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# TOLERANCE OF INDIGENOUS FOREST SPECIES SEEDLINGS TO DEGRADED LATERITIC SOILS OF KERALA


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# 1. INTRODUCTION

The forest wealth of our country is on a decline due to unscientific exploitation that has been happening during the past few decades. As an augmentation measure, large scale plantations of various forest species are being raised. Forest species have also been used widely for rehabilitating the degraded lands and in agroforestry systems. These programmes often encounter problems in matching the plants to an alien soil environments. When the forest species are grown in a new environment, other than their natural habitat, they have to encounter several fluctuating soil fertility problems of pH, nutrient availability, salinity etc. In the past, the approach to such soil fertility problems in plant production emphasized changing the soils to match the plants by adjusting pH and nutrients to optimum levels for a given plant species. This high-input approach coupled with the heavy use of chemical fertilizers was effective in the temperate zones where soils do not have extreme chemical properties. But these high-input genotypes usually have a limited adaptability to the adverse soil conditions that prevail in the tropics and subtropics. The realization of the difficulties or failure of the high-input approach in most tropical and subtropical soils necessitated a shift in approach towards matching the plants to the soils. This requires genotypes better adapted to given ecological conditions. This low-input approach using adaptable genotypes with more efficient use of nutrients from soil reserves and fertilizers is reported to give yields that are 80-90% of the maximum. So it is always advisable to practise planting programmes according to the suitability of soil. The mechanism by which wild plants adapt to adverse soil condition is different and these mechanisms are regulated separately although some are interrelated. Considering the pressing demand of forest species for various plantation, afforestation and agroforestry programmes, now it has become the need of the day to generate information on the tolerance of these species to adverse soil conditions and classify them based on their adaptability. The results of such a study will be very useful in selecting the species according to soil suitability for various plantation and afforestation programmes and managing them successfully with low inputs under adverse soil conditions.

The present study envisages to generate information on the adaptability of selected indigenous forest species to degraded lateritic soils of Kerala so that they can be classified according to their tolerance to such soils and selected for various afforestaion and plantation programmes. The main thrust of the study is to look for high nutrient efficiency, tolerance to Al and Mn toxicity, moisture stress and soil compaction. The species thus selected can thrive in the adverse soil condition in a better way and flourish well on degraded soil with low inputs compared to less tolerant species.

The objectives of the study are :

1. To study the nutrient efficiency and rate of absorption of nutrients in *Ailanthus triphysa, Bambusa bamboos, Dalbergia latifolia, Haldina cordifolia, Pterocarpus marsupium, Terminalia crenulata and Xylia xylocarpa.*

2. To study the tolerance of above species to soil moisture, soil compaction, exchangeable Al and Mn

3. To study the cation exchange capacity of roots of selected species and to find out the relation, if any, with their adaptability to degraded soil

4. Based on the above, to categorize the above species in the order of their tolerance to degraded lateritic soil

## 2. REVIEW OF LITERATURE

Acid soil and associated mineral toxicity are great restrictions for plant production and excessive Al is one of the most important problems in soils with pH less than 5. Degraded lateritic soils of the tropics, especially of Kerala, are characterized by high acidity, low organic carbon and nutrients and excessive levels of free and exchangeable Al. So, for better adaptation of plants to such soils, high tolerance to Al and highly efficient utilization of mineral nutrients are required. The problem of Al toxicity and tolerance of plants to excessive levels of Al had been a subject of study in various agricultural crops (Foy *et al.,* 1999; Gallardo *et al.,* 1999; Rout *et al.,* 2001., Almeida *et al.,* 2000). Among the annual root crops, cassava is known for its high tolerance to acid soils compared to sweet potatoes and yams. Other acid soil tolerant crops are cowpea, peanut and potato whereas maize, soybean and wheat are non tolerant crops (Sanchez and Salinas, 1981). Unlike in the case of tolerant crops, a large input of nutrients are necessary to adjust the soil properties, mainly by liming to meet the requirements of non tolerant crops. Thus the low-input approach aims not only the selection of plants fitting to extreme soil chemical conditions but also to identify plants those utilise soil and fertilizer nutrients with high efficiency. So species which require low inputs for better survival and growth in adverse soil conditions are preferred for planting in degraded areas. Among the forest species of Kerala, reed bamboo was found promising in reclothing the degraded lateritic soils (Sujatha, *et al.,*2002), but no information is available on the adaptability of other indigenous species. The species selected for the present study are *Ailanthus triphysa, Bambusa bambos, Dalbergia latifolia, Haldina cordifolia, Pterocarpus marsupium, Terminalia crenulata and Xylia xylocarpa.* These selected species are found in the moist deciduous forests of Kerala and are being used for timber, matchwood, pulp etc.

# 3. NUTRIENT EFFICIENCY AND RATE OF ABSORPTION OF NUTRIENTS

This section of the study is described under two major headings ie nutrient efficiency and nutrient absorption. The materials and methods used and results obtained along with discussions are elaborated under each heading.

## 3.1. Nutrient efficiency

The term nutrient efficiency has been used widely as a measure of the capacity of a plant to acquire and utilize nutrients for production of timber, crops or forages. Definitions of nutrient efficiency generally can be divided into those emphasizing productivity and those emphasizing the internal nutrient requirement of the plant. In this experiment, the nutrient efficiency emphasizing productivity is assessed by comparing the biomass of various species grown in nutrient poor soils as well as with increasing levels of nutrient inputs. Here the nutrient efficiency is considered as the ability of the plant to grow under limited nutrient condition. So the study aims to chalk out nutrient efficient plants which can grow and yield better in nutrient poor, degraded, lateritic soil.

Nutrient efficiency emphasizing the internal nutrient requirement is termed as nutrient use efficiency, which is the product of yield times the reciprocal of nutrient concentration (Siddiqi and Glass, 1981). Actually the species with higher nutrient use efficiency is considered to produce higher biomass per unit of nutrient absorbed or utilised.

### 3.1.1. Materials and Method

In order to study the nutrient efficiency of selected species, a pot culture experiment was conducted at KFRI, Peechi. For this, seeds of seven indigenous species were collected and germinated in vermiculite. Germinated seeds were then potted in polythene bags during May 2007. Degraded lateritic soil with low organic carbon (<0.5%) was collected and filled in concrete pots of size 1'x1'x1'. Five treatments (organic manure treatments @1 and 1.5 kg/pot and in organic treatments N, P, K, Ca and Mg in the ratios of (20:10:30:10:10, 40:20:60:20:20 and 60:40:120:40:40) were applied to these soils in the pots in four replications. Four pots with each species were kept aside for control. Experiment was laid out by adopting CRD. Seedlings were planted in the pots on 24/8/2007 and watered regularly. To avoid the influence of rain water, silproof 90 GSM uv sheet was spread over bamboo poles allowing the passage of sunlight. Initial measurements on height of the seedlings were recorded. Growth measurements were recorded at six month interval. After a period of one year the plants were harvested and oven dry weight of total plant biomass, shoot biomass and root biomass were recorded separately. Oven dried samples were then powdered, digested in sulphuric acid - salicylic acid- hydrogen peroxide mixture and the content of N (using Scalar autoanalyser), P (vanadomolybdate yellow colour) and K (flame photometry ) were estimated.

Uptake of nutrients were calculated by multiplying the nutrient concentration with biomass. Statistical analysis of the data were carried out using SPSS package.

### 3.1.2. Results and Discussion

*a. __Growth performance/productivity__*

In this part of the study it was intended to compare the growth of seedlings of selected species based on their growth under limited supply of nutrients from the soil as well as their response to increasing doses of nutrient inputs. Since the objective of the study was to rank the species based on their performance under low soil fertility (control) and increasing doses of nutrient inputs, statistical significance of growth parameters was tested between species, between treatments and the interaction effect of species and treatments.

Statistical analysis revealed that irrespective of the treatments all the species differed significantly with respect to height at six month, height and girth at collar region at twelve month, shoot biomass, root biomass and total biomass. Each species by its genetic nature owes a specific growth pattern and hence the growth, irrespective of treatments, revealed such pattern.

Table 1. Influence of treatments on total biomass of seedlings at 12 month after planting

| Species/Treatments | Control | CF1 | CF2 | CF3 | OM1 | OM2 |
|---|---|---|---|---|---|---|
| Haldina | $55^{ab}$ | $289.8^{c}$ | $144^{ab}$ | $142.8^{bc}$ | $125^{b}$ | $105^{abc}$ |
| Bambusa | $64.5^{ab}$ | $216.3^{c}$ | $219.3^{bc}$ | $159b^{c}$ | $318.3^{d}$ | $337.5^{d}$ |
| Ailanthus | $130^{b}$ | $275.5^{c}$ | $300.5^{c}$ | $332.5^{d}$ | $135.8^{b}$ | $197^{c}$ |
| Pterocarpus | $23.8^{ab}$ | $39.8^{a}$ | $65.5^{a}$ | $46.3^{ab}$ | $25^{ab}$ | $28^{ab}$ |
| Xylia | $66.8^{ab}$ | $116.8^{ab}$ | $106.5^{ab}$ | $49^{ab}$ | $47.3^{ab}$ | $48.3^{ab}$ |
| Dalbergia | $14.8^{a}$ | $25.5^{a}$ | $44.2^{a}$ | $20.3^{a}$ | $6^{a}$ | $8.8^{a}$ |
| Terminalia | $90^{ab}$ | $215.5^{bc}$ | $209.3^{bc}$ | $167^{c}$ | $257.8^{c}$ | $129.8^{bc}$ |

Figures superscribed by same letter in a column indicates non significance. LSD=115.74

CF1= Chemical fertiliser at 1st level; CF2= Chemical fertiliser at 2nd level; CF3= Chemical fertiliser at 3rd level; OM1= Organic manure at 1st level; OM2 = Organic manure at 2nd level

Table 2. Influence of treatments on shoot biomass of seedlings at 12 month after planting

| Species/Treatments | Control | CF1 | CF2 | CF3 | OM1 | OM2 |
|---|---|---|---|---|---|---|
| Haldina | $35.8^{ab}$ | $21.6^{c}$ | $101.3^{abc}$ | $94.8^{ab}$ | $82.5^{ab}$ | $73^{a}$ |
| Bambusa | $51.5^{ab}$ | $139.3^{bc}$ | $176.3^{c}$ | $107.5^{b}$ | $252.3^{c}$ | $254.5^{c}$ |
| Ailanthus | $99.5^{b}$ | $210.8^{c}$ | $242.8^{d}$ | $257^{c}$ | $104.3^{b}$ | $158.5^{b}$ |
| Pterocarpus | $12.3^{a}$ | $26^{a}$ | $47.3^{a}$ | $31.5^{ab}$ | $16^{a}$ | $19.3^{a}$ |
| Xylia | $36^{ab}$ | $81.8^{ab}$ | $66.8^{ab}$ | $32.8^{ab}$ | $30.3^{ab}$ | $31^{a}$ |
| Dalbergia | $7^{a}$ | $17^{a}$ | $27.3^{a}$ | $14.3^{a}$ | $3.8^{a}$ | $4.4^{a}$ |
| Terminalia | $58.8^{ab}$ | $158^{bc}$ | $136.3^{bc}$ | $110.9^{b}$ | $196.8^{c}$ | $87.5^{ab}$ |

Figures superscribed by same letter in columnwise indicates non significance. LSD= 86.17

CF1= Chemical fertiliser at 1st level; CF2= Chemical fertiliser at 2nd level; CF3= Chemical fertiliser at 3rd level; OM1= Organic manure at 1st level; OM2 = Organic manure at 2nd level

Table 3. Influence of treatments on root biomass of seedlings at 12 month after planting

| Species/ Treatments | Control | CF1 | CF2 | CF3 | OM1 | OM2 |
|---|---|---|---|---|---|---|
| Haldina | 19.3$^{a}$ | 73.8$^{b}$ | 42.8$^{ab}$ | 48$^{bc}$ | 42.5$^{bc}$ | 32$^{ab}$ |
| Bamboo | 32$^{a}$ | 77$^{b}$ | 43$^{ab}$ | 51.5$^{c}$ | 66$^{d}$ | 83$^{c}$ |
| Ailanthus | 30.5$^{a}$ | 64.8$^{b}$ | 57.8$^{b}$ | 75.5$^{c}$ | 31.5$^{abc}$ | 38.5$^{b}$ |
| Pterocarpus | 11.5$^{a}$ | 13.8$^{a}$ | 18.3$^{a}$ | 14.8$^{ab}$ | 9$^{ab}$ | 8.8$^{ab}$ |
| Xylia | 30.8$^{a}$ | 35$^{ab}$ | 39.8$^{ab}$ | 16.3$^{ab}$ | 17.3$^{ab}$ | 17.3$^{ab}$ |
| Dalbergia | 7.8$^{a}$ | 8.5$^{a}$ | 17$^{a}$ | 6$^{a}$ | 2.3$^{a}$ | 4.3$^{a}$ |
| Terminalia | 31.3$^{a}$ | 57.5$^{b}$ | 73$^{b}$ | 56.3$^{c}$ | 61$^{cd}$ | 42.3$^{b}$ |

Figures superscribed by same letter in columnwise indicates non significance. LSD =33.6

CF1= Chemical fertiliser at 1st level; CF2= Chemical fertiliser at 2nd level; CF3= Chemical fertiliser at 3rd level; OM1= Organic manure at 1st level; OM2 = Organic manure at 2nd level

When interaction between species and treatments, which was the main focus of this study, was considered, only few parameters such as total biomass, shoot biomass and root biomass were found significant. When the total biomass of all the species in the control plot (limited supply of nutrients) was considered separately (Table 1), significantly higher yield was obtained in ailanthus followed by terminalia, xylia, bambusa, haldina, pterocarpus and dalbergia. Similarly with respect to shoot biomass, ailanthus was ranked as the highest yielder. The only variation in the trend was that bamboo ranked as third and xylia fourth. Unlike in total biomass and shoot biomass, higher yield in root biomass was in bamboo followed by terminalia, xylia, ailanthus, haldina, pterocarpus and dalbergia. But the root biomass of all the species in the control plot were on par due to the higher value of LSD.

On evaluating the response to nutrient inputs, it was observed that, at low doses of chemical fertiliser, haldina ranked first in yielding total biomass followed by ailanthus, bamboo, terminalia, xylia, pterocarpus and dalbergia. But in the treatments with second and third doses of chemical fertilisers, the highest yielder was ailanthus and at both doses of organic manure bamboo ranked first. Data in general revealed that except in the treatments with low doses of chemical fertiliser, ailanthus, bamboo and terminalia were the best performers even though there was a slight variation in their ranking with respect to the treatments applied. Performance of other species were in the order haldina> xylia>pterocarpus>dalbergia and it followed the same order in all the treatments.

Shoot biomass of all the species (Table 2) followed similar pattern as that of total biomass in control as well as nutrient applied treatments.

As far as root biomass was concerned (Table 3), a different trend was observed. In the control plot, higher root biomass was obtained in terminalia followed by bamboo, ailanthus as well as xylia, haldina, pterocarpus and dalbergia. At low levels of nutrients both in the form of chemical as well as organic, higher root biomass was observed in bamboo. Terminalia, ailanthus and haldina produced higher root biomass at higher doses of nutrients. The order of species producing higher root biomass at low level of chemical fertiliser was bamboo> haldina>ailanthus> terminalia>xylia> pterocarpus> dalbergia and the order at low level of organic manure was bamboo>terminalia>haldina>ailanthus>xylia = pterocarpus>dalbergia. As in the case of total biomass and shoot biomass, haldina, pterocarpus and dalbergia were the poor yielders of root biomass in the control pot and xylia, pterocarpus and dalbergia were in the pots applied with nutrient inputs.

**b. *Nutrient uptake***

Uptake of major nutrients viz., N, P and K were determined by multiplying the concentration of nutrients with the biomass. Since the concentration of nutrients in the biomass does not lead to a meaningful conclusion, the uptake of nutrients in the shoot biomass were taken into consideration to assess the potential of each species to extract nutrients from the soil and to utilise them to produce relatively higher biomass.

*Nitrogen*

In the control pots where no nutrients were added, the uptake of N was high (2.7 g) in ailanthus followed by bamboo, xylia, terminalia and haldina (Table 4). On the other hand, low up take of N was found in dalbergia followed by pterocarpus. This indicates that ailanthus, bamboo, xylia and terminalia are able to extract higher quantity of nitrogen in spite of its low availability in soil.

Table 4. Uptake of nitrogen (g/kg) by the seedlings at 12 month growth stage

| Species/Treatments | Control | CF1 | CF2 | CF3 | OM1 | OM2 |
|---|---|---|---|---|---|---|
| Haldina | 1.1$^{a}$ | 4.6$^{bc}$ | 2.2$^{a}$ | 4.7$^{b}$ | 2$^{ab}$ | 2.3$^{a}$ |
| Bambusa | 1.9$^{a}$ | 6.8$^{cd}$ | 10.9$^{b}$ | 5$^{b}$ | 14.5$^{d}$ | 11.6$^{b}$ |
| Ailanthus | 2.7$^{a}$ | 10.1$^{d}$ | 12.7$^{b}$ | 10.8$^{c}$ | 5.6$^{bc}$ | 10.9$^{b}$ |
| Pterocarpus | 0.5$^{a}$ | 0.7$^{ab}$ | 2.7$^{a}$ | 1.4$^{ab}$ | 0.3$^{a}$ | 0.7$^{a}$ |
| Xylia | 1.9$^{a}$ | 3.9$^{abc}$ | 3.5$^{a}$ | 2.1$^{ab}$ | 1.9$^{ab}$ | 2.3$^{a}$ |
| Dalbergia | 0.1$^{a}$ | 0.3$^{a}$ | 0.4$^{a}$ | 0.2$^{ab}$ | 0.1$^{a}$ | 0.1$^{a}$ |
| Terminalia | 1.8$^{a}$ | 4.6$^{bc}$ | 4.1$^{a}$ | 4.3$^{ab}$ | 8$^{c}$ | 3.4$^{a}$ |

Figures superscribed by same letter in a column indicates non significance. LSD = 4.195

CF1= Chemical fertiliser at 1$^{st}$ level; CF2= Chemical fertiliser at 2$^{nd}$ level; CF3= Chemical fertiliser at 3$^{rd}$ level; OM1= Organic manure at 1$^{st}$ level; OM2 = Organic manure at 2$^{nd}$ level

Table 5. Uptake of phosphorus (g/kg) by the seedlings at 12 month growth stage

| Species | Control | CF1 | CF2 | CF3 | OM1 | OM2 |
|---|---|---|---|---|---|---|
| Haldina | 0.67$^{b}$ | 0.76$^{b}$ | 0.42$^{a}$ | 0.46$^{a}$ | 0.29$^{ab}$ | 0.17$^{a}$ |
| Bamboo | 0.12$^{a}$ | 0.4$^{ab}$ | 0.34$^{a}$ | 0.18$^{a}$ | 0.67$^{bc}$ | 0.56$^{a}$ |
| Ailanthus | 0.59$^{a}$ | 1.63$^{c}$ | 2.07$^{b}$ | 2.66$^{b}$ | 1.38$^{d}$ | 1.74$^{b}$ |
| Pterocarpus | 0.07$^{a}$ | 0.18$^{ab}$ | 0.22$^{a}$ | 0.23$^{a}$ | 0.05$^{a}$ | 0.12$^{a}$ |
| Xylia | 0.1$^{a}$ | 0.36$^{ab}$ | 0.3$^{a}$ | 0.17$^{a}$ | 0.16$^{ab}$ | 0.15$^{a}$ |
| Dalbergia | 0.02$^{a}$ | 0.04$^{a}$ | 0.17$^{a}$ | 0.05$^{a}$ | 0.01$^{a}$ | 0.01$^{a}$ |
| Terminalia | 0.2$^{a}$ | 0.76$^{b}$ | 0.68$^{a}$ | 0.57$^{a}$ | 0.94$^{cd}$ | 0.37$^{a}$ |

Figures superscribed by same letter in a column indicates non significance. LSD = 0.66

CF1= Chemical fertiliser at 1$^{st}$ level; CF2= Chemical fertiliser at 2$^{nd}$ level; CF3= Chemical fertiliser at 3$^{rd}$ level; OM1= Organic manure at 1$^{st}$ level; OM2 = Organic manure at 2$^{nd}$ level

Table 6. Uptake of potassium (g/kg) by the seedlings at 12 month growth stage

| Species/Treatments | Control | CF1 | CF2 | CF3 | OM1 | OM2 |
|---|---|---|---|---|---|---|
| Haldina | 0.37$^{abc}$ | 2.71$^{d}$ | 0.96$^{c}$ | 1.47$^{d}$ | 0.72$^{b}$ | 0.86$^{c}$ |
| Bambusa | 0.07$^{a}$ | 0.20$^{a}$ | 0.28$^{a}$ | 0.13$^{ab}$ | 0.38$^{ab}$ | 0.22$^{ab}$ |
| Ailanthus | 0.94$^{d}$ | 2.76$^{d}$ | 2.40$^{a}$ | 2.53$^{e}$ | 1.37$^{c}$ | 2.06$^{d}$ |
| Pterocarpus | 0.12$^{ab}$ | 0.30$^{a}$ | 0.41$^{ab}$ | 0.38$^{ab}$ | 0.08$^{a}$ | 0.20$^{ab}$ |
| Xylia | 0.47$^{bc}$ | 1.25$^{b}$ | 0.76$^{bc}$ | 0.47$^{b}$ | 0.61$^{b}$ | 0.45$^{b}$ |
| Dalbergia | 0.01$^{a}$ | 0.02$^{a}$ | 0.04$^{a}$ | 0.02$^{a}$ | 0.003$^{a}$ | 0.003$^{a}$ |
| Terminalia | 0.59$^{cd}$ | 1.67$^{c}$ | 1.02$^{c}$ | 1.05$^{c}$ | 2.52$^{d}$ | 0.63$^{c}$ |

Figures superscribed by same letter in a column indicates non significance. LSD = LSD 0.3822

CF1= Chemical fertiliser at 1$^{st}$ level; CF2= Chemical fertiliser at 2$^{nd}$ level; CF3= Chemical fertiliser at 3$^{rd}$ level; OM1= Organic manure at 1$^{st}$ level; OM2 = Organic manure at 2$^{nd}$ level

Fig. 1. Pot culture study on nutrient efficiency at KFRI, Peechi campus

As seen in the control pots, ailanthus ranked first in the uptake of N from nutrient added soils both in the form of chemical and organic. Ailanthus was followed by bamboo, haldina, terminalia and xylia. The general observation is that haldina responds quite well to chemical fertilisers and absorb more quantity of N under fertilised condition than xylia. But such a difference between the above two species is not significant in organic manure applied soils. This might be due to the comparatively low availability of nutrients due to the slow and gradual release from organic amendments. However in all the treatments dalbergia and pterocarpus absorbed very low quantity of N.

*Phosphorus*

In degraded soil when no nutrient was applied, significantly higher uptake of P was shown by haldina and ailanthus (Table 5) followed by terminalia, bamboo and xylia. As seen in the case of N, pterocarpus and dalbergia could extract only very low quantity of P from soil.

At all levels of chemical fertilisers, significantly higher uptake of P was shown by ailanthus. The decreasing order of P uptake at the first two levels of chemical fertilisers was ailanthus>terminalia>haldina>bamboo>xylia>pterocarpus>dalbergia while at higher level of fertiliser, pterocarpus, was found to extract more P than bamboo and xylia.

In the treatment applied with organic manure also ailanthus was significantly superior to others in extracting more P. Next to ailanthus, terminalia and bamboo were high P accumulators. In general the order of descending P uptake was ailanthus>bamboo>terminalia>haldina>xylia>pterocarpus>dalbergia.

*Potassium*

With regard to the uptake of K (Table 6) in the control pots, significantly higher values were recorded in ailanthus followed by terminalia, xylia and haldina. The uptake of K was significantly low in pterocarpus, bamboo and dalbergia.

In fertiliser applied pots, the order of accumulation of K was almost the same as in control pots, but here, haldina seemed to accumulate more K than xylia. But at both levels of organic manure, bamboo was ranked before pterocarpus.

The uptake of a nutrient by the plant is directly proportional to the biomass and it is calculated by multiplying the concentration of nutrient by the biomass yield. Since the variation in the concentration of plant nutrients due to treatments in general is very narrow compared to biomass, the treatment with higher biomass is always with higher nutrient uptake and this is evident from this study.

Even though bamboo is considered to be an accumulator of K, such a character was not observed in this study when compared with other species except dalbergia. This might be due to the fact that the plant was only one year old without appreciable development of culm which is the main storehouse of K.

## 3.2. Nutrient absorption

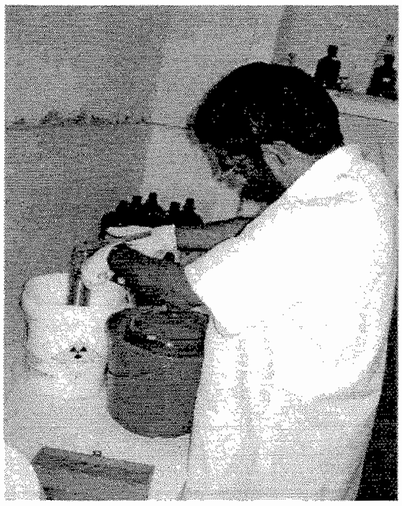
Absorption of nutrients by the plants varies with nutrient requirement as well as growth characteristics, which are mainly decided by their genetic nature. Usually the plants which can meet their nutrient demand mainly from the soil than from added fertiliser are preferred for degraded soil. So the aim of this study is to categorize the species based on their potential to extract maximum nutrients from degraded soil rather than from applied chemical fertilisers and this was accomplished by studying nutrient absorption using radioisotope technique.

### 3.2.1. Materials and Methods

To study the rate of nutrient absorption using the isotope of P, 25 m Ci labelled P in HCl medium was purchased from Board of Radiation and Isotope Technology, Mumbai. Degraded soil was sieved using 2 mm sieve, filled in plastic pots of 10" size and kept in the radio tracer lab at Kerala Agricultural University, Vellanikkara. Seedlings were planted in these pots on 02 September 2007. Different levels of P were applied as basal dose in the form of labelled $^{32}P$ in a carrier solution of $KH_2PO_4$. $^{32}P$ was applied at the rate of 8 $\mu$ Ci, 16 $\mu$Ci and 32 $\mu$ Ci through carrier P solution of 1000 mg P per liter so as to get a specific activity of 2 $\mu$ Ci / mg P. Leaf samples were drawn on the 15$^{th}$ day after application and kept in a hot air oven for two days. Leaves were chopped into small pieces and digested using di acid extract. The digested samples were made up to 20 ml using distilled water and counts were taken in the multi label three in one counter (Triathler) and the estimation of radioactive phosphorus was carried out.

### 3.2.2. Results and Discussion

The study on nutrient absorption was conducted through a pot culture experiment by applying different levels of labelled P to the plants grown in degraded soil. The data on percentage of P derived from fertilizer (Table 7) clearly demonstrate the significant variation among the species in absorbing P from applied fertiliser pool. With increase in the rate of P applied, the PPdf (Percentage of P derived from fertiliser) increased in all the species. At 4 mg of applied P, PPdf was significantly high in



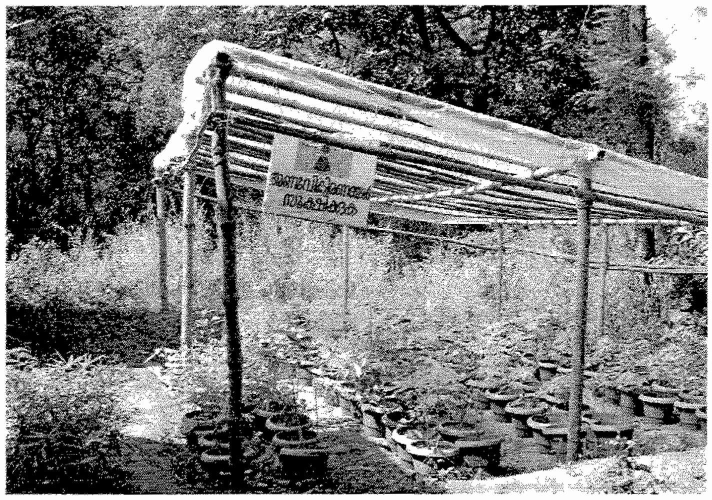


Fig. 2. Pot culture study on nutrient absorption by seedlings using $^{32}P$ at Radio tracer laboratory, Kerala Agrl. University, Vellanikkara

haldina followed by dalbergia and significantly low in terminalia, pterocarpus and bamboo. The decreasing order of PPdf at this level of applied P was haldina>dalbergia>xylia>ailanthus>bamboo>pterocarpus> terminalia.

At 8 mg of applied P also PPdf was significantly high in haldina followed by dalbergia, bamboo and ailanthus. Significantly lower PPdf was noted in terminalia, pterocarpus and xylia. The decreasing order of PPdf at this level of applied P was haldina>dalbergia>bamboo>ailanthus>xylia>pterocarpus>terminalia.

At 16 mg of applied P haldina could not thrive and PPdf was significantly high in haldina followed by pterocarpus, ailanthus, xylia and bamboo. Here also significantly low PPdf was noted in terminalia. The decreasing order of PPdf was haldina> pterocarpus > ailanthus >xylia>bamboo>dalbergia>terminalia.

The results in general revealed that even though the PPdf in all the species increased with increase in the rate of applied P, the pattern of absorption of P was almost similar in all the species. It was seen that absorption of P from applied fertiliser pool is significantly low in terminalia. But at the same time terminalia could produce relatively higher biomass along with higher P uptake. This clearly demonstrates its

Table 7. Percentage of P derived from fertilizer by various indigenous species at different levels of applied P

| Sl. No | Species | Quantity of applied P | | |
|---|---|---|---|---|
| | | 4 mg | 8 mg | 16 mg |
| 1 | Terminalia | $0.34^{c}$ | $0.54^{d}$ | $1.10^{b}$ |
| 2 | Pterocarpus | $0.47^{c}$ | $0.73^{cd}$ | $8.16^{a}$ |
| 3 | Bamboo | $0.66^{c}$ | $1.47^{bc}$ | $2.57^{b}$ |
| 4 | Dalbergia | $1.44^{ab}$ | $1.76^{ab}$ | $1.63^{b}$ |
| 5 | Alianthus | $0.78^{bc}$ | $1.15^{bcd}$ | $3.17^{b}$ |
| 6 | Xylia | $1.60^{a}$ | $0.99^{bcd}$ | $3.04^{b}$ |
| 7 | Haldina | $1.74^{a}$ | $2.41^{a}$ | -- |

Same superscripts in a column indicate non significance

higher potential to extract P from soil pool of degraded lateritic soil. In other words terminalia seemed to be highly tolerant to degraded lateritic soil with its higher potential to extract maximum P from soil pool rather than applied fertiliser pool to produce relatively higher biomass. Similarly lower P absorption from fertilised pool coupled with higher P uptake and biomass were noticed in bamboo, xylia and ailanthus.

On the other hand, dalbergia extracted relatively higher P from the 1st and 2nd level of applied fertiliser pool, but could produce only very low biomass, thus demonstrating its inability to grow and proliferate even with high P uptake. But at highest level of applied P (16 mg), absorption was very low in dalbegia.

Unlike in the above cases, higher P absorption from fertilised pool resulted in higher biomass in haldina while lower absorption from fertilised pool coupled with lower biomass production was noticed in pterocarpus. But at 3rd level of applied P Pterocarpus was found to absorb higher amount of P. These observations indicated that at highest level of applied P, both dalbergia and pterocarpus could produce only lower quantity of biomass irrespective of the quantity of P absorbed by them.

Thus based on the above results it is evident that terminalia, bamboo, xylia and ailanthus were superior species in extracting P from soil pool of degraded lateritic soil to produce relatively higher biomass.

**A value**

A value is a measure of plant available nutrient consequent to the application of fertilizer. Unlike the chemical extraction methods, A value measures the dynamics of phosphorus under growing plants. High A values of 31.5 and 33.1 were observed at 2nd and 3rd level of applied P in terminalia which could be due to its low absorption from applied pool as explained above. This could also be related to the fact that % P derived from soil was also high in this species compared to others.

Table 8. Variation in A value at different levels of P applied to various indigenous species

| Sl. No | Species | Quantity of applied P | | |
|---|---|---|---|---|
| | | 4 mg | 8 mg | 16 mg |
| 1 | Terminalia | $6.47^{bc}$ | $31.50^{a}$ | $33.10^{a}$ |
| 2 | Pterocarpus | $8.69^{c}$ | $25.10^{ab}$ | $4.44^{c}$ |
| 3 | Bamboo | $11.93^{d}$ | $14.83^{bc}$ | $12.31^{bc}$ |
| 4 | Dalbergia | $2.85^{d}$ | $9.03^{c}$ | $20.29^{b}$ |
| 5 | Alianthus | $4.63^{cd}$ | $13.93^{bc}$ | $10.37^{bc}$ |
| 6 | Xylia | $3.00^{d}$ | $14.13^{bc}$ | $10.64^{bc}$ |
| 7 | Haldina | - | $6.63^{c}$ | - |

Same superscripts in a column indicate non significance

## 4. TOLERANCE TO ALUMINIUM AND MANGANESE TOXICITIES

By definition, any soil with a pH of less than 7 is acidic but the detrimental conditions for plant growth may not appear until the soils have a pH of 5.0 or less. The main problems for plant growth on acid soils are low reserves of plant nutrients and toxic levels of exchangeable Al and Mn. The use of species or cultivars tolerant to acid soils is the first step for low-input soil management. So in this section of the study the focus has been mainly to identify the tolerant level of each species to Al and Mn so that they can be easily suggested for afforestation programme with low- input soil management.

### 4.1. Materials and Methods

#### 4.1.1. *Tolerance to Al toxicity*

Tolerance of seedlings of seven indigenous species to Al was studied through hydroponics. The experiment was conducted on the laboratory tables in the Soil Science Department of KFRI, Peechi. For this, seeds of all the species were collected from the Forest Seed Centre, KFRI and seedlings raised in vermiculite during March 2009. About 7-10 days old, vigorous, healthy seedlings of each species were transferred to each of the continuously bubbling hydroponic glass tanks of 2 litre capacity fitted with aerators. Each tank was covered with removable lids with four holes of suitable size so that one seedling could easily fit and grow through it. The hydroponic nutrient solution was prepared as detailed by Epstein (1972). The pH of the nutrient solution was then adjusted to 5.5 using drops of HCl. Aluminium treatments were given in the form of aluminium chloride. All the species tested for aluminium tolerance were indigenous to acid soils of Kerala and hence the levels of aluminium concentrations fixed in this study were in the highest range compared to the low levels used for genotypes preferring low concentration of Al. A trial experiment with wide range of concentrations of $Al^{3+}$ was conducted to arrive at desired levels of $Al^{3+}$. Based on the observations, in the preliminary trial 25 ppm, 50 ppm, 100 ppm, 500 ppm, 750 ppm and 1000 ppm of $Al^{3+}$ were selected for the experiment. The desired aluminium concentration for each tank was prepared separately. Seedlings @ four in each tank were grown in different concentrations of Al and measurements on root growth, shoot growth and survival period were recorded.

### 4.1.2. *Tolerance to Mn toxicity*

This experiment was also conducted through hydroponics as stated under 5.1.1. The only deviation from the above experiment was that instead of aluminium chloride, manganese sulphate was used as the source of Mn and the different levels of Mn fixed were 25 ppm, 50 ppm, 100 ppm, 500 ppm, 750 ppm and 1000 ppm

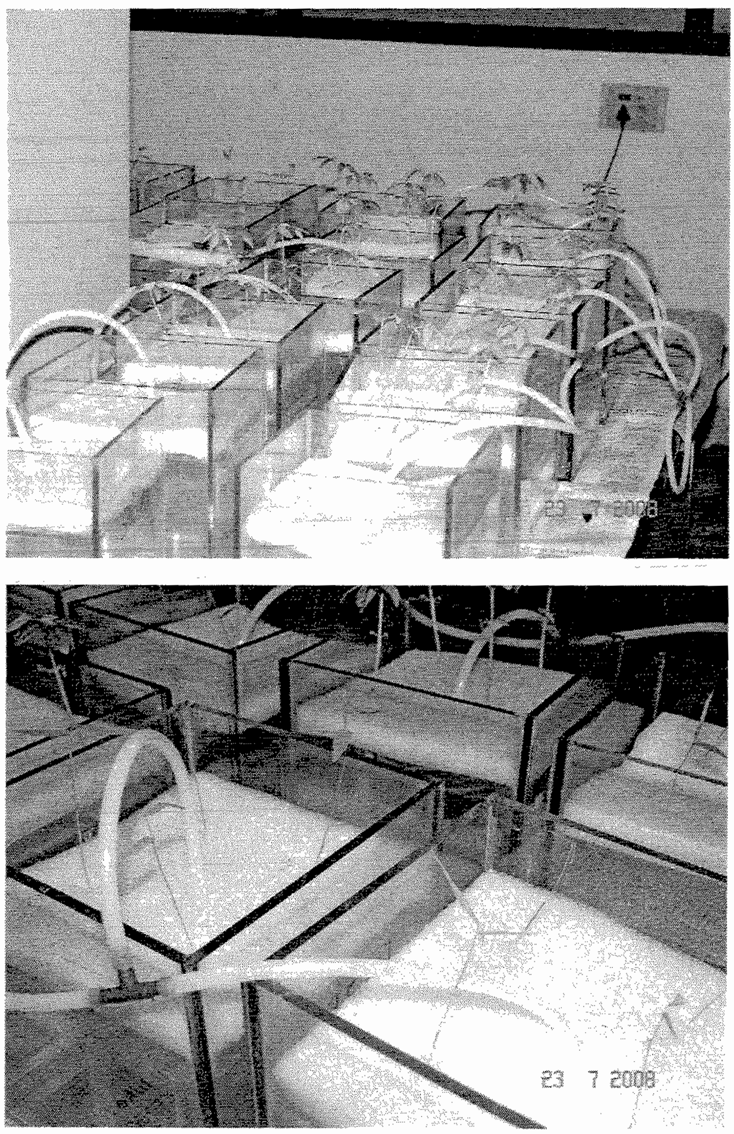



Fig.3. Hydroponic study for determining the tolerance to Al and Mn toxicities

## 4.2. Results and Discussion

### 4.2.1 *Tolerance to aluminium toxicity*

Poor growth of plants in acid soils could be related directly to Al saturation. The restriction of plant growth by excess soluble Al in acid soils may arise from either the direct inhibition of nutrient uptake or disturbance of root cell functions. The tolerance to high Al concentrations by indigenous plants of acid soils can be due to the mechanisms of Al exclusion from root cells and/or intrinsic tolerance to the element. However, in this study it was intended to categorize various indigenous forest species based on their tolerance to Al through hydroponic experiments. Tolerance of seedlings of seven indigenous forest species were evaluated based on their survival period, root and shoot growth etc.

*Survival period*

Data given in Table 9 indicated that at 25 ppm of $Al^{3+}$ concentration, survival period of xylia was highest (31 days) followed by bamboo (26 days), haldina (21 days) and ailanthus (18 days). Survival period was very low in dalbergia (10 days), pterocarpus (9) and terminalia (9).

Even with increased concentration of Al, xylia was found to survive for more number of days compared to other species. Up to 500 ppm, bamboo and haldina came next to xylia followed by ailanthus. But above 500 ppm, survival period was more for ailanthus and haldina than bamboo. Similarly up to 250 ppm, survival period was more for dalbergia than terminalia, but above 250 ppm terminalia took the lead. However, in all the concentrations pterocarpus was ranked as the least. Thus the results in general indicated that among the species tried, in all the concentrations, survival period was highest for xylia and least for pterocarpus. Up to 250 ppm of $Al^{3+}$, the order of survival was xylia> bamboo= haldina> ailanthus> dalbergia> terminalia.

Table 9. Survival period of various indigenous species at different concentrations of aluminium

| Species | Concentration, ppm | | | | | | |
|---|---|---|---|---|---|---|---|
| | 25 | 50 | 100 | 250 | 500 | 750 | 1000 |
| Haldina | $21^{d}$ | $20^{d}$ | $23^{d}$ | $24^{d}$ | $14^{d}$ | $13^{d}$ | $11^{d}$ |
| Bamboo | $26^{cd}$ | $17^{cd}$ | $23^{cd}$ | $10^{cd}$ | $16^{cd}$ | $16^{cd}$ | $6^{cd}$ |
| Ailanthus | $18^{c}$ | $15^{c}$ | $16^{c}$ | $17^{c}$ | $16^{c}$ | $8^{c}$ | $10^{c}$ |
| Pterocarpus | $9^{a}$ | $4^{a}$ | $4^{a}$ | $5^{a}$ | $8^{a}$ | $5^{a}$ | $5^{a}$ |
| Xylia | $31^{e}$ | $27^{e}$ | $17^{e}$ | $16^{e}$ | $18^{e}$ | $16^{e}$ | $16^{e}$ |
| Dalbergi | $8^{b}$ | $9^{b}$ | $9^{b}$ | $8^{b}$ | $5^{b}$ | $4^{b}$ | $4^{b}$ |
| Terminalia | $9^{b}$ | $9^{b}$ | $8^{b}$ | $8^{b}$ | $8^{b}$ | $9^{b}$ | $9^{b}$ |

Same superscripts indicat non significance

Table 10. Change in shoot length of various indigenous species at different concentrations of aluminium

| Species | Concentration(ppm) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 25 | 50 | 100 | 250 | 500 | 750 | 1000 |
| Haldina | $0.4^{ab}$ | $0.3^{ab}$ | $0.2^{ab}$ | $0.2^{ab}$ | $0.1^{ab}$ | $0.1^{ab}$ | $-0.1^{ab}$ |
| Bamboo | $0.8^{ab}$ | $0.6^{ab}$ | $0.6^{ab}$ | $0.2^{ab}$ | $-0.3^{ab}$ | $-0.2^{ab}$ | $-0.7^{ab}$ |
| Ailanthus | $0.7^{b}$ | $0.6^{b}$ | $0.5^{b}$ | $0.4^{b}$ | $0.4^{b}$ | $0.3^{b}$ | $0.2^{b}$ |
| Pterocarpus | $0.2^{a}$ | $0.1^{a}$ | $-0.3^{a}$ | $-0.1^{a}$ | $-0.1^{a}$ | $0.2^{a}$ | $-0.5^{a}$ |
| Xylia | $2.4^{c}$ | $1.4^{c}$ | $0.9^{c}$ | $0.7^{c}$ | $0.5^{c}$ | $0.5^{c}$ | $0.3^{c}$ |
| Dalbergi | $0.5^{ab}$ | $0.3^{ab}$ | $0.3^{ab}$ | $0.1^{ab}$ | $-0.5^{ab}$ | $-0.3^{ab}$ | $-0.1^{ab}$ |
| Terminalia | $0.1^{a}$ | $0^{a}$ | $-0.1^{a}$ | $0.03^{a}$ | $-0.2^{a}$ | $-0.1^{a}$ | $-0.3^{a}$ |

Same superscripts indicate non significance

Table 11. Change in root length of various indigenous species at different concentrations of aluminium

| Species | Concentration (ppm) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 25 | 50 | 100 | 250 | 500 | 750 | 1000 |
| Haldina | $0.4^{a}$ | $0.4^{a}$ | $0.3^{a}$ | $0.2^{a}$ | $0.1^{a}$ | $0.1^{a}$ | $-0.1^{a}$ |
| Bamboo | $0.6^{b}$ | $0.5^{b}$ | $0.3^{b}$ | $0.3^{b}$ | $0.2^{b}$ | $0.1^{b}$ | $0.1^{b}$ |
| Ailanthus | $0.4^{ab}$ | $0.3^{ab}$ | $0.3^{ab}$ | $0.2^{ab}$ | $0.2^{ab}$ | $0.1^{ab}$ | $-0.1^{ab}$ |
| Pterocarpus | $0.6^{ab}$ | $0.5^{ab}$ | $0.1^{ab}$ | $-0.2^{ab}$ | $-0.1^{ab}$ | $-0.1^{ab}$ | $-0.1^{ab}$ |
| Xylia | $5^{c}$ | $3.3^{c}$ | $1.7^{c}$ | $1.5^{c}$ | $1.4^{c}$ | $1.1^{c}$ | $0.5^{c}$ |
| Dalbergia | $0.5^{b}$ | $0.2^{b}$ | $-0.2^{b}$ | $-0.4^{b}$ | $-0.7^{b}$ | $-0.9^{b}$ | $-1.1^{b}$ |
| Terminalia | $0.1^{b}$ | $-0.1^{b}$ | $-0.2^{b}$ | $-0.1^{b}$ | $-0.1^{b}$ | $-0.1^{b}$ | $-0.2^{b}$ |

Same superscripts indicate non significance

*Shoot growth*

The hydroponic study with different levels of $Al^{3+}$ was conducted for a period of 31 days and the data on shoot length of each plant was recorded at the end of survival period. Since each species varied in its growth pattern, the main thrust was given to the rate of change in shoot length rather than total shoot length. Data on measurements (Table 10) indicated a general decreasing trend in shoot growth with increase in concentration of $Al^{3+}$. In the case of xylia and ailanthus, shoot growth was not found retarded even at 1000 ppm. Elongation of shoot was found terminated at 1000 ppm in the case of Haldina. Shoot growth of bamboo and dalbergia was found affected negatively at 750 ppm of $Al^{3+}$ while the shoots of pterocarpus and terminalia could not grow even at 100 ppm $Al^{3+}$. So the results in general pointed out that the tolerance level of seedlings of various species with respect to shoot elongation was in the sequence xylia= ailanthus> haldina> bamboo, dalbergia> pterocarpus> terminalia.

*Root growth*

As with shoot growth , length of roots in all the species were also evaluated at the end of survival period at all the levels of $Al^{3+}$. The measurements of root length shown in Table 11 conveyed that even though rate of increase in root length was decreasing with increase in concentration of $Al^{3+}$ in all the species, root retardation was not observed in the case of xylia and bamboo even at 1000 ppm of $Al^{3+}$. But in the case of haldina and ailanthus, root retardation started at 1000 ppm of $Al^{3+}$. Root growth was inhibited at 50 ppm in terminalia, at 100 ppm in dalbergia and at 250 ppm in pterocarpus. Thus the results in general indicated that tolerance level of species with respect to root growth was in the order xylia = bamboo> haldina= ailanthus> pterocarpus> dalbergia> terminalia.

#### 4.2.1. *Tolerance to manganese toxicity*

In order to find out the the tolerance level of various species to Mn toxicity hydroponic study was conducted with various levels of manganese such as 25, 50, 100, 250, 500, 750 and 1000 ppm of Mn. Experiment was conducted for a period of 30 days and the growth of plants was monitored with respect to survival period and elongation of shoot and root.

*Survival period*

Data on survival period (Table 12) indicated that up to 100 ppm of Mn, haldina could survive for more number of days (27-30) followed by xylia, ailanthus, bamboo, dalbergia, pterocarpus and terminalia. Among the species tried, pterocarpus and dalbergia were very poor survivors.

Table 12. Survival period of various indigenous species at different concentrations of manganese

| Species | Concentration, ppm | | | | | | |
|---|---|---|---|---|---|---|---|
| | 25 | 50 | 100 | 250 | 500 | 750 | 1000 |
| Haldina | $30^{e}$ | $26^{e}$ | $27^{e}$ | $15^{e}$ | $13^{e}$ | $12^{e}$ | $12^{e}$ |
| Bambusa | $17^{c}$ | $20^{c}$ | $21^{c}$ | $18^{c}$ | $13^{c}$ | $14^{c}$ | $15^{c}$ |
| Ailanthus | $21^{d}$ | $18^{d}$ | $19^{d}$ | $17^{d}$ | $12^{d}$ | $15^{d}$ | $13^{d}$ |
| Pterocarpus | $6^{a}$ | $5^{a}$ | $6^{a}$ | $11^{a}$ | $12^{a}$ | $5^{a}$ | $5^{a}$ |
| Xylia | $20^{e}$ | $21^{e}$ | $28^{e}$ | $21^{e}$ | $20^{e}$ | $25^{e}$ | $20^{e}$ |
| Dalbergia | $16^{b}$ | $17^{b}$ | $6^{b}$ | $12^{b}$ | $5^{b}$ | $4^{b}$ | $4^{b}$ |
| Terminalia | $9^{a}$ | $7^{a}$ | $7^{a}$ | $2^{a}$ | $3^{a}$ | $7^{a}$ | $2^{a}$ |

Same superscripts indicate non significance

Table 13. Change in shoot length of various indigenous species at different concentrations of manganese

| Species | Concentration, ppm | | | | | | |
|---|---|---|---|---|---|---|---|
| | 25 | 50 | 100 | 250 | 500 | 750 | 1000 |
| Haldina | $0.1^{bc}$ | $0.1^{bc}$ | $0.4^{bc}$ | $0.2^{bc}$ | $0.2^{bc}$ | $0.2^{bc}$ | $0.1^{bc}$ |
| Bambusa | $0.6^{c}$ | $1^{c}$ | $0.2^{c}$ | $0.5^{c}$ | $0.8^{c}$ | $0.3^{c}$ | $0.5^{c}$ |
| Ailanthus | $0.6^{c}$ | $0.5^{c}$ | $0.6^{c}$ | $0.6^{c}$ | $0.5^{c}$ | $0.6^{c}$ | $0.3^{c}$ |
| Pterocarpus | $0.1^{abc}$ | $-0.2^{abc}$ | $0.3^{abc}$ | $0.1^{abc}$ | $0.3^{abc}$ | $-0.1^{abc}$ | $-0.1^{abc}$ |
| Xylia | $2.7^{d}$ | $3.5^{d}$ | $2.1^{d}$ | $1.4^{d}$ | $3.6^{d}$ | $1.7^{d}$ | $2.2^{d}$ |
| Dalbergia | $-0.1^{a}$ | $-0.3^{a}$ | $0.1^{a}$ | $-0.2^{a}$ | $0.3^{a}$ | $0^{a}$ | $0.4^{a}$ |
| Terminalia | $0.2^{ab}$ | $0.1^{ab}$ | $-0.1^{ab}$ | $-0.2^{ab}$ | $-0.1^{ab}$ | $-0.1^{ab}$ | $-0.3^{ab}$ |

Same superscripts indicate non significance

Table 14. Change in root length of various indigenous species at different concentrations of manganese

| Species | Concentration, ppm | | | | | | |
|---|---|---|---|---|---|---|---|
| | 25 | 50 | 100 | 250 | 500 | 750 | 1000 |
| Haldina | $0.2^{abc}$ | $0.2^{abc}$ | $0.2^{abc}$ | $0.1^{abc}$ | $0^{abc}$ | $-0.2^{abc}$ | $-0.1^{abc}$ |
| Bambusa | $0.4^{c}$ | $0.5^{c}$ | $0.5^{c}$ | $0.3^{c}$ | $0.4^{c}$ | $0.4^{c}$ | $0.5^{c}$ |
| Ailanthus | $0.6^{c}$ | $0.4^{c}$ | $0.5^{c}$ | $0.4^{c}$ | $0.3^{c}$ | $0.1^{c}$ | $0^{c}$ |
| Pterocarpus | $0.3^{bc}$ | $-0.1^{bc}$ | $0.2^{bc}$ | $0.5^{bc}$ | $0^{bc}$ | $0.2^{bc}$ | $-0.1^{bc}$ |
| Xylia | $0.2^{d}$ | $-0.4^{d}$ | $3.5^{d}$ | $2.5^{d}$ | $1.7^{d}$ | $2.4^{d}$ | $2.1^{d}$ |
| Dalbergia | $-0.2^{a}$ | $-0.1^{a}$ | $-0.2^{a}$ | $-0.2^{a}$ | $-0.5^{a}$ | $0.1^{a}$ | $-0.1^{a}$ |
| Terminalia | $0.3^{ab}$ | $-0.1^{ab}$ | $0.1^{ab}$ | $-0.1^{ab}$ | $-0.1^{ab}$ | $-0.1^{ab}$ | $-0.4^{ab}$ |

Same superscripts indicate non significance

survivors. But beyond 100 ppm xylia was better survivor than haldina. At higher concentrations of 500, 750 and 1000 ppm the order of decreasing tolerance was xylia>ailanthus>haldina>bamboo>dalbergia>pterocarpus>terminalia.

With increase in the concentration of Mn, the survival period was found decreasing in all the species. But it is a notable feature of xylia that survival period remained constant in all the concentrations of Mn. This reveals the high tolerance of xylia in degraded lateritic soils with high concentrations of Mn.

*Shoot length*

With respect to shoot length (Table 13), the rate of increase dropped with increase in concentration in all the species. But compared to other species, xylia showed asignificant increase in shoot length in all the concentrations tested. Shoot growth was found arrested at 1000 ppm in bamboo, 750 ppm in pterocarpus, 100 ppm in terminalia and at 25 ppm in dalbergia. In general, the order of tolerance with respect to shoot length up to 50 ppm was xylia> bamboo=ailanthus=haldina> pterocarpus>terminalia> dalbergia. And beyond 50 ppm the order was xylia>ailanthus> haldina> bamboo> pterocarpus> terminalia> dalbergia.

*Root length*

As in the case of shoot growth, root growth (Table 14) of xylia in all the concentrations of Mn was found significantly higher than others. Root growth was found arrested at 1000 ppm in ailanthus, 500 ppm in haldina and pterocarpus, 250 ppm in terminalia and 50 ppm in dalbergia. The order of decreasing tolerance was xylia> ailanthus= bamboo> pterocarpus> haldina> terminalia> dalbergia. Unlike in survival period and shoot growth, root growth of haldina was found negatively influenced even at low concentration of Mn.

## 5. TOLERANCE TO SOIL MOISTURE STRESS AND SOIL COMPACTION

Availability of water is a major environmental factor which influences the distribution and abundance of plant species in natural communities. It is also a limiting factor in afforestation and forest plantation programmes and species vary widely in their ability to tolerate soil moisture stresses through morphological or physiological responses. Similarly stress due to soil compaction also affects the growth of the plants adversely by hindering the normal proliferation and development of root system which lead to inadequate absorption of water and nutrients and also improper anchorage. So in this part of the study it was intended to compare the tolerance of the species to stresses due to soil moisture and compaction and also to categorize them in the order of their tolerance to above stresses.

### 5.1. Materials and Methods

The present investigation was carried out at the sub centre of the Institute at Nilambur by providing three levels of soil moisture and three levels of compaction. Soil moisture levels of 20 per cent, 10 per cent and 5 per cent were maintained by periodic watering with predetermined volume of water necessary to bring the soil moisture to the required levels and verifying it using a soil moisture meter. Soil compaction was achieved by compacting the soil at around 10-15 per cent moisture with the help of a roller by moving it up and down the plot several times. A penetrometer was made use of to ensure the levels of soil compaction at the specified levels of 1.2, 1.4 and 1.6 $gcm^{-3}$bulk density. The treatments including 3 moisture levels and 3 compaction

Fig. 4. Measuring soil moisture in the experimental field using soil moisture probe

levels were replicated three times. Plots of 2m x 2m were planted with each species at a spacing of 40 cm thus accommodating 25 plants in each plot. Planting was done in May 2008 and height growth monitored till September 2009. Oven dry biomass yield was determined in October 2009 by destructive sampling at 18 months growth stage. Significance of variation in height and biomass production among the species was tested through SPSS package.

## 5.2. Results and Discussion

### 5.2.1. *Growth response to soil moisture stress*

Response of different species to the stresses due to soil moisture was assessed in terms of height growth and biomass production. Data on the height of various species as influenced by different levels of moisture (25%, 10% and 5%) at 18 months growth stage (Table 15) revealed significant variation between them. Among the species, terminalia was with maximum height followed by bamboo. The species in their decreasing order of height were terminalia> bamboo> pterocarpus> ailanthus> xylia>dalbergia>haldina. By increasing the stress to 10% moisture, the order changed to terminalia> bamboo> pterocarpus> ailanthus> dalbergia> xylia > haldina and further increasing the stress to 5% moisture, the order was bamboo> terminalia> ailanthus> dalbergia> pterocarpus> xylia> haldina.

With respect to biomass also species varied at different levels of moisture. Significantly higher biomass at 20% moisture level was produced by bamboo followed by ailanthus= terminalia> xylia> haldina> pterocarpus> dalbergia. But by increasing the stress to 10% moisture, the order was ailanthus> bamboo> terminalia>xylia > haldina > pterocarpus>dalbergia. At extreme level of moisture stress (5% moisture) the decreasing order of tolerance level of species was in the order bamboo> ailanthus> terminalia> xylia> pterocarpus> haldina> dalbergia.

Table 15. Influence of different levels of soil moisture on the height (cm) of various species 18 month after planting

| Sl. No. | Species | Soil moisture level | | |
|---|---|---|---|---|
| | | 20% | 10% | 5% |
| 1 | Dalbergia | $63.8^{cA}$ | $65.9^{cdA}$ | $54.3^{dA}$ |
| 2 | Xylia | $48.2^{dA}$ | $55.1^{cdA}$ | $56.8^{dA}$ |
| 3 | Pterocarpus | $57.1^{cdC}$ | $122.9^{abA}$ | $97.4^{bB}$ |
| 4 | Haldina | $26.8^{eB}$ | $33.4^{dA}$ | $26.3^{eB}$ |
| 5 | Terminalia | $90.0^{bB}$ | $138.0^{aA}$ | $120.3^{aAB}$ |
| 6 | Ailanthus | $81.5^{bB}$ | $90.3^{bcA}$ | $76.9^{cB}$ |
| 7 | Bamboo | $124.8^{aA}$ | $132.9^{abA}$ | $105.4^{abB}$ |

*Means with same small letter as super script is homogeneous within a column*
*Means with same capital letter as super script is homogeneous within a row*

Table 16. Influence of different levels of soil moisture on the biomass (g) of various species 18 month after planting

| Sl. No. | Species | Soil moisture level | | |
|---|---|---|---|---|
| | | 20% | 10% | 5% |
| 1 | Dalbergia | $20.0^{gA}$ | $15.2^{fB}$ | $13.7^{gB}$ |
| 2 | Xylia | $431.1^{dA}$ | $389.7^{cB}$ | $205.8^{dC}$ |
| 3 | Pterocarpus | $231.3^{fA}$ | $224.0^{eA}$ | $198.3^{eB}$ |
| 4 | Haldina | $416.5^{eA}$ | $327.1^{dB}$ | $57.4^{fC}$ |
| 5 | Terminalia | $1614.0^{cA}$ | $1374.0^{bB}$ | $667.0^{cC}$ |
| 6 | Ailanthus | $2762.0^{bA}$ | $2256.1^{aB}$ | $1213.0^{bC}$ |
| 7 | Bamboo | $5757.5^{aA}$ | $2243.7^{aB}$ | $1956.0^{aC}$ |

*Means with same small letter as super script is homogeneous within a column*
*Means with same capital letter as super script is homogeneous within a row*

The results in general demonstrated that among the species bamboo, ailanthus and terminalia were highly tolerant to the stress due to moisture, both in terms of height and biomass. Even though pterocarpus could attain more height than xylia under higher level of moisture stress, xylia was superior to pterocarpus with respect to the production of biomass. However haldina and dalbergia were found inferior to others in tolerating the stress due to moisture.

### *5.2.2. Growth response to soil compaction*

In this experiment seedlings of various species were subjected to different levels of soil compaction such as 1.2, 1.4 and 1.6 $gcm^{-3}$ and influence of compaction was assessed based on their growth in terms of height and biomass at 18 months after planting. Results indicated (Table 17) that the species varied widely in their tolerance to compaction as the height and biomass slashed down significantly with increase in the stress due to compaction.

Table 17. Influence of soil compaction on the height (cm) of various species 18 month after planting

| Sl. No. | Species | Soil compaction | | |
|---|---|---|---|---|
| | | 1.2 $gcm^{-3}$ | 1.4 $gcm^{-3}$ | 1.6 $gcm^{-3}$ |
| 1 | Dalbergia | $60.7^{cA}$ | $40.7^{cB}$ | $32.7^{cB}$ |
| 2 | Xylia | $38.6^{dA}$ | $28.6^{dB}$ | $25.5^{dB}$ |
| 3 | Pterocarpus | $63.6^{bcA}$ | $44.4^{cB}$ | $35.0^{cB}$ |
| 4 | Haldina | $30.4^{dA}$ | $24.9^{dA}$ | $22.5^{dA}$ |
| 5 | Terminalia | $74.0^{abA}$ | $52.0^{bB}$ | $41.3^{bC}$ |
| 6 | Ailanthus | $69.4^{abcA}$ | $52.2^{bB}$ | $41.3^{bC}$ |
| 7 | Bamboo | $78.2^{aA}$ | $68.1^{aB}$ | $56.8^{aC}$ |

*Means with same small letter as super script is homogeneous within a column*
*Means with same Capital letter as super script is homogeneous within a row*

Among the species, maximum height was observed in bamboo at all levels of compaction. The species in the decreasing order of height growth at 1.2 $gcm^{-3}$ level of soil compaction were bamboo>terminalia>ailanthus>pterocarpus>dalbergia>xylia> haldina. At 1.4 and 1.6 $gcm^{-3}$ levels of soil compaction, the same order was found repeated. With regard to biomass production, significant reduction at all levels of soil compaction was noted in bamboo only. Biomass reduction in terminalia and haldina occurred at 2nd level of compaction while in ailanthus, pterocarpus, xylia and dalbergia the reduction was seen only at 3rd level of compaction.

Table 18. Influence of soil compaction on the biomass (g) of various species 18 months after planting

| Sl. No. | Species | Soil compaction | | |
|---|---|---|---|---|
| | | 1.2 $gcm^{-3}$ | 1.4 $gcm^{-3}$ | 1.6 $gcm^{-3}$ |
| 1 | Dalbergia | $44.5^{fA}$ | $40.7^{fA}$ | $27.2^{fB}$ |
| 2 | Xylia | $353.7^{dA}$ | $315.5^{fA}$ | $285.4^{dB}$ |
| 3 | Pterocarpus | $332.7^{dA}$ | $307.6^{dA}$ | $235.8^{dB}$ |
| 4 | Haldina | $150.5^{eA}$ | $133.2^{eB}$ | $117.5^{eB}$ |
| 5 | Terminalia | $726.0^{cA}$ | $470.7^{cB}$ | $409.0^{cB}$ |
| 6 | Ailanthus | $1444.2^{bA}$ | $1417^{bA}$ | $825.9^{bB}$ |
| 7 | Bamboo | $3172.4^{aA}$ | $2048.8^{aB}$ | $1436.1^{aC}$ |

*Means with same small letter as super script is homogeneous within a column*
*Means with same Capital letter as super script is homogeneous within a row*

With regard to biomass production, significant reduction was noted in all the species with increase in the level of soil compaction. This reduction at all levels of soil compaction was noted in bamboo only. Biomass reduction in terminalia and haldina occurred at 2nd level of soil compaction while in ailanthus, pterocarpus, xylia and dalbergia it was seen only at 3rd level of compaction.

As in the case of height, significantly higher biomass production was noted in bamboo at all levels of compaction followed by ailanthus and terminalia. The decreasing order of biomass production was bamboo> ailanthus> terminalia> xylia> pterocarpus> haldina> dalbergia and this order was same at all the levels of soil compaction.

## 6. CATION EXCHANGE CAPACITY OF ROOTS

Absorption of nutrients by plant roots is reported to have a significant relation with the CEC of roots, which is mainly decided by the number and type of roots. Since the nature of root system of a plant is governed by its genetic nature, there exists considerable variation between the species. The process of absorption of nutrients, being a key process during the establishment phase of a plant in soil, root CEC is assumed to have great significance in matching the plant to soil under a given climatic condition. So here in this study, it was intended to determine the cation exchange capacity of roots of selected species and to find out the relation, if any, with their adaptability to degraded lateritic soil.

## 6.1. Materials and Method

Root CEC of seven species was estimated at nursery stage. For this three g of fresh roots were taken, washed and wrapped in muslin cloth. The roots in the cloth wrap were dipped in 0.01N HCl contained in a beaker, which was kept in an ice bath. The wrap was intermittently raised and removed by a series of washings in distilled water contained in three beakers, all kept cooled in an icebath. The cloth wrap was then removed and the roots were transferred to 150 ml of 1*N* neutral KCl, whose pH was adjusted to 7 using KOH/HCl before the introduction of roots. The change in pH due to the introduction of roots were measured by titrating it back to 7 using 0.01 N KOH and the volume of KOH solution was noted. The roots were taken out, dried to constant weight in an air dry oven at 80-85 $^{O}$C and CEC was measured

## 6.2 Results and Discussion

The data on root CEC of various species at 3-4 months of growth in the nursery (Table 18) revealed a significant variation among the species. Significantly higher root CEC was observed in ailanthus followed by xylia and terminalia. Comparatively poor root CEC was noted for haldina followed by bamboo. Thus the decreasing order of root CEC at nursery stage was ailanthus> xylia> pterocarpus> terminalia> dalbergia>bamboo>haldina. Comparatively high root CEC associated with ailanthus coupled with its high tolerance to degraded soils points out a close relation between them. Similarly higher root CEC of xylia and terminalia is also found related with their tolerance to degraded lateritic soil. But in the case of bamboo, even though its root CEC was very low, it falls in the group of superior species with regard to its tolerance especially to soil moisture and soil compaction stresses. Usually monocots have low CEC compared to dicots and this might be the reason for higher tolerance of bamboo in spite of its lower root CEC. However, the results of present study, in general, gives an indication that the species with higher root CEC are associated with higher tolerance to degraded lateritic soil. But in monocot like bamboo, in spite of its lower root CEC, it was seen as a relatively tolerant species to degraded lateritic soil.

Table 19. Root CEC of indigenous species at nursery stage

| Sl.No. | Species | Root CEC( cmol(+)/kg) |
|---|---|---|
| 1 | Haldina | 0.185 |
| 2 | Bamboo | 0.545 |
| 3 | Ailanthus | 2.303 |
| 4 | Pterocarpus | 0.903 |
| 5 | Xylia | 1.118 |
| 6 | Dalbergia | 0.63 |
| 7 | Terminalia | 0.97 |

## 7. CATEGORIZATION OF SPECIES IN THE ORDER OF THEIR TOLERANCE TO DEGRADED LATERITIC SOIL

Based on the results discussed above, it was evident that species varied widely in their tolerance to each adverse condition of degraded lateritic soil. With respect to nutrient efficiency, which was evaluated in terms of total biomass, shoot biomass, root biomass and nutrient uptake, ailanthus was most efficient followed by terminalia and xylia (Table 20). Even though haldina ranked first in extracting higher quantity of nutrient (phosphorus) from soil, its biomass yield was relatively very low. It was noticed that terminalia and bamboo were superior in producing relatively higher root biomass and hence they can be considered for using as vegetative barrier in erosion prone areas. With respect to nutrient absorption, selective absorption of P from soils was more in terminalia followed by pterocarpus, bamboo and ailanthus.

In soils with Al and Mn toxicities, xylia followed by ailanthus and haldina were good performers. But bamboo seemed to be the superior species in tolerating the stresses due to soil moisture and soil compaction. Ailanthus and terminalia were found equally good after bamboo in tolerating the stresses due to soil moisture and soil compaction.

Table 20. Categorization of species in the order of their tolerance to degraded lateritic soil

| Sl. No. | Character | | Species in the decreasing order of tolerance | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 1. | Nutrient efficiency | Total biomass | Ailan. | Termi. | Xylia | Bamb. | Hald. | Ptero. | Dal. |
| | | Shoot biomass | Ailan. | Termi. | Xylia | Bamb. | Hald. | Ptero. | Dal. |
| | | Root biomass | Termi. | Bamb. | Ailan. | Xylia | Hald. | Ptero. | Dal. |
| | | Uptake of N | Ailan. | Bamb. | Xylia | Termi. | Hald. | Ptero. | Dal. |
| | | Uptake of P | Hald. | Ailan | Termi. | Bamb. | Xylia | Ptero. | Dal. |
| | | Uptake of K | Ailan. | Termi. | Xylia | Hald. | Ptero. | Bamb. | Dal. |
| 2. | Nutrient absorption | | Termi. | Ptero. | Bamb. | Ailan. | Xylia | Dal. | Hald. |
| 3. | Al toxicity | Survival period | Xylia | Ailan. | Hald. | Bamb. | Termi. | Dal. | Ptero. |
| | | Shoot growth | Xylia | Ailan. | Hald. | Bamb. | Dal. | Ptero. | Termi. |
| | | Root growth | Xylia | Bamb. | Hald. | Ailan. | Ptero. | Dal. | Termi. |
| 4. | Mn toxicity | Survival period | Xylia | Ailan. | Hald. | Bamb. | Dal. | Ptero. | Termi. |
| | | Shoot growth | Xylia | Ailan. | Hald. | Bamb. | Ptero. | Termi. | Dal. |
| | | Root growth | Xylia | Ailan. | Bamb. | Ptero. | Hald. | Termi. | Dal. |
| 5. | Soil moisture stress | Height | Bamb. | Ailan. | Termi. | Dal. | Ptero. | Xylia | Hald. |
| | | Biomass | Bamb. | Termi. | Ailan. | Xylia | Ptero. | Hald. | Dal. |
| 6. | Soil compaction | Height | Bamb. | Termi. | Ailan. | Ptero. | Dal. | Xylia | Hald. |
| | | Biomass | Bamb. | Ailan. | Termi. | Xylia | Ptero. | Hald. | Dal. |
| 7. | Root CEC | | Ailan. | Xylia | Ptero. | Termi. | Dal. | Bamb. | Hald. |

Species such as ailanthus, xylia and terminalia which were proved to be the tolerant species to degraded lateritic condition were also found associated with higher root CEC. But terminalia even with its higher root CEC could not thrive at higher levels of Al and Mn toxicities while haldina with its lowest root CEC seemed to be a hardy species in this regard.

## 8. CONCLUSION

Based on the above study it is concluded that significant variation exists between the indigenous species in their tolerance to various degraded lateritic soil conditions of Kerala and hence priority must be given to species site matching while selecting species for successful afforestation or reforestation programmes especially in degraded lateritic soils.

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