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# IMPROVEMENT IN PRODUCTIVITY OF *Eucalyptus tereticornis* THROUGH NUTRIENT INPUTS AND SILVICULTURAL TREATMENTS

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# IMPROVEMENT IN PRODUCTIVITY OF *Eucalyptus tereticornis* THROUGH NUTRIENT INPUTS AND SILVICULTURAL TREATMENTS

(Final report of the project KFRI 263/96 December 1996 – June 2000)

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**March 2003**

## ABSTRACT OF THE PROJECT PROPOSAL

| | | |
|---|---|---|
| Project No. | : | KFRI 263/96 |
| Title | : | Improvement in productivity of *Eucalyptus tereticornis* through nutrient inputs and silvicultural treatments |
| Objectives | : | To study the effect of different levels of spacing and pit sizes along with four nutrient combinations on the growth of *E. tereticornis* |
| | : | To evaluate the nutrient uptake and partitioning in different parts of the tree by destructive sampling |
| Date of commencement | : | December 1996 |
| Scheduled date of completion | : | June 2000 |
| Funding Agency | : | Kerala Forest Department |
| Principal investigator | : | M.Balagopalan |
| Associate investigator | : | P. Rugmini |

# CONTENTS

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ABSTRACT

This project was undertaken to study the effect of various nutrient inputs and silvicultural treatments on the growth and nutrient uptake and portioning in different parts of eucalypt (*Eucalyptus tereticornis*). The study was carried out on a 5 ha experimental area at the Field Research Centre of Kerala Forest Research Institute, Palappilly. Six silvicultural treatments *viz*., three levels of spacing (1 m x 1 m, 2 m x 2 m and 3 m x 3 m) and two levels of pit sizes (30 cm x 30 cm x 30 cm and 40 cm x 40 cm x 40 cm) and four nutrient combinations of Nitrogen, Phosphorus and Potassium, selected on the basis of a preliminary study, were tried. Nutrients in the form of Urea for nitrogen, Mussorie rock phosphate for phosphorus and Muriate of potash for Potassium were used. Two levels of nitrogen (30 and 40 g/plant), three levels of phosphorus (15, 30 and 40 g/plant) and three levels of potassium (0, 15 and 30 g/plant) were applied in combinations in two split doses in the first two years. In the third year, only one application was made.

One-half of the fertilizer dose was applied initially in the pit before planting in June and the remaining half was added in a furrow in October in the first year. In the second year, doses were doubled and one-half was applied in June and the remaining half in October in a furrow. In the third year, application of nutrients was not done in June while in October, nutrients equal to what had been applied in October during the second year was applied.

Height measurements were taken at a three-month interval during the initial 12 months after which measurements were taken at the end of 16, 25, 28 and 34 months during the next 22 months. Girth at breast height (gbh) was measured at a height of 1.37 m. The volume of the trees over bark was estimated using a prediction equation.

There was significant effect due to silvicultural treatments and nutrient combinations on height of trees. Among various silvicultural treatments, trees in the 3 m x 3 m spacing and pit size of 30 cm x 30 cm x 30 cm had the highest values for height and gbh and volume/tree and was found to differ significantly from other treatments.

Among the various nutrient combinations, application of 30 g of nitrogen, 30 g of phosphorus and 15 g of potassium (65 g Urea, 150 g Mussorie rock phosphate and 29 g Muriate of potash ) per tree in the first year was found to be the best. This is equal to 72.215 kg of urea, 166.650 kg Mussorie rock phosphate and 32.219 kg of Muriate of Potash per ha for 1,111 plants.

It was found that bole wood retained most of the nutrients. The quantity of nutrients in bole wood, leaves, bark and branches varied and depended on the spacing. The bole wood had 68, 53 and 35%, bark contained 10, 16 and 22%, branches constituted 9, 16 and 24% while leaves accounted for 13, 15 and 19% of the total tree nutrients in the 1 m x 1 m, 2 m x 2 m and 3 m x 3 m spacing, respectively. Out of the total nutrients, there was considerable quantity of total nutrients in the bole wood in 1 m x 1 m spacing (680 kg/ha out of 999.80 kg/ha) while in the 3 m x 3 m spacing, the bole wood had 64.02 kg/ha out of 184.31 kg/ha. Thus by removing the bole wood alone, a major portion of the stores of nutrients in the above ground biomass is removed.

# 1. INTRODUCTION

Eucalypts (*Eucalyptus tereticornis* and *E. grandis*) were introduced in Kerala on a large scale as part of afforestation programme during the 1970s because of their wider adaptability, faster growth and industrial demand.

Eucalypts are sensitive to site and there are plantations which have yielded only a few tonnes/ha and some yielding more than 150 tonnes/ha in Kerala (Goyal, 1986). According to Jayaraman and Krishnankutty (1990), in Kerala, the average yield for *E. tereticornis* is 72.59 $m^3$/ha at the rotation age of 10 years. A study by Chaturvedi (1988) revealed that in the terai region, eucalypt produced a volume of 180.7 $m^3$/ha of debarked wood, an average diameter of 14.8 cm and height of 18.1 m in $8^1/_2$ years. The mean annual increment was found to be 19.7 $m^3$ or about 13.8 tonnes/ha. He also reported that no other species was able to produce this volume in India.

In Kerala, eucalypt plantations occupy an area of about 25,650 ha (Govt. of Kerala, 1999). The estimated yield at the time of introduction of the species was 100 tonnes/ha after one rotation of 10 years. Available eucalypt raw material during the period 1998-99 was 97,379 tonnes from an area of 3248 ha (Govt. Kerala, 1999). Today, the demand far exceeds their production whereas the productivity is found to decline. The present production is not even one - third of the demand. For meeting the requirement, one option is either to increase the area under this plantation, which is impossible due to many socio-economic constraints, or all efforts should be made to increase the productivity of existing plantations. The latter is the only option under the present scenario as far as forestry is concerned.

The productivity of plantations can be enhanced through tree improvement programmes including application of biotechnology and improved/modified silvicultural practices coupled with nutrient management in the existing areas.

Judicious management of tree nutrition coupled with efficacious planting techniques is an important tool not only to ensure increased productivity but also for sustained productivity over a long-term period (Balagopalan *et al.*, 1998).

Studies conducted in several parts of the world showed that the effect of nutrients on the growth and development of eucalypt plantations varied. The application of nutrients to ecualypt crops is becoming widespread where it can be afforded and there is need for direct attention to the selection of clones with low requirements for nutrient and/or which use it efficiently (Bahuguna, 1991; Cromer *et al.*, 1993 a, b; Schonau and Herbert, 1986).

Eucalypts responded dramatically to fertilising in short rotation systems in skeletal soils and other soils of low nutrient status in regions with good rainfall (Singh *et al.*, 1986). There is very little response to nutrients at sites where water is the limiting factor (Dury and Manjunath, 1992). Responses to nitrogen, phosphorus, potassium and calcium and their combinations have produced different results in different soils (Prasad *et al.*, 1984).

In Kerala, a study on *E. grandis* revealed that biomass production could be increased with the application of nutrients coupled with different silvicultural treatments (Balagopalan *et al.*, 1998). The study revealed that among different silvicultural treatments, wider spacing, complete skinning, 20 cm x 20 cm x 20 cm pit size and a nutrient combination of 30 g of N, 30 g of P and 15 g of K/plant were found to be the best treatments for *E. grandis*. They also reported that large quantities of nutrients are removed from the site at the time of harvesting.

Hence, in the case of short rotations, the loss has to be made up through the addition of nutrient (George, 1986; George and Varghese, 1991; Jorgensen and Wells, 1986; Pande *et al.*, 1987). The application of nutrients has now become a regular practice of management in Argentina, Brazil, Portugal, Spain and South Africa. It has also been practised in high-density plantations in India (Knudson *et al.*, 1970; Schultz, 1976).

Since the nutrient requirements vary among eucalypt species, a study was conducted for *E. tereticornis* with the following objectives:

1. to evaluate the effect of three levels of spacing *viz.*, 1 m x 1 m, 2 m x 2 m and 3 m x 3 m, two levels of pit sizes of 30 cm x 30 cm x 30 cm and 40 cm x 40 cm x 40 cm and four nutrient combinations on the growth and yield, and

2. to assess the nutrient uptake and partitioning in different parts of the tree.

## 2. MATERIALS AND METHODS

### 2.1. Study area

The study was carried out at Field Research Centre, Kerala Forest Research Institute, Palappilly (Fig.1). The area is gently undulating with an elevation of 80 m asl. The average rainfall during the year 1997-2000 was 2700 mm per annum with an average minimum temperature of 20 $^{O}$C and a maximum of 38 $^{O}$C.

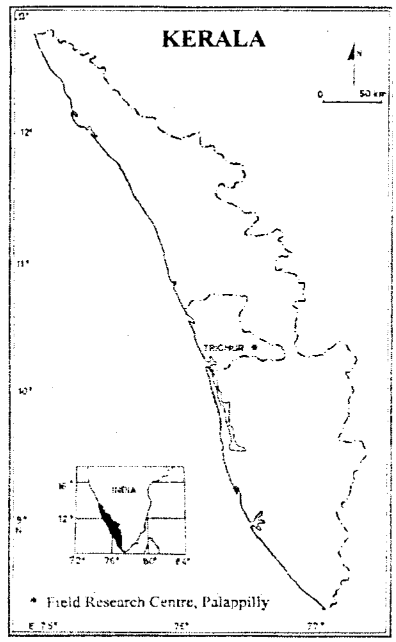


**Fig.1. Location of the study area**

### 2.2. Seedling production and planting

One-month-old naked seedlings of *E. tereticornis* collected from the mother nursery of Wadakkancherry range were transported to Palappilly and transplanted to polythene bags of size 10 cm x 20 cm in March 1997. The potting mixture used was soil and sand in the ratio 3:1. Even though addition of farmyard manure is a traditional practice for potting mixture, this was not added in anticipation of the termite problem. The seedlings were kept in the polythene bags till June 1997 when they were field planted. The height of the seedlings was recorded at the time of planting.

### 2.3. Soils

Fifteen surface soil samples were collected from different parts of the study area. In addition to this, 10 soil pits were also taken and samples collected from 0-20, 20-40 and 40-60 cm layers of soil pits. The gravel contents were found out. Analyses were carried out for estimation of particle–size separates, soil pH, organic carbon, total N, available P and K and cation exchange capacity (CEC) as per standard procedures in

ASA (1965) and Jackson (1958). The soil physical and chemical properties are given in Table 1.

Table 1. Physical and chemical properties of soils in different layers of soil pits

| | Layers (cm) | | |
|---|---|---|---|
| Properties | 0-20 | 20-40 | 40-60 |
| Sand % | 85 | 84 | 82 |
| Silt % | 7 | 9 | 10 |
| Clay % | 8 | 7 | 8 |
| Textural class | LS | LS | LS |
| Soil pH | 5.9 | 6.1 | 6.1 |
| Org. carbon % | 1.09 | 0.78 | 0.48 |
| Total N % | 0.09 | 0.05 | 0.04 |
| Av. P ppm | 4 | 3 | 2 |
| Av. K ppm | 22 | 10 | 8 |
| CEC me/100g | 12 | 9 | 7 |

LS= Loamy sand; CEC = Cation exchange capacity

The soils were highly degraded and belonged to red ferrallitic type. There were iron concretions even at the surface. In the lower layers, reddish yellow mottles were observed.

The soil was loamy sand in all the layers and slightly acidic in the surface and medium acidic in deeper layers. It contained low organic carbon in all the three layers. The ratios of organic carbon : total N were 12.11, 15.10 and 12.00 in the surface, subsurface and 40-60 cm layers, respectively. The available P status was very low and the K content was also found to be low. The Cation exchange capacity values varied from 8 to 12 me/100 g soil.

### 2.4. Experimental design

The experiment was laid out in split plot design with six silvicultural treatments forming the levels of the main plot factor and four nutrient combinations constituting the levels of the subplot factor. Both the main plot and subplot factors had a factorial structure. The different silvicultural and nutrient combinations are given below.

#### 2.4.1. Silvicultural treatments

The different silvicultural treatments are given below:

| Code | Treatments |
|---|---|
| $S_1P_1$ | Planting at 1 m x 1m spacing in pits of size 30 cm x 30 cm x 30 cm |
| $S_2P_1$ | Planting at 2 m x 2 m spacing in pits of size 30 cm x 30 cm x 30 cm |
| $S_3P_1$ | Planting at 3 m x 3 m spacing in pits of size 30 cm x 30 cm x 30 cm |
| $S_1P_2$ | Planting at 1 m x 1 m spacing in pits of size 40 cm x 40 cm x 40 cm |
| $S_2P_2$ | Planting at 2 m x 2 m spacing in pits of size 40 cm x 40 cm x 40 cm |
| $S_3P_2$ | Planting at 3 m x 3 m spacing in pits of size 40 cm x 40 cm x 40 cm |

#### 2.4.2. Nutrient combinations

The different nutrient combinations are given below:

| Code | Treatments |
|---|---|
| $N_2P_2K_1$ | 30 g N, 30 g P and 15 g K |
| $N_3P_2K_1$ | 45 g N, 30 g P and 15 g K |
| $N_2P_1K_0$ | 30 g N, 15 g P |
| $N_3P_3K_2$ | 45 g N, 45 g P and 30 g K |

Nitrogen was applied in the form of Urea, phosphorus in the form of Mussorie rock phosphate and potassium in the form of Muriate of potash. The quantities of nutrients added were as follows:

| Nutrients | Quantity (g/plant) |
|---|---|
| Urea | 65 and 97.5 g for 30 and 45 g N |
| Mussorie rock phosphate | 75, 150 and 225 g for 15, 30 and 45 g P |
| Muriate of potash | 0, 29 and 58 g for 0, 30 and 45 g K |

The experiment was replicated three times. Thus there were six main plots within a replication. Planting pattern of a single main plot is shown in Figure 2. There were 4032 (16 x 14 x 6 x 3) seedlings in each experiment. Each main plot was surrounded by border plants on all sides as shown in Figure 2. Hence, under each silvicultural treatment (main plot), there were four nutrient treatments (subplots). One nutrient treatment was applied to three columns of plants with 10 plants/column. The plants in the middle column were considered for observational purposes in order to avoid the border effect. The casualties which amounted to 15% were replaced in June 1998.

### 2.5. Mode of application of nutrients

The nutrient dose was split into two equal halves and one half of nutrients was applied just before planting in June 1997 in the planting pit. This was followed by application of remaining half in a furrow 5-10 cm deep and 10 cm away around the plant during October 1997. The furrow was filled with the soil. In the second year, the nutrient dose was doubled and applied in two split doses, one half in June and second half in October 1998. This was done in a furrow 10-15 cm deep and 15 cm away around the plant. During the third year, nutrient application was not done in June 1999 while in October 1999, the same dose of the nutrients applied in October 1998 was applied in a furrow 15-20 cm deep and 20 cm away around the plant and the furrow covered with soil.

### 2. 6. Growth measurements

The height of the seedlings was recorded at the time of planting in June 1997 and thereafter at a three-month interval *i.e.*, in September and December, 1997 and March and June 1998 (up to 12 months). After that, the observations were taken in October 1998, July and October 1999 and April 2000. In the first year, the second observation was taken just before the application of nutrients. The observations made in the second year in June and October 1998 were just before the application of nutrients. In the third year, the observations, taken in October 1999, were just before the application of nutrients. The girth at breast-height (gbh) of trees was measured from second year onwards for the trees at a height of 1.37 m. The observations on height and gbh were taken till 34 months since planting. Mean values of height and gbh of trees were computed excluding the casualties replaced.

Fig. 2. Pictorial representation of the planting pattern for a single main plot

| | | | 1 | | | 2 | | | 3 | | | 4♦ | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | # | * | # | # | * | # | # | * | # | # | * | # | 0 | 0 |
| 0 | 0 | # | * | # | # | * | # | # | * | # | # | * | # | 0 | 0 |
| 0 | 0 | # | * | # | # | * | # | # | * | # | # | * | # | 0 | 0 |
| 0 | 0 | # | * | # | # | * | # | # | * | # | # | * | # | 0 | 0 |
| 0 | 0 | # | * | # | # | * | # | # | * | # | # | * | # | 0 | 0 |
| 0 | 0 | # | * | # | # | * | # | # | * | # | # | * | # | 0 | 0 |
| 0 | 0 | # | * | # | # | * | # | # | * | # | # | * | # | 0 | 0 |
| 0 | 0 | # | * | # | # | * | # | # | * | # | # | * | # | 0 | 0 |
| 0 | 0 | # | * | # | # | * | # | # | * | # | # | * | # | 0 | 0 |
| 0 | 0 | # | * | # | # | * | # | # | * | # | # | * | # | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

0 – border plants
# – treated plants not included for measurements
* – treated plants considered for measurements

♦ 1. $N_2P_2K_1$ (N at 30 g, P at 30 g, K at 15 g per plant)
2. $N_3P_2K_1$ (N at 45 g, P at 30 g, K at 15 g per plant)
3. $N_2P_1K_0$ (N at 30 g, P at 15 g per plant)
4. $N_3P_3K_2$ (N at 45 g, P at 45 g, K at 30 g per plant)

At the end of the experiment, trees with height and gbh close to the respective mean values in each silvicultural treatment and nutrient combination were harvested. The per cent of bark in each treatment was found out.

### 2.7. Statistical analyses

For the purpose of statistical analyses, data from the net plot containing 10 plants from each gross plot of 30 plants were considered. Arithmetic means of height and gbh values of plants within each net plot, for all periods, were computed. The total volume of trees in each plot was estimated by applying the prediction equation reported by Chaturvedi (1973). The plot volume was then converted to hectare basis. The volume equation used was,

$$\sqrt{V} = -0.0868 + 2.8335\,D$$

where V = volume ($m^3$)
D = diameter at breast height (m) over bark

Data on mean height and mean gbh were statistically analysed through split plot analysis of variance (ANOVA) separately for each period in order to evaluate the effect of the silvicultural treatments, nutrient combinations and the interaction between silvicultural treatments and nutrient combinations (Gomez and Gomez, 1984). Data on volume per hectare attained by trees at the end of the experiment was subjected to split plot ANOVA. The ANOVA was followed by comparison of means by the method proposed by Calinski and Corsten (1985) wherever needed.

### 2.8. Plant analyses

At the end of the experiment, trees with height and gbh close to the respective mean values in each silvicultural treatment and nutrient combination were harvested. The nutrient contents N, P and K in bole wood, bark, branches and leaves of trees in each silvicultural treatment and nutrient combination were found out using the procedures in Wilde *et al.* (1972). Nitrogen was determined by Kjeldahl's digestion followed by distillation method, P by spectrophotometry and K by flame photometry.

## 3. RESULTS AND DISCUSSION

### 3.1. Effect of silvicultural treatments and nutrient combinations on growth of trees

### 3.1.1. Height

There was significant effect of silvicultural treatments on height of trees from 9$^{th}$ month onwards after planting (Table 2) while height of trees was influenced by nutrient combinations from 6th month onwards. The interaction between silvicultural treatments and nutrient combinations was found to be significant during 25$^{th}$, 28$^{th}$ and 34$^{th}$ month after planting.

Pair-wise comparison between the different silvicultural treatments showed that 3 m x 3 m and 2 m x 2 m spacing in both the pit sizes differed significantly from all the other treatments (Table 3). The treatments involving 3 m x 3 m spacing with 30 cm x 30 cm x 30 cm and 40 cm x 40 cm x 40 cm pit sizes showed higher mean values for height as compared to 1 m x 1 m and 2 m x 2 m spacing with 30 cm x 30 cm x 30 cm and 40 cm x 40 cm x 40 cm pit sizes throughout the study period.

Table 2. Analysis of variance of data on mean height of trees at different periods

| Source of variation | DF | June 1997 $0^{th}$ month | | Sept.1997 $3^{rd}$ month | | Dec. 1997 $6^{th}$ month | | Mar. 1998 $9^{th}$ month | | June 1998 $12^{th}$month | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | MS | F values | MS | F values | MS | F values | MS | F values | MS | F values |
| Silvicultural treatments | 5 | 2.08 | 1.97ns | 25.65 | 2.12ns | 134.36 | 2.70ns | 254.66 | 4.24* | 1362.59 | 11.49* |
| Replication | 2 | 1.55 | 1.47ns | 191.94 | 15.88* | 662.84 | 13.34* | 648.84 | 10.80* | 1709.86 | 14.42* |
| Error(1) | 10 | 1.06 | | 12.09 | | 49.69 | | 60.08 | | 118.61 | |
| Nutrient combinations | 3 | 0.66 | 1.52ns | 93.17 | 29.60* | 893.2 7 | 80.63* | 1405.47 | 94.67* | 6532.84 | 194.33* |
| Silvicultural treatments x Nutrient combinations | 15 | 0.52 | 1.19ns | 3.74 | 1.19ns | 13.07 | 1.18ns | 17.45 | 1.18ns | 55.30 | 1.65ns |
| Error (2) | 36 | 0.43 | | 3.15 | | 11.08 | | 14.85 | | 33.62 | |

DF- Degrees of freedom; MS – Mean square; * - significant at P= 0.05; ns – nonsignificant

(Contd….)

Table 2. Contd…

| Source of variation | DF | Oct. 1998 16th month | | July 1999 25th month | | Oct. 1999 28th month | | April 2000 34th month | |
|---|---|---|---|---|---|---|---|---|---|
| | | MS | F values | MS | F values | MS | F values | MS | F values |
| Silvicultural treatments | 5 | 7513.39 | 16.80* | 20183.12 | 35.46* | 67445.65 | 31.14* | 200050.36 | 46.74* |
| Replication | 2 | 5328.60 | 11.92* | 8127.88 | 14.28* | 34714.47 | 16.038* | 72089.47 | 16.84* |
| Error(1) | 10 | 447.09 | | 569.20 | | 2166.01 | | 4279.85 | |
| Nutrient combinations | 3 | 28451.49 | 120.56* | 69126.07 | 279.48* | 200933.16 | 258.60* | 624034.01 | 370.06* |
| Silvicultural treatments x Nutrient combinations | 15 | 316.87 | 1.34ns | 568.40 | 2.30* | 1539.21 | 1.98* | 4970.53 | 2.95* |
| Error(2) | 36 | 235.99 | | 247.34 | | 777.01 | | 1686.32 | |

DF- Degrees of freedom; MS – Mean square ; * - significant at P= 0.05; ns - nonsignificant

Table 3. Mean values of height (cm) corresponding to six silvicultural treatments in different months

| Silvicultural treatments | Height (cm) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Period (months) | | | | | | | | |
| | 0 | 3 | 6 | 9* | 12 | 16 | 25 | 28 | 34 |
| $S_1P_1$ | 27.19 | 43.54 | 76.74 | $84.86^a$ | $134.40^a$ | $226.37^a$ | $278.06^a$ | $378.69^a$ | $543.01^a$ |
| $S_2P_1$ | 27.68 | 45.95 | 81.88 | $91.91^b$ | $149.89^b$ | $258.44^b$ | $329.54^b$ | $442.25^b$ | $656.99^b$ |
| $S_3P_1$ | 28.42 | 48.08 | 87.05 | $98.64^b$ | $164.48^b$ | $292.54^b$ | $388.47^b$ | $574.73^b$ | $881.38^b$ |
| $S_1P_2$ | 28.09 | 46.41 | 81.92 | $90.05^b$ | $142.26^a$ | $238.45^a$ | $294.38^a$ | $404.16^a$ | $578.83^a$ |
| $S_2P_2$ | 27.99 | 46.26 | 83.17 | $93.21^b$ | $152.94^b$ | $269.97^b$ | $346.03^b$ | $499.94^b$ | $730.31^b$ |
| $S_3P_2$ | 27.87 | 46.43 | 83.49 | $94.44^b$ | $156.80^b$ | $279.47^b$ | $358.33^b$ | $522.89^b$ | $791.71^b$ |

$S_1$, $S_2$ and $S_3$ were 1 m x 1 m , 2 m x 2 m and 3 m x 3 m spacing respectively; $P_1$ and $P_2$ were 30 cm x 30 cm x 30 cm and 40 cm x 40 cm x 40 cm pit sizes, respectively.

* Values super scribed by the same letter in column-wise do not differ significantly

Table 4. Mean values of height (cm) corresponding to four nutrient combinations in different months

| Nutrient Treatment | Height (cm) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Period (months) | | | | | | | | |
| | 0 | 3 * | 6 | 9 | 12 | 16 | 25 | 28 | 34 |
| $N_2P_2K_1$ | 28.12 | $49.25^a$ | $91.55^a$ | $103.56^a$ | $174.37^a$ | $304.81^a$ | $394.29^a$ | $582.71^a$ | $901.19^a$ |
| $N_3P_3K_1$ | 27.84 | $46.33^b$ | $84.05^b$ | $94.41^b$ | $155.26^b$ | $282.25^b$ | $374.48^b$ | $532.42^b$ | $799.19^b$ |
| $N_2P_1K_0$ | 27.87 | $44.47^b$ | $78.17^c$ | $87.30^c$ | $140.07^c$ | $238.72^c$ | $297.05^c$ | $413.82^c$ | $593.76^c$ |
| $N_3P_3K_2$ | 27.66 | $44.40^b$ | $75.73^c$ | $83.47^c$ | $130.80^d$ | $217.71^d$ | $264.05^d$ | $352.81^d$ | $494.00^d$ |

$N_2$ and $N_3$ were 65 and 97.5 g Urea per plant, respectively; $P_1$, $P_2$ and $P_3$ were 75, 150 and 225 g Mussoric rock phosphate, respectively; $K_0$, $K_1$ and $K_2$ were 0, 29 and 58 g Muriate of potash per plant, respectively.

* Values super scribed by the same letter in column-wise do not differ significantly

The four nutrient combinations differed significantly from each other (Table 4). The treatment $N_2P_2K_1$ had the highest value when compared to other three treatment mean values throughout the study period. The lowest values were in $N_3P_3K_2$ combination.

### 3.1.2. Girth at breast height (gbh)

There was significant influence of silvicultural treatments and nutrient combinations on gbh from 12th month onwards (Table 5). The effect due to interaction between silvicultural treatments and nutrient combinations was found to be nonsignificant.

Pair-wise comparison between the silvicultural treatments showed that 3 m x 3 m spacing in both pit sizes differed significantly from all the other treatments (Table 6). The treatments involving 3 m x 3 m spacing with 30 cm x 30 cm x 30 cm and 40 cm x 40 cm x 40 cm pit sizes showed higher mean values for gbh in comparison to 1 m x 1 m and 2 m x 2 m spacing with 30 cm x 30 cm x 30 cm and 40 cm x 40 cm x 40 cm pit sizes.

The different nutrient combinations showed that there was significant difference between each other (Table 7) on gbh throughout the study period. The treatment $N_2P_2K_1$ showed the highest value while the lowest value was in $N_3P_3K_2$ throughout the study period.

### 3. 1. 3. Bark content

The bark contents of trees in different spacing are given below. Bark content decreased with increase in spacing.

| Spacing | Bark content (%) |
|---|---|
| 1 m x 1m | 41 |
| 2 m x 2 m | 28 |
| 3 m x 3 m | 19 |

Table 5. Analysis of variance of data on mean gbh of trees at different periods

| Source of variation | DF | June 1998 12th month | | Oct.1998 16th month | | July 1999 25th month | | Oct. 1999 28th month | | April 2000 34th month | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | MS | F values | MS | F values | MS | F values | MS | F values | MS | F values |
| Silvicultural treatment | 5 | 61.07 | 26.91* | 22.14 | 9.62* | 27.32 | 16.50* | 42.36 | 23.73* | 69.27 | 25.26* |
| Replication | 2 | 61.72 | 27.19* | 2.17 | 0.94ns | 1.03 | 0.62ns | 2.28 | 1.28ns | 2.04 | 0.74ns |
| Error(1) | 10 | 2.27 | | 2.30 | | 1.66 | | 1.78 | | 2.74 | |
| Nutrient combination | 3 | 366.38 | 67.19* | 60.18 | 51.48* | 84.06 | 82.86* | 126.93 | 97.32* | 210.19 | 76.96* |
| Silvicultural reatment x Nutrient combination | 15 | 6.19 | 1.13ns | 0.63 | 0.54ns | 0.59 | 0.58ns | 0.84 | 0.65ns | 3.09 | 1.13ns |
| Error(2) | 36 | 5.45 | | 1.17 | | 1.01 | | 1.30 | | 2.73 | |

DF- Degrees of freedom; MS – Mean square ; * - significant at P= 0.05; ns - nonsignificant

Table 6. Mean values of gbh (cm) corresponding to six silvicultural treatments at different months

| Silvicultural treatments | Gbh (cm) Period (months) | | | | |
|---|---|---|---|---|---|
| | 12* | 16 | 25 | 28 | 34 |
| $S_1P_1$ | 5.28[a] | 11.71[a] | 14.08[a] | 16.76[a] | 21.06[a] |
| $S_2P_1$ | 8.03[b] | 13.46[b] | 15.67[b] | 18.79[b] | 23.28[b] |
| $S_3P_1$ | 11.39[c] | 14.91[b] | 17.55[c] | 21.20[c] | 26.55[c] |
| $S_1P_2$ | 6.67[a] | 12.18[a] | 13.98[a] | 16.73[a] | 20.55[a] |
| $S_2P_2$ | 8.54[b] | 13.71[b] | 15.81[b] | 18.61[b] | 23.29[b] |
| $S_3P_2$ | 10.31[c] | 14.99[b] | 17.24[c] | 20.64[c] | 25.70[c] |

$S_1$, $S_2$ and $S_3$ were 1 m x 1 m, 2 m x 2 m and 3 m x 3 m spacing respectively; $P_1$ and $P_2$ were 30 cm x 30 cm x 30 cm and 40 cm x 40 cm x 40 cm pit sizes, respectively.

* Values super scribed by the same letter in the same column do not differ significantly

Table 7. Mean values of gbh (cm) corresponding to four nutrient combinations in different months

| Nutrient combinations | Gbh (cm) Period (months) | | | | |
|---|---|---|---|---|---|
| | 12* | 16 | 25 | 28 | 34 |
| $N_2P_2K_1$ | 13.20[a] | 15.47[a] | 18.21[a] | 21.82[a] | 27.42[a] |
| $N_3P_3K_1$ | 10.76[a] | 14.45[a] | 16.61[b] | 19.93[b] | 24.82[b] |
| $N_2P_1K_0$ | 6.47[b] | 12.70[b] | 14.86[c] | 17.68[c] | 21.72[c] |
| $N_3P_3K_2$ | 3.04[c] | 11.35[c] | 13.21[d] | 15.72[d] | 19.65[d] |

$N_2$ and $N_3$ are 65 and 97.5 g Urea/ plant, respectively; $P_1$, $P_2$ and $P_3$ are 75, 150 and 225 g Mussorie rock phosphate/ plant, respectively; $K_0$, $K_1$ and $K_2$ are 0, 29 and 58 g Muriate of potash/ plant, respectively.

* Values superscribed by the same letter in the same column do not differ significantly

### 3.1.4. Volume

The differences in volume were mainly attributable to the highly significant influence of silvicultural treatments, nutrient combinations and the interaction between silvicultural treatments and nutrient combinations (Table 8). The interaction effect was also highly significant, indicating that the nutrient combination differences were not the same at different silvicultural treatments.

Table 8. Analysis of variance of data on mean volume per ha

| Source of variation | DF | Mean sum of squares | F values |
|---|---|---|---|
| Silvicultural treatment | 5 | 19517.64 | 111.19* |
| Replication | 2 | 97.01 | 0.55ns |
| Error(1) | 10 | 175.54 | |
| Nutrient combination | 3 | 14956.45 | 45.15* |
| Silvicultural treatment x Nutrient combination | 15 | 1749.82 | 5.28* |
| Error(2) | 36 | 331.23 | |

DF- Degrees of freedom; * - significant at P= 0.05; ns - nonsignificant

Pair-wise comparison between the silvicultural treatments showed that 3 m x 3 m spacing in both pit sizes differed significantly from all the other treatments (Table 9). Volume per tree in the 3 m x 3 m spacing with pit sizes of 30 cm x 30 cm x 30 cm and 40 cm x 40 cm x 40 cm registered higher values when compared to all the other treatments. This was followed by that in 2 m x 2 m spacing. When the volume per ha is considered, it is highest in 1 m x 1 m spacing followed by that in 2 m x 2 m.

Pair-wise comparison between nutrient combinations revealed that the treatment, $N_2P_2K_1$ differed significantly from all other treatments. Mean volume was minimum in $N_3P_3$ $K_2$ (31.9 $m^3$/ha) and maximum in $N_2P_2K_1$ (93.5 $m^3$/ha) (Table 10).

Table 9. Volume of trees in the different silvicultural treatments

| Silvicultural treatments | Volume per tree over bark ($m^3$)* | Volume per tree under bark ($m^3$)* | Number of trees per ha at the end of 34 months | Volume of trees under bark ($m^3$/ha)* |
|---|---|---|---|---|
| $S_1P_1$ | $0.0106^a$ | $0.0063^a$ | 9201 | $57.97^a$ |
| $S_2P_1$ | $0.0152^b$ | $0.0109^b$ | 2423 | $26.41^b$ |
| $S_3P_1$ | $0.0233^b$ | $0.0189^b$ | 1047 | $19.79^b$ |
| $S_1P_2$ | $0.0097^a$ | $0.0057^a$ | 9021 | $51.42^a$ |
| $S_2P_2$ | $0.0152^b$ | $0.0109^b$ | 2399 | $26.15^b$ |
| $S_3P_2$ | $0.0210^b$ | $0.0170^b$ | 1069 | $18.17^b$ |

$S_1$, $S_2$ and $S_3$ were 1 m x 1 m , 2 m x 2 m and 3 m x 3 m spacing, respectively; $P_1$ and $P_2$ were 30 cm x 30 cm x 30 cm and 40 cm x 40 cm x 40 cm pit sizes, respectively.

* Values super scribed by the same letter in the same column do not differ significantly

Table 10. Volume of trees ($m^3$/ha) in different nutrient combinations

| Nutrient combinations | Volume of trees over bark ($m^3$/ha)* |
|---|---|
| $N_2P_2K_1$ | $93.53167^a$ |
| $N_3P_3K_1$ | $70.63133^b$ |
| $N_2P_1K_0$ | $38.20550^c$ |
| $N_3P_3K_2$ | $31.91978^c$ |

$N_2$ and $N_3$ were 65 and 97.5 g Urea per plant, respectively; $P_1$, $P_2$ and $P_3$ were 75, 150 and 225 g Mussorie rock phosphate per plant respectively; $K_0$, $K_1$ and $K_2$ were 0, 29 and 58 g Muriate of potash per plant, respectively.

* Values super scribed by the same letter do not differ significantly

## 3. 2. Plant analyses

### 3.2.1. Nutrient contents in different parts of trees

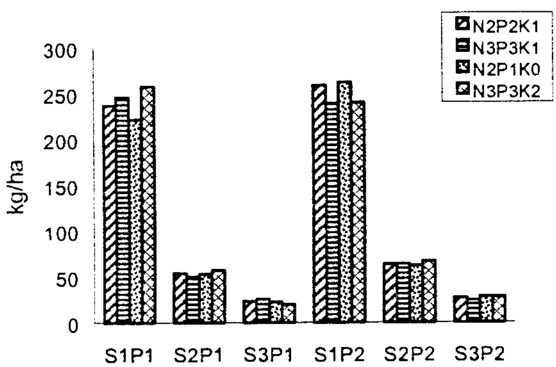
#### 3.2.1.1. Bole wood

The nutrients *viz.* N, P and K contents in the bole wood fraction (kg/ha) are given in Figures 2- 4. Bole wood N, P and K contents were highest in 1 m x 1 m and lowest in 3 m x 3 m spacing, irrespective of pit sizes. Between the two pit sizes, trees in 40 cm x 40 cm x 40 cm registered higher values for N, P and K contents.

Among the different nutrient combinations, in general, $N_2P_2K_1$ treatment had lower values for N, P and K. The treatment $N_3P_3K_2$ had relatively higher values for N while P and K contents were higher in $N_2P_1K_0$.

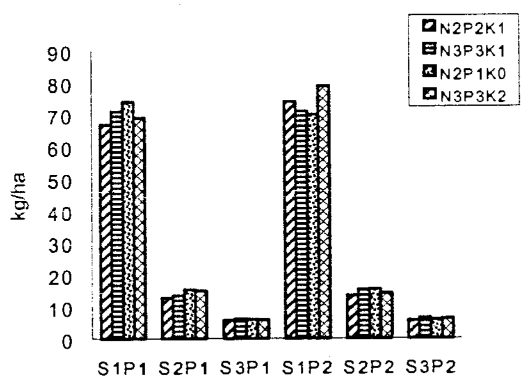
### 3. 2. 1. 2. Branches

Nitrogen, P and K contents in the branches (kg/ha) were highest in 1 m x 1 m spacing and lowest in 3 m x 3 m spacing, irrespective of pit sizes (Figs. 5 - 7). The trees in 40 cm x 40 cm x 40 cm pit size registered higher values for N and P while K contents were higher in 30 cm x 30 cm x 30 cm pit size. In the nutrient combinations, trees in $N_3P_3K_2$ had the highest N and K contents and for P, there was no trend.




S1P1 – 1 m x 1 m 30 cm x 30 cm x 30 cm
S1P2 – 1 m x 1 m 40 cm x 40 cm x 40 cm
S2P1 – 2 m x 2 m 30 cm x 30 cm x 30 cm
S2P2 – 2 m x 2 m 40 cm x 40 cm x 40 cm
S3P1 – 3 m x 3 m 30 cm x 30 cm x 30 cm
S3P2 – 3 m x 3 m 40 cm x 40 cm x 40 cm

Fig. 2. Nitrogen contents (kg/ha) in the bole wood

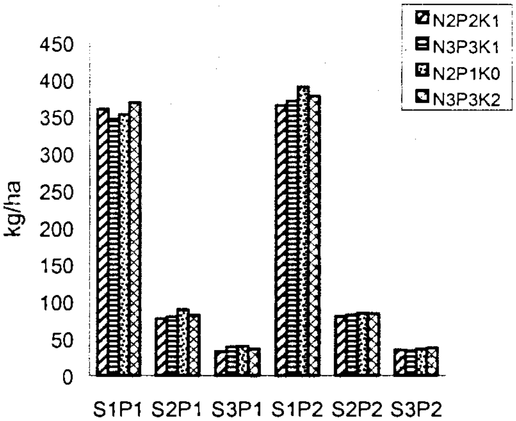



S1P1 – 1 m x 1 m 30 cm x 30 cm x 30 cm
S1P2 – 1 m x 1 m 40 cm x 40 cm x 40 cm
$S2P_1$ – 2 m x 2 m 30 cm x 30 cm x 30 cm
S2P2 – 2 m x 2 m 40 cm x 40 cm x 40 cm
$S3P_1$ – 3 m x 3 m 30 cm x 30 cm x 30 cm
S3P2 – 3 m x 3 m 40 cm x 40 cm x 40 cm

Fig.3. Phosphorus contents (kg/ha) in the bole wood

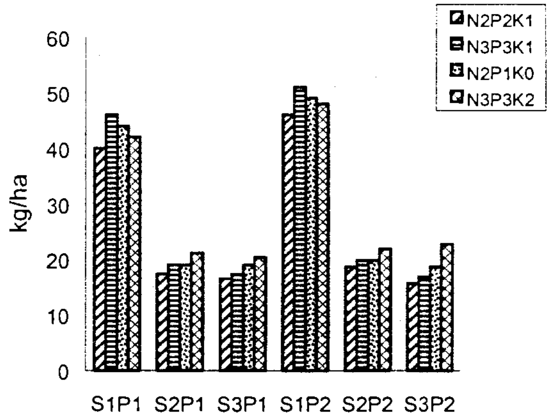
### 3. 2. 1. 3. Leaves

Nitrogen, P and K contents in leaves (kg/ha) were highest in 1 m x 1 m spacing and *vice versa* in 3 m x 3 m x 3 m spacing. Among the pit sizes, trees in 40 cm x 40 cm x 40 cm had relatively higher N and P contents while for K, no definite pattern was observed (Figs. 8-10). With respect to nutrient combinations, trees in $N_3P_3K_2$ had the highest N, P and K contents.



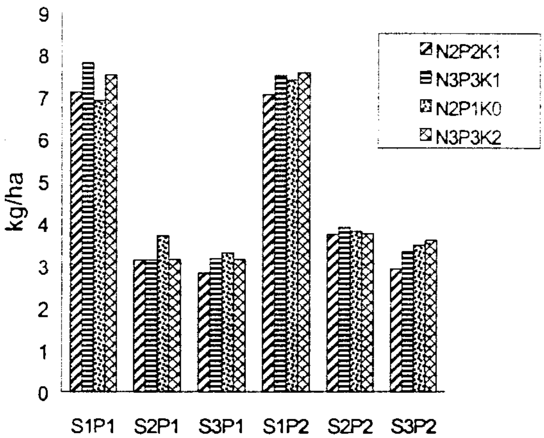

S1P1 – 1 m x 1 m 30 cm x 30 cm x 30 cm
S1P2 – 1 m x 1 m 40 cm x 40 cm x 40 cm
S2P1 – 2 m x 2 m 30 cm x 30 cm x 30 cm
S2P2 – 2 m x 2 m 40 cm x 40 cm x 40 cm
S3P1 – 3 m x 3 m 30 cm x 30 cm x 30 cm
S3P2 – 3 m x 3 m 40 cm x 40 cm x 40 cm

Fig. 4. Potassium contents (kg/ha) in the bole wood



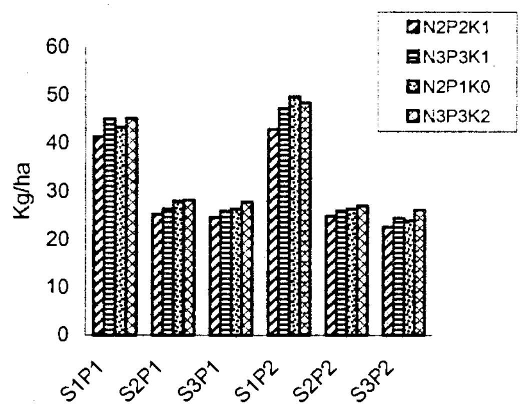

S1P1 – 1 m x 1 m 30 cm x 30 cm x 30 cm
S1P2 – 1 m x 1 m 40 cm x 40 cm x 40 cm
$S2P_1$ – 2 m x 2 m 30 cm x 30 cm x 30 cm
S2P2 – 2 m x 2 m 40 cm x 40 cm x 40 cm
$S3P_1$ – 3 m x 3 m 30 cm x 30 cm x 30 cm
S3P2 – 3 m x 3 m 40 cm x 40 cm x 40 cm

Fig. 5. Nitrogen contents (kg/ha) in the branches



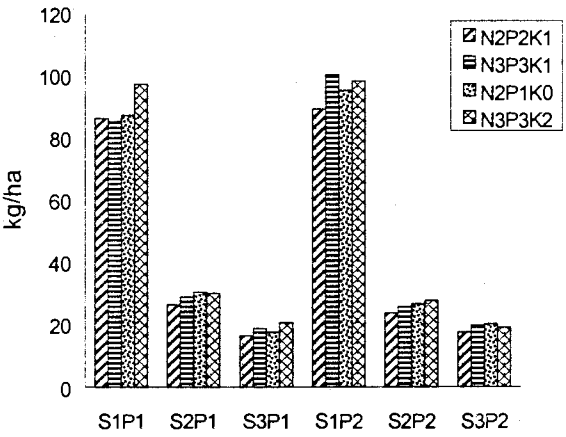

S1P1 – 1 m x 1 m 30 cm x 30 cm x 30 cm
S1P2 – 1 m x 1 m 40 cm x 40 cm x 40 cm
S2P1 – 2 m x 2 m 30 cm x 30 cm x 30 cm
S2P2 – 2 m x 2 m 40 cm x 40 cm x 40 cm
S3P1 – 3 m x 3 m 30 cm x 30 cm x 30 cm
S3P2 – 3 m x 3 m 40 cm x 40 cm x 40 cm

Fig. 6. Phosphorus contents (kg/ha) in the branches



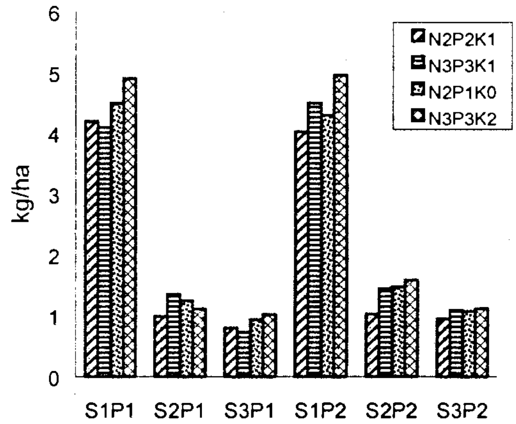

S1P2 – 1 m x 1 m 40 cm x 40 cm x 40 cm
$S2P_1$ – 2 m x 2 m 30 cm x 30 cm x 30 cm
S2P2 – 2 m x 2 m 40 cm x 40 cm x 40 cm
$S3P_1$ – 3 m x 3 m 30 cm x 30 cm x 30 cm
S3P2 – 3 m x 3 m 40 cm x 40 cm x 40 cm

Fig. 7. Potassium contents (kg/ha) in the branches



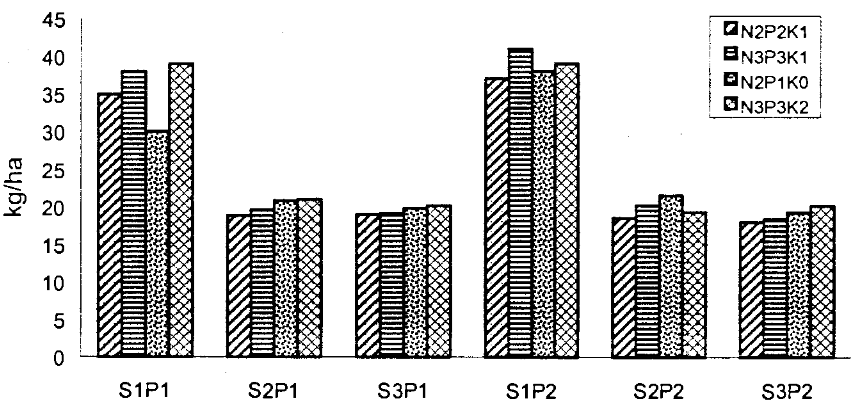

S1P1 – 1 m x 1 m 30 cm x 30 cm x 30 cm
S1P2 – 1 m x 1 m 40 cm x 40 cm x 40 cm
S2P1 – 2 m x 2 m 30 cm x 30 cm x 30 cm
S2P2 – 2 m x 2 m 40 cm x 40 cm x 40 cm
S3P1 – 3 m x 3 m 30 cm x 30 cm x 30 cm
S3P2 – 3 m x 3 m 40 cm x 40 cm x 40 cm

Fig. 8. Nitrogen contents (kg/ha) in the leaves




S1P1 – 1 m x 1 m 30 cm x 30 cm x 30 cm
S1P2 – 1 m x 1 m 40 cm x 40 cm x 40 cm
S2P1 – 2 m x 2 m 30 cm x 30 cm x 30 cm
S2P2 – 2 m x 2 m 40 cm x 40 cm x 40 cm
S3P1 – 3 m x 3 m 30 cm x 30 cm x 30 cm
S3P2 – 3 m x 3 m 40 cm x 40 cm x 40 cm

Fig. 9. Phosphorus contents (kg/ha) in the leaves

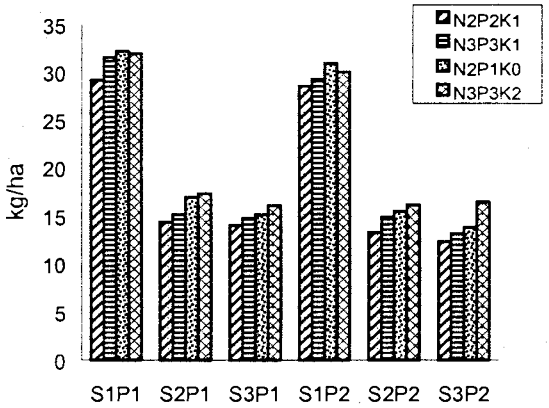



S1P1 – 1 m x 1 m 30 cm x 30 cm x 30 cm
S1P2 – 1 m x 1 m 40 cm x 40 cm x 40 cm
S2P1 – 2 m x 2 m 30 cm x 30 cm x 30 cm
S2P2 – 2 m x 2 m 40 cm x 40 cm x 40 cm
S3P1 – 3 m x 3 m 30 cm x 30 cm x 30 cm
S3P2 – 3 m x 3 m 40 cm x 40 cm x 40 cm

Fig. 10. Potassium contents (kg/ha) in the leaves

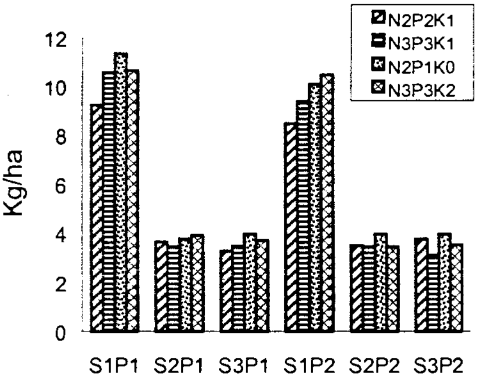
### 3.2.1.4. Bark

In the bark portion, it was found that trees in 1 m x 1 m spacing had the highest N, P and K contents (Figs. 11-13). This was followed by those in 2 m x 2 m and the lowest was in 3 m x 3 m spacing. The N and K contents were relatively higher in the 30 cm x 30 cm x 30 cm pit size whereas no trend was seen for P. Trees in $N_3P_3K_2$ combination had the highest N, P and K contents.



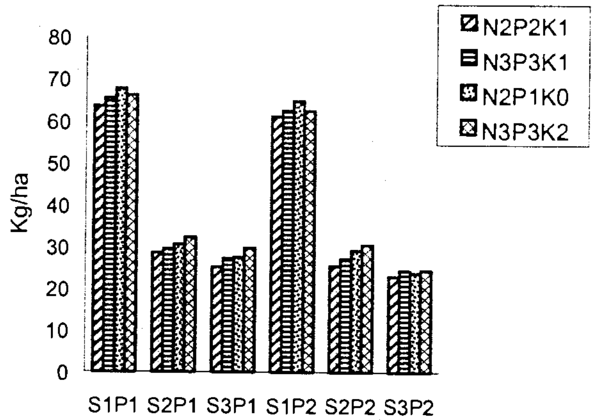

S1P1 – 1 m x 1 m 30 cm x 30 cm x 30 cm
S1P2 – 1 m x 1 m 40 cm x 40 cm x 40 cm
S2P1 – 2 m x 2 m 30 cm x 30 cm x 30 cm
S2P2 – 2 m x 2 m 40 cm x 40 cm x 40 cm
S3P1 – 3 m x 3 m 30 cm x 30 cm x 30 cm
S3P2 – 3 m x 3 m 40 cm x 40 cm x 40 cm

Fig. 11. Nitrogen contents (kg/ha) in the bark




S1P1 – 1 m x 1 m 30 cm x 30 cm x 30 cm
S1P2 – 1 m x 1 m 40 cm x 40 cm x 40 cm
S2P1 – 2 m x 2 m 30 cm x 30 cm x 30 cm
S2P2 – 2 m x 2 m 40 cm x 40 cm x 40 cm
S3P1 – 3 m x 3 m 30 cm x 30 cm x 30 cm
S3P2 – 3 m x 3 m 40 cm x 40 cm x 40 cm

Fig. 12. Phosphorus contents (kg/ha) in the bark




S1P1 – 1 m x 1 m 30 cm x 30 cm x 30 cm
S1P2 – 1 m x 1 m 40 cm x 40 cm x 40 cm
S2P1 – 2 m x 2 m 30 cm x 30 cm x 30 cm
S2P2 – 2 m x 2 m 40 cm x 40 cm x 40 cm
S3P1 – 3 m x 3 m 30 cm x 30 cm x 30 cm
S3P2 – 3 m x 3 m 40 cm x 40 cm x 40 cm

Fig. 13. Potassium contents (kg/ha) in the bark

It could thus be seen that the total quantity of nutrients in the best nutrient combination per ha in the bole wood was highest in 1 m x 1 m spacing (680.00 kg) and lowest in 3 m x 3 m spacing (64.02 kg). In other words, it was more than 10 times in 1 m x 1 m spacing (Table 11).

Table 11. Nutrients (N, P and K) (kg/ha) in the bole wood in different spacing in the best nutrient combination

| Spacing | Nutrients (kg/ha) | | | |
|---|---|---|---|---|
| | Nitrogen | Phosphorus | Potassium | Total |
| 1 m x 1 m | 248.00 | 70.50 | 361.50 | 680.00 |
| 2 m x 2 m | 58.85 | 13.10 | 78.05 | 150.00 |
| 3 m x 3 m | 25.05 | 5.70 | 33.27 | 64.02 |

In the branches, the total quantity of nutrients per ha was 92.21 kg in 1 m x 1 m spacing and 43.44 kg in 3 m x 3 m spacing whereas in the leaves, it was 127.62 kg in 1 m x 1 m spacing and 36.21 kg in the 3 m x 3 m spacing (Tables 12-13).

Table 12. Nutrients (N, P and K) (kg/ha) in the branches in different spacing in the best nutrient combination

| Spacing | Nutrients (kg/ha) | | | |
|---|---|---|---|---|
| | Nitrogen | Phosphorus | Potassium | Total |
| 1 m x 1 m | 43.00 | 7.07 | 42.14 | 92.21 |
| 2 m x 2 m | 18.03 | 3.42 | 25.04 | 46.49 |
| 3 m x 3 m | 17.00 | 2.87 | 23.57 | 43.44 |

Table 13. Nutrients (N, P and K) (kg/ha) in the leaves in different spacing in the best nutrient combination

| Spacing | Nutrients (kg/ha) | | | |
|---|---|---|---|---|
| | Nitrogen | Phosphorus | Potassium | Total |
| 1 m x 1m | 87.50 | 4.12 | 36.00 | 127.62 |
| 2 m x 2 m | 24.88 | 1.01 | 18.63 | 44.52 |
| 3 m x 3 m | 16.90 | 0.88 | 18.43 | 36.21 |

The bark portion contained 99.97 kg in 1m x 1m spacing and 40.64 kg in 3 m x 3 m spacing (Table 14). The total quantity of nutrients in bark and branches was more than two times in 1 m x 1 m spacing.

Table 14. Nutrients (N, P and K) (kg/ha) in the bark in different spacing in the best nutrient combination

| Spacing | Nutrients (kg/ha) | | | |
|---|---|---|---|---|
| | Nitrogen | Phosphorus | Potassium | Total |
| 1 m x 1 m | 28.84 | 8.83 | 62.30 | 99.97 |
| 2 m x 2 m | 13.78 | 3.57 | 26.96 | 44.31 |
| 3 m x 3 m | 13.12 | 3.51 | 24.01 | 40.64 |

*Eucalyptus tereticornis* has very fast rate of growth. It has been noted that within a span of 34 months, the height of the trees increased from 27- 28 cm to 543 – 881 cm (Table 3). This shows that the increase varied from 18 to 30 times over a period of 34 months. The maximum height was found in 3 m x 3 m spacing and 30 cm x 30 cm x 30 cm pit size. In other words, wider spacing had higher values for height. In the 1 m x 1 m spacing, the height variation was very much and some of the smaller trees started to show stunted growth. There was no general trend with respect to the effect of pit size on height of trees. In the case of spacing, it was observed that trees in 3 m x 3 m had maximum height when compared with other spacing.

The gbh of trees varied from 5.28 – 11.39 cm to 20.55 – 26.55 cm over a period of 22 months *i.e.*, from 12 to 34 months. The maximum gbh was recorded in 3 m x 3 m spacing and 30 cm x 30 cm x 30 cm pit size. Similar to height, gbh also registered higher values in wider spacing. In the 1 m x 1 m spacing, the gbh variation was very much while in the wider spacing, the gbh values were very close. The gbh values increased from 1.33 to 2.99 times within a period of 22 months. The maximum increase was found in 1 m x 1 m spacing and 30 cm x 30 cm x 30 cm pit size. In the wider spacing, initial gbh was relatively higher than that in close spacing and so the increase was not as prominent as seen.

There was considerable difference in the volume of trees in different spacing while in the two pit sizes, there was not much difference. The volume per tree in 3 m x 3 m spacing was three times more than that in 1 m x 1 m spacing and more than one and half times in 2 m x 2 m spacing (Table 7). When the volume per ha is considered, the trend is just opposite. It was three times more in 1 m x 1 m spacing and two times more in 2 m x 2 m spacing when compared with 3 m x 3 m spacing.

The bark content was considerably higher in 1 m x 1 m spacing, 41% when compared to 19% in 3 m x 3 m spacing and 28% in 2 m x 2 m spacing. This showed that there was an increase of 22% in the volume of wood in 3 m x 3 m spacing and 13% in 2 m x 2 m spacing.

In the four nutrient combinations, the height increased from 27.66 cm to 901.19 cm within a period of 34 months. The maximum height was recorded in $N_2P_2K_1$ treatment.

The height varied from 17 to 31 times in the different nutrient combinations. The maximum increase, 31 times, was in $N_2P_2K_1$ treatment and the least in $N_3P_3K_2$ treatment.

The gbh values of trees showed a variation from 3.04 cm to 27.42 cm. The lowest value at the $12^{th}$ month was in $N_3P_3K_2$ treatment so also in the $34^{th}$ month and *vice versa* in $N_2P_2K_1$ treatment. The increment in gbh values showed different trends. It varied from 1.07 cm in $N_2P_2K_1$ treatment to 5.46 cm in $N_3P_3K_2$ treatment. The very high increment in $N_3P_3K_2$ treatment was due to the fact that the initial value was very low in this treatment and the tree could acquire about two-third of the gbh of other treatments.

The volume of trees was lowest in $N_3P_3K_2$treatment (31.92 $m^3$/ha) and highest in $N_2P_2K_1$ treatment (93.53 $m^3$/ha). Had the nutrients been added in June 1999, there would have been considerable difference in height, gbh and hence volume of trees.

The total quantity of nutrients per hectare in the bole wood, bark and branches was 872.18 kg in 1 m x 1 m spacing and 148.10 kg in 3 m x 3 m spacing *i.e.* about six times in 1 m x 1 m spacing.

Thus when the bole wood, bark and branches are removed from the site in 1 m x 1 m and 3 m x 3 m spacing, about six times of nutrients will be removed more from the site where 1 m x 1 m spacing is followed. The yield/ha under bark is 54.70 $m^3$ in 1 m x 1m spacing and 18.98 $m^3$ in 3 m x 3 m spacing *i.e.*, about three times.

The cost of NPK mixture of 17:17:17 is Rs.425/- per 50 kg bag and it will require about Rs.14,535/- per ha in order to compensate for the nutrients removed from the 1 m x 1 m spacing site. This is only with respect to the cost of nutrients. The other factors *viz.*, water requirement, soil compaction, environmental hazards, etc. have not been considered here. Moreover, in close spacing, whether the stand density of 10,000 trees per ha will be the same at the end of the rotation is also a question while in wider spacing, such a question will not arise. Here at the end of the study (34 months), the number of trees got reduced from 10,000 to 9111, in addition to some of the trees which showed stunted growth, the fate of which will have to be viewed.

Spacing is an integral part of short rotation, high yield plantations. Spacing practice is strongly controlled by market forces. While competition for moisture, nutrients and light are physical determinants, the market for the product is also an essential component in selecting tree spacing since spacing markedly influences diameter and, under certain market situation, financial yield.

In the present study, spacing has affected the yield. This is in contrary to Zohar (1989) who noted in a trial of 4 year old *E. camaldulensis* in Israel under high soil water and temperature conditions, that high density stocking had no effect on biomass production when the stocking varied from 1,670 to 3,300 per hectare. In Nepal, in a seasonally dry monsoon climate, a stocking of 1,000-1,667/ha also had no effect on wood production (White, 1988). Spacing trials at Dongmen, China, indicated that 1,000-2,000 trees per hectare is required for optimum production of *E. camaldulensis* and *E. grandis* (Mo Quiping and Mannion, 1989). In the present study, the variation was from 1111 to 10,000 trees/ha, which is about 9 times and has considerable effect on the volume of trees on the one hand and removal of nutrients on the other hand.

The quantity of nutrients, N, P and K when partitioned into bole wood, bark, leaves and branches, it could be seen that bole wood retained most of them. In the case of N, bole wood had one and half times of that in leaves, branches and bark put together in the 1m x 1 m spacing. In the 2 m x 2 m spacing, bole wood N more or less equalled to those in leaves, branches and bark put together while in the 3 m x 3 m spacing, bole wood N was half of those in leaves, branches and bark put together.

The P content in the bole wood was more than three times in the 1 m x 1 m while that in 2 m x 2 m spacing was half of those in leaves, branches and bark put together. In the 3 m x 3 m spacing, it was more or less equal to those in leaves, branches and bark put together. The K accumulation in the bole wood in 1 m x 1m spacing was two and half times of those in leaves, branches and bark put together. In the 2 m x 2 m and 3 m x 3 m spacing, the contents were close and half of those in leaves, branches and bark put together, respectively.

The bole wood had 68, 53 and 35%, bark contained 10, 16 and 22%, branches constituted 9, 16 and 24% while leaves accounted for 13, 15 and 19% of the total tree nutrients in the 1 m x 1 m, 2 m x 2 m and 3 m x 3 m spacing, respectively. Out of the total nutrients, there was considerable quantity of total nutrients in the bole wood in 1 m x 1 m spacing (680 kg/ha out of 999.80 kg/ha) while in the 3m x 3m spacing, the bole wood had 64.02 kg/ha out of 184.31 kg/ha. Thus by removing the bole wood alone, a major portion of the stores of nutrients in the above ground biomass is removed.

In firewood - scarce regions, like in Kerala, except for the roots below ground level, nothing else is left behind. In such a system, there is bound to be a loss of nutrients. If branches, leaves and bark are left *in situ*, the natural inputs build up the nutrient chain sufficiently to maintain the site productivity. Out of the total quantity of branches, quite a large amount will be taken away from the site for fuel wood. Only twigs and very small branches will be left in the site.

A substantial proportion of the nutrients in a tree crop is returned periodically to the soil through foliage. This nutrient turnover is responsible for improvement of soil fertility by plantations. Maintenance of the nutrient cycle is critical to the long- term productivity of soils and it is essential that foliage and leaf litter are not removed from the site. Even greater benefits accrue if bark is also left behind. Thus if leaves are retained in the site, considerable amount of N, P and K will be added into the soil through their decomposition.

This shows that eucalypts adversely affect soil fertility, if bark and branches along with bole wood in close spacing are removed from the site. Early eucalypt plantation growth involves a nutrient uptake and use greater than in older stands. As the trees age, nutrient distribution occurs with the efficient withdrawal of nutrients as tissue converts to heartwood, in this way nutrient applications as nutrient are long effective.

## 4. CONCLUSIONS

The study revealed that

1. height, gbh and volume per hectare of *Eucalyptus tereticornis* were found to be influenced significantly by six silvicultural treatments involving three levels of spacing (1 m x 1 m, 2 m x 2 m and 3 m x 3 m) and two levels of pit sizes (30 cm x 30 cm x 30 cm and 40 cm x 40 cm x 40 cm) and four nutrient combinations involving two levels of N, three levels of P and three levels of K ($N_2P_2K_1$, $N_3P_2K_1$, $N_2P_1K_0$ and $N_3P_3K_2$).

2. among the six silvicultural treatments, 3 m x 3 m spacing with 30 cm x 30 cm x 30 cm pit size was found to differ significantly from all the other treatments with regard to growth parameters height, gbh and volume/tree.

3. among the various nutrient combinations, $N_2P_2K_1$ *i.e.,* application of 30 g of nitrogen, 30 g of phosphorus and 15 g of potassium (65 g Urea, 150 g Mussorie rock phosphate and 29 g Muriate of potash ) per tree in the first year was found to be the best. This is equal to 72.215 kg of urea, 166.650 kg Mussorie rock phosphate and 32.219 kg of Muriate of potash per ha for 1,111 plants.

4. the quantity of nutrients in bole wood, leaves, bark and branches varied and depended on the spacing. The bole wood had 68, 53 and 35%, bark contained 10, 16 and 22%, branches constituted 9, 16 and 24% while leaves accounted for 13, 15 and 19% of the total tree nutrients in the 1 m x 1m, 2 m x 2 m and 3 m x 3 m spacing, respectively. Bole wood retained 680 kg/ha out of 999.80 kg/ha in 1m x 1m spacing; 150.00 kg/ha out of 285.32 kg/ha in 2 m x 2 m spacing; 64.02 kg/ha out of 184.31 kg/ha in 3 m x 3 m spacing. Thus by removing the bole wood alone, a major portion of the stores of nutrients in the above ground biomass is removed.

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