters except available P and K levels at 8.7 years after tree planting. In general available soil P availability was more in the low density stands and available K was highest in the medium stocking level. Fertiliser application in general improved total soil N, available P, K and organic C levels.

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* Original not seen.

Appendices

APPENDIX I

Mean weather parameters during the experimental period (Jan 1991-Dec 2000) recorded by the Department of Meteorology, College of Horticulture, Kerala Agricultural University.

Months	Temperature (°C)		
	Maximum	Minimum	Rainfall (mm)
January	32.8	22.04	3.42
February	34.7	22.7	7.66
March	36.2	23.8	21.81
April	35.3	24.8	164.81
May	33.6	24.64	347.61
June	30.2	23.25	695.06
July	28.9	22.83	665.89
August	29.5	23.23	439.86
September	30.6	23.32	196.95
October	31.4	23.18	246.34
November	31.5	23.12	102.32
December	31.4	22.42	7.0
Mean	32.17	23.27	2898.7

APPENDIX II

Abstracts of ANOVA table for tree growth characteristics of Ailanthus at 8.3 years of age as affected by tree population density and fertiliser regimes.

Source	Mean Square		
	Growth characteristics		
	df	Height	DBH
Replication	1	5.349	0.735
Density	3	2.154	10.902*
Error (A)	3	1.195	0.231
Fertiliser	3	0.706	1.156
Interaction	9	1.240	1.991
Error (B)	12	1.179	3.025

APPENDIX III

Abstracts of ANOVA table for tree growth characteristics of Ailanthus at 8.7 years of age as affected by tree population density and fertiliser regimes

Source	Mean Square			
	Growth characteristics			
	df	Total height	Clear bole height	DBH
Replication	5	3.863	1.029	3.921
Density	3	11.020**	8.322**	13.765*
Error (A)	15	1.380	1.385	3.845
Fertiliser	3	0.419	0.547	2.855
Interaction	9	7.565**	3.478**	14.416*
Error (B)	60	1.807	1.239	6.794

* Significant at 5% of level

** Significant at1% level

APPENDIX IV

Abstracts of ANOVA table for leaf area, root depth and root spread of 8.7 year old Ailanthus as affected by tree population density and fertiliser regimes

Source	df	Mean Square	
		Leaf area/tree	Leaf area/ha
Replication	5	335.507	1261202681.20
Density	3	587.370**	3297328038.67**
Error (A)	15	102.007	374956962.47
Fertiliser	3	33.688	457604238.75
Interaction	9	87.036	438271124.35
Error (B)	60	106.353	449593298.83

Source	df	Mean square		
		LAI	Root depth	Root spread
Replication	1	0.058	0.066	0.045
Density	3	1.126	0.027	0.021
Error (A)	3	1.514	0.017	0.128
Fertiliser	3	0.82	0.004	0.036
Interaction	9	0.510	0.010	0.030
Error (B)	12	0.437	0.015	0.010

** Significant at 1% level

APPENDIX V

Abstracts of ANOVA table for dry matter yield (kg tree^{-1}) of ailanthus at 8.7 years of age as affected by tree population density and fertiliser regimes

Source	df	Mean Square			
		Biomass components			
		Stemwood	Branchwood	Foliage	Above ground
Replication	5	524.380	22.280	5.968	675.822
Density	3	438.935	13.190*	11.960*	748.640
Error (A)	15	276.032	3.276	2.408	336.110
Fertiliser	3	3.233	0.015	2.360	3.250
Interaction	9	234.830	3.330	3.090	284.980
Error (B)	60	166.405	6.030	2.540	246.160

Source	df	Roots	Total
Replication	1	5.777	307.250
Density	3	1.743	283.820
Error (A)	3	1.470	135.280
Fertiliser	3	0.332	0.808
Interaction	9	5.752*	120.655
Error (B)	12	2.036	158.090

* Significant at 5% of level

APPENDIX VI

Abstracts of ANOVA table for dry matter yield (Mg ha^{-1}) of ailanthus at 8.7 years of age as affected by tree population density and fertiliser regimes

Source	df	Mean Square				
		Biomass components				
		Stemwood	Branch wood	Foliage	Above ground	MAI
Replication	5	1922.31	110.170	29.02	2822.65	37.295
Density	3	18328.16**	357.590**	70.69**	26179.27**	345.800**
Error (A)	15	1473.26	25.820	8.96	1791.24	23.660
Fertiliser	3	268.29	0.822	11.75	393.92	5.202
Interaction	9	840.77	12.520	11.17	961.69	12.701
Error (B)	60	747.83	25.720	10.79	1094.34	14.463

Source	df	Roots	Total
Replication	1	18.956	562.600
Density	3	175.880**	11357.290*
Error (A)	3	3.934	729.263
Fertiliser	3	5.917	183.690
Interaction	9	30.910*	444.288
Error (B)	12	10.650	851.216

* Significant at 5% of level

** Significant at1% level

APPENDIX VII

Abstracts of ANOVA table for N concentration (%)of 8.7 year old ailanthus as affected by tree population density and fertiliser regimes

Source	df	Mean Square			
		Biomass component			
		Foliage	Branchwood	Stemwood	Roots
Replication	5	0.032	0.072	0.006	0.004
Density	3	0.026	0.004	0.012*	0.003
Error (A)	15	0.029	0.023	0.003	0.001
Fertiliser	3	0.016	0.066**	0.010	0.001
Interaction	9	0.033	0.060**	0.011	0.005
Error (B)	60	0.016	0.015	0.007	0.003

APPENDIX VIII

Abstracts of ANOVA table for P concentration (%)of 8.7 year old ailanthus as affected by tree population density and fertiliser regimes

Source	df	Mean Square			
		Biomass component			
		Foliage	Branchwood	Stemwood	Roots
Replication	5	0.00100	0.0001	0.0001	0.0001
Density	3	0.00030	0.0581	0.1139**	0.0010*
Error (A)	15	0.00020	0.0265	0.0065	0.0001
Fertiliser	3	0.01000**	3.3334**	0.8359**	0.0010*
Interaction	9	0.00040**	0.0842	0.0160	0.0010**
Error (B)	60	0.00008	0.0487	0.0124	0.0002

* Significant at 5% of level

** Significant at1% level

APPENDIX IX

Abstracts of ANOVA table for K concentration(%) of 8.7 year old ailanthus as affected by tree population density and fertiliser regimes

Source	df	Mean Square			
		Biomass component			
		Foliage	Branchwood	Stemwood	Roots
Replication	5	0.016	0.010	0.002	0.020
Density	3	0.015	0.018	0.008*	0.011*
Error (A)	15	0.018	0.187	0.002	0.003
Fertiliser	3	0.431**	0.150**	0.035**	0.080**
Interaction	9	0.020	0.139	0.008**	0.011**
Error (B)	60	0.010	0.461	0.003	0.002

APPENDIX X

Abstracts of ANOVA table for nitrogen accumulation (kg tree^{-1}) of 8.7 year old ailanthus as affected by tree population density and fertiliser regimes

Source	df	Mean Square			
		Biomass components			
		Stemwood	Branchwood	Foliage	Above ground
Replication	5	0.021	0.0010	0.005	0.054
Density	3	0.017	0.0010	0.008*	0.059
Error (A)	15	0.015	0.0004	0.002	0.025
Fertiliser	3	0.002	0.0003	0.001	0.002
Interaction	9	0.011	0.0004	0.002	0.022
Error (B)	60	0.008	0.0010	0.002	0.019

Source	df	Roots	Total
Replication	1	0.0347	0.018
Density	3	0.0113	0.022
Error (A)	3	0.0114	0.008
Fertiliser	3	0.0012	0.001
Interaction	9	0.0342*	0.009
Error (B)	12	0.0119	0.012

* Significant at 5% of level

** Significant at1% level

APPENDIX XI

Abstracts of ANOVA table for nitrogen accumulation (kg ha^{-1}) of 8.7 year old ailanthus as affected by tree population density and fertiliser regimes

Source	df	Mean Square			
		Biomass components			
		Stemwood	Branchwood	Foliage	Above ground
Replication	5	96794.26	6683.34	23974.31	262431.24
Density	3	1017718.80**	27998.85**	59589.19**	1986599.26**
Error (A)	15	84847.32	2065.67	7034.95	135901.09
Fertiliser	3	4473.42	1874.64	9811.95	30210.16
Interaction	9	47625.96	2111.49	8295.09	89529.19
Error (B)	60	36360.90	2192.23	8556.74	84847.19

Source	df	Roots	Total
Replication	1	658.246	30539.330
Density	3	9866.203**	819038.970*
Error (A)	3	334.230	39618.680
Fertiliser	3	584.150	12160.313
Interaction	9	1690.460*	39497.035
Error (B)	12	557.550	59854.430

* Significant at 5% of level

** Significant at1% level

APPENDIX XII

Abstracts of ANOVA table for phosphorus accumulation (kg tree^{-1}) of 8.7 year old ailanthus as affected by tree population density and fertiliser regimes

Source	df	Mean Square			
		Biomass components			
		Stemwood	Branchwood	Foliage	Above ground
Replication	5	0.0002	0.0012	0.0310	0.00020
Density	3	0.1444*	0.0107	0.1047*	0.00030*
Error (A)	15	0.0417	0.0034	0.0402	0.00006
Fertiliser	3	0.1047*	0.0087	0.0519	0.00030
Interaction	9	0.0427	0.0033	0.0488	0.00010
Error (B)	60	0.0345	0.0064	0.0355	0.00008

Source	df	Roots	Total
Replication	1	0.0002	0.0003
Density	3	0.0002	0.0165
Error (A)	3	0.0002	0.0026
Fertiliser	3	0.0002	0.0086
Interaction	9	0.0003	0.0028
Error (B)	12	0.0002	0.0059

* Significant at 5% of level

APPENDIX XIII

Abstracts of ANOVA table for phosphorus accumulaiton (kg ha^{-1}) of 8.7 year old ailanthus as affected by tree population density and fertiliser regimes

Source	df	Mean Square			
		Biomass components			
		Stemwood	Branchwood	Foliage	Above ground
Replication	5	337.790	104.300	53.244	954.09
Density	3	2149.520**	379.506**	86.114**	5534.68**
Error (A)	15	206.404	25.192	15.544	366.25
Fertiliser	3	264.772	47.783	14.532	662.68
Interaction	9	68.520	23.971	18.422	128.70
Error (B)	60	136.773	29.630	16.531	351.11

Source	df	Roots	Total
Replication	1	5.839	59.757
Density	3	51.510*	2456.980*
Error (A)	3	2.257	112.790
Fertiliser	3	3.602	233.090
Interaction	9	14.317	52.414
Error (B)	12	7.567	287.327

* Significant at 5% of level

** Significant at1% level

APPENDIX XIV

Abstracts of ANOVA table for Potassium accumulation (kg $tree^{-1}$) of 8.7 year old ailanthus as affected by tree population density and fertiliser regimes

Source	df	Mean Square			
		Biomass components			
		Stemwood	Branchwood	Foliage	Above ground
Replication	5	0.011	0.0020	0.0001	0.016
Density	3	0.010	0.0010*	0.0010*	0.023*
Error (A)	15	0.004	0.0002	0.0003	0.006
Fertiliser	3	0.005	0.0003	0.0003	0.009
Interaction	9	0.006	0.0003	0.0004	0.008
Error (B)	60	0.003	0.0004	0.0003	0.008

Source	Df	Roots	Total
Replication	1	0.01	0.002
Density	3	0.06	0.009
Error (A)	3	0.05	0.002
Fertiliser	3	0.10*	0.004
Interaction	9	0.06*	0.003
Error (B)	12	0.02	0.004

* Significant at 5% of level

APPENDIX XV

Abstracts of ANOVA table for Potassium accumulation (kg ha^{-1}) of 8.7 year old ailanthus as affected by tree population density and fertiliser regimes

Source	df	Mean Square			
		Biomass components			
		Stemwood	Branchwood	Foliage	Above ground
Replication	5	38381.200	7794.780	1794.450	69265.02
Density	3	328450.120**	20703.504**	5606.532**	618718.51**
Error (A)	15	22853.350	1407.401	743.761	31722.59
Fertiliser	3	18977.005	770.769	819.592	30362.82
Interaction	9	18393.020	1456.070	1282.31	22932.19
Error (B)	60	14109.630	1539.397	1015.51	28066.26

Source	df	Roots	Total
Replication	1	201.332	3695.57
Density	3	1553.82	238963.06*
Error (A)	3	186.87	13295.05
Fertiliser	3	158.39	11606.74
Interaction	9	241.61	7092.17
Error (B)	12	88.70	19058.88

* Significant at 5% of level

** Significant at1% level

APPENDIX XVI

Abstracts of ANOVA tables for Nitrogen use efficiency (kg biomass g^{-1} N)of 8.7 year old ailanthus as affected by tree population density and fertiliser regimes

Source	df	Mean Square			
		Biomass components			
		Stemwood	Branchwood	Foliage	Above ground
Replication	5	0.0002	0.0010	0.0002	0.0004
Density	3	0.0010*	0.1059	0.0046	0.0003
Error (A)	15	0.0001	0.3751	0.0047	0.0002
Fertiliser	3	0.0010	1.3740**	0.0026	0.0003
Interaction	9	0.0004	1.0960**	0.0058	0.0003
Error (B)	60	0.0003	0.2411	0.0028	0.0002

Source	Df	Roots	Total
Replication	1	0.0185	0.0001
Density	3	0.0202	0.0027
Error (A)	3	0.0308	0.0048
Fertiliser	3	0.0235	0.0094
Interaction	9	0.0447	0.0130
Error (B)	12	0.0196	0.0105

* Significant at 5% of level

** Significant at1% level

APPENDIX XVII

Abstracts of ANOVA tables for Phosphorus use efficiency (kg biomass g^{-1} P) of 8.7 year old ailanthus as affected by tree population density and fertiliser regimes

Source	df	Mean Square			
		Biomass components			
		Stemwood	Branchwood	Foliage	Above ground
Replication	5	0.002	0.0004	0.001	0.020
Density	3	0.591*	0.0040	0.045*	0.244*
Error (A)	15	0.030	0.0030	0.013	0.063
Fertiliser	3	3.810**	0.3460**	0.452**	1.790**
Interaction	9	0.085	0.0090	0.024**	0.111**
Error (B)	60	0.062	0.0060	0.009	0.027

Source	df	Roots	Total
Replication	1	0.126	0.009
Density	3	0.109	0.097
Error (A)	3	0.058	0.032
Fertiliser	3	0.209	0.478**
Interaction	9	0.227	0.022
Error (B)	12	0.196	0.021

* Significant at 5% of level

** Significant at1% level

APPENDIX XVIII

Abstracts of ANOVA tables for Potassium use efficiency (kg biomass g^{-1} K) of 8.7 year old Ailanthus as affected by tree population density and fertiliser regimes

Source	df	Mean Square			
		Biomass components			
		Stemwood	Branchwood	Foliage	Above ground
Replication	5	0.0020	0.0004	0.001	0.0002
Density	3	0.0020*	0.00030	0.0003	0.0010
Error (A)	15	0.0005	0.00040	0.0004	0.0005
Fertiliser	3	0.0170**	0.00200**	0.0060**	0.0090**
Interaction	9	0.0030**	0.00100*	0.0004	0.0010*
Error (B)	60	0.0010	0.00025	0.0005	0.0004

Source	df	Roots	Total
Replication	1	0.030	0.0002
Density	3	0.003	0.0050
Error (A)	3	0.006	0.0010
Fertiliser	3	0.022**	0.0030
Interaction	9	0.002	0.0010
Error (B)	12	0.002	0.0020

APPENDIX XIX

Abstracts of ANOVA tables for soil chemical properties as affected by tree population density and fertiliser regimes

Source	df	Mean Square				
		Org. C	Total N	Available P	Available K	Soil pH
Replication	5	0.023	0.003	5.947	1830.33	0.104
Density	3	0.083	0.003	6.388*	1178.68*	0.036
Error (A)	15	0.038	0.001	1.699	321.070	0.052
Fertiliser	3	0.319**	0.006**	37.86**	1641.09**	0.073
Interaction	9	0.033	0.002*	9.401**	421.690	0.053
Error (B)	60	0.022	0.001	1.510	237.480	0.036

* Significant at 5% of level

** Significant at1% level

PRODUCTIVITY OF AILANTHUS (*Ailanthus triphysa*) UNDER DIFFERENT FERTILISER REGIMES AND POPULATION DENSITIES

By

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ABSTRACT OF THE THESIS

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ABSTRACT

A split plot experiment involving ailanthus (*Ailanthus triphysa* (Dennst.) Alston) at four population densities (3333, 2500, 1600 an 1111 tpha) and four 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}) was initiated in June 1991. The objectives included evaluating the biomass production potential of ailanthus grown under different spacing and fertiliser regimes and estimating nutrient export through whole tree harvesting.

Height, diameter and stand leaf area of ailanthus trees at 8.7 years of age was greater in the 2500 trees per hectare (tpha) stand than other density levels. Lower densities recorded higher biomass on a per tree basis whereas on a stand basis, the high density stand (3333 tpha) showed greater biomass yield. Fertilisers applied at 1.2, 2.25 and 5.25 years had no significant effect on biomass accumulation. Regarding the partitioning of tree biomass, stemwood was the most important component in all density and fertiliser treatments while foliage contributed the least. Nonetheless, foliage registered the highest N, P and K concentration (%). NPK concentration of other fractions decreased in the order: branchwood > roots > stemwood.

Nutrient accumulation (N, P and K) on a per tree basis was higher in the lower densities while on a stand basis, greater accumulation was noted in the higher density stands (3333 and 2500 tpha). Bole fraction accounted for only 56 per cent of total nutrients removed during harvest. Thus leaving other biomass components (foliage and branches) at the site will greatly reduced the nutrient export associated with tree harvesting.

Stands with 1600 and 1111 tpha showed higher N and K use efficiencies whereas for P, the tree population density of 2500 tpha showed the highest efficiency. Regarding fertiliser effect, trees in the control plot (no fertiliser) exhibited highest efficiencies for N, P and K.

Available soil P, K and organic carbon concentrations declined with increasing tree population density. However, there was an overall increase in total N and available K levels compared to the previous observation at 3 years of age. Increasing levels of fertilisers in general resulted in higher soil organic carbon, N, available P and K levels.