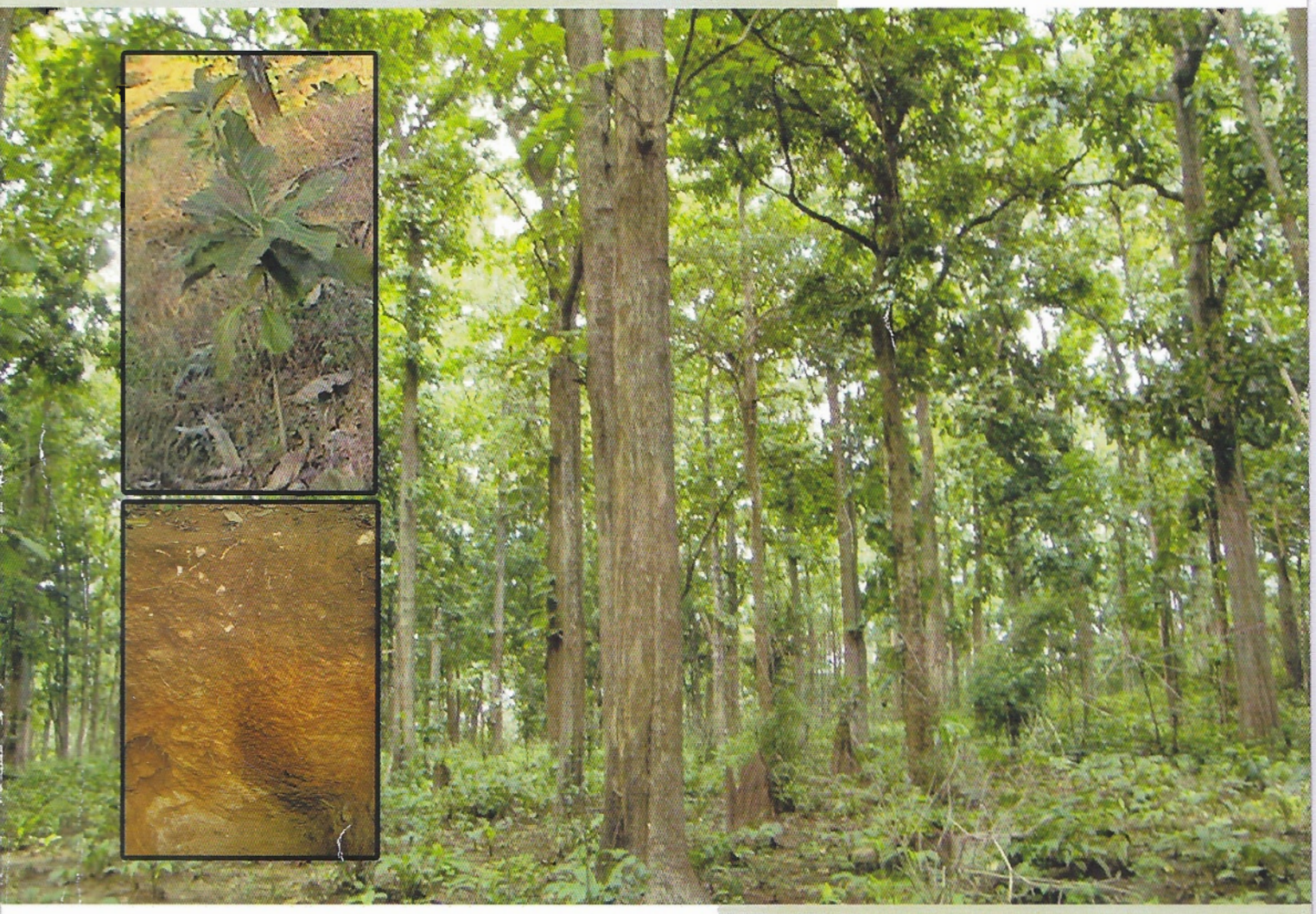
KFRI Research Report 425

ISSN 0970-8103

Protocol for residual nutrients in the soil



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May 2012

PROJECT PROPOSAL

1. Code	: KFRI 394/03
2. Title	: Protocol for residual nutrients in the soil
3. Objectives	: Find out the status of nutrients in the soil at different periods after the application in different year teak plantations
	: Develop a protocol for evaluation of residual nutrients in the soil
4. Date of commencement	: April 2003
5. Date of completion	: December 2005
6. Funding agency	: Plan Fund
7. Investigators	
Principal Investigator	: M. Balagopalan
Associate Investigator	: P. Rugmini

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ACKNOWLEDGEMENTS

We have great pleasure to record our deep gratitude to Dr. J. K. Sharma, Former Director for suggesting this concept and for providing necessary fund for this project. We are extremely indebted to him for the encouragement and valuable suggestions at different stages of the project. The Staff at Pariyaram and Vellikkulangara Forest Ranges, Kerala Forest Department greatly helped for field work and we are highly thankful to them. We express our sincere thanks to Dr. (Mrs.) T. Geetha, Research Fellow for her earnest help in the field and laboratory without which this project would not have accomplished. We are also very grateful to Dr. K. V. Sankaran, Director for the kind support for publication of the Report.

ABSTRACT

Prolonged application of fertilizers beyond requirement of crop and natural occurrence of high levels of plant nutrients in soils can lead to high residual soil fertility. Knowing the residual fertility level of soil is important to determine if fertilizers are necessary for economically optimum crop production. The present study was undertaken to find out the status of nutrients in soil at different periods after application in teak plantations and to develop a protocol for evaluation of residual nutrients in the soil.

The study was carried out in the teak plantations established in the years 2002 and 2003 at Pariyaram and Vellikkulangara Forest Ranges in the Chalakkudy Forest Division with root trainer seedlings and stumps. In each range, 24 blocks, each of 75m x 15m were demarcated of which 12 blocks each were for root trainer seedlings and stumps. The experiment was laid out in a complete randomized block design with five fertilizer treatments. The fertilizer treatment was the one prescribed by KFRI *viz.,* 30g each of N, P, K, Ca and Mg per plant during the first year and double the dose during the second and third years. The different fertilizer treatments selected for the study were Control (T0), Full dose of fertilizers (T1), 75% of full dose of fertilizers (T2), 50% of full dose of fertilizers (T3) and 25% of full dose of fertilizers (T4).

The soil samples from the experimental sites were analysed for general characteristics and initial N, P, K, Ca and Mg status. The soils at Vellikkulangara range were medium acid in all layers and sandy loam in the surface and loam in deeper layers. The organic carbon and total N as well as available P, K, Ca and Mg contents were low. At Pariyaram range,

the soils were medium acid in all layers and loamy sand in the surface and loam in deeper layers. The organic carbon and total N as well as available P, K, Ca and Mg contents were also low.

In both the locations, the effect due to treatment, period and the interaction between period and treatment turned out to be highly significant with regard to height in root trainer seedlings as well as stumps. The interaction between period and treatment was highly significant, indicating that the treatments differed in their height growth pattern across time. Pair wise comparison between treatments at each period showed that the nutrient treatment recommended by KFRI differed significantly from all the other treatments.

The total N, and available P, K, Ca and Mg contents at the time of application of fertilizers and during three months of application revealed that there was an increase in the nutrient status which gradually decreased and approached close to the initial levels after three months at Vellikulangara range. The same pattern was observed at Pariyaram range. However, the P levels remained same during the second and third months of application of fertilizers. The persistence of the fertilizers in the soils revealed that within three months time, most of them were either degraded, adsorbed or leached. The etiquette for residual nutrients as well as the effect of nutrients on growth revealed that the recommendation of 30g each of N, P, K. Ca and Mg in the first year and double the dose in the second and third years and rather than applying the whole dosage in single application, it would be prudent to apply in two or three split doses. Though economically and administratively unwieldy, from the scientific angle, this practice is highly beneficial.

1. INTRODUCTION

Many materials can be applied to soil as sources of plant nutrients, but the term fertilizer is often used to refer to relatively soluble nutrient sources with a high analysis or concentration (Bierman and Rosen, 2005). Chemical fertilizing is a method of directly supplying the elements such as Nitrogen, Phosphorus and Potassium, which are essential to plant growth and development. Chemical fertilizing simply bypasses the process by which matter breaks down from an organic state to a mineral one (Singh and Singh, 2001). Application of chemical fertilizers constitutes a practice to correct the deficiencies of nutrient elements. The case of significant increase in fertilizer consumption and increase in crop production is obvious from several studies carried out so far. However, the main problem is deciding on the optimum dosage and applications since the fertilizer costs are quite high.

Commercially available fertilizers supply essential elements in a variety of chemical forms, but many are relatively simple inorganic salts. Advantages of commercial fertilizers are their high water solubility, immediate availability to plants, high concentration and the uniformity and accuracy with which specific amounts can be applied. Because they are relatively homogeneous compounds of fixed and known composition, it is fairly easy to calculate precise application rates and attain relatively consistent performance. This is in contrast to organic nutrient sources, which are a much greater challange to manage, because of their variable composition, variable nutrient availability, and patterns of nutrient release that are greatly affected by temperature, moisture, and other conditions that alter biological activity.

Mindless use of chemical fertilizers is harmful for soil and biodiversity. This is a global scenario. Craving for highest income is the main cause for this burning problem. The negative consequences of this universal problem are soil pollution and biodiversity destruction. In intensive agriculture, soil often gets sickness due to continuous use of chemical fertilizers (Nottidge *et al.*, 2005).

The solubility of commercial fertilizers can sometimes be a problem, because soluble nutrients may move out of fields when applied in excess or when large rains occur soon after fertilizer application. Chemical fertilizers, especially nitrogen and phosphorus are a serious form of pollution, as the excess leaches into lakes, rivers and the water table. Chemical reactions transform the nitrogen into nitrites and nitrates that are wreaking havoc with natural ecosystems. Soluble nutrients can be lost by leaching on well-drained soils and through runoff on poorly drained soils. Denitrification can cause large losses of nitrate-N from water-saturated soils.

Continuous application of fertilizers beyond crop needs and naturally high levels of plant nutrients in soils can lead to residual soil fertility. Low phosphorus levels are often found on unfertilized soils formed from low phosphate parent materials.

Increasing soil cation exchange capacity by increasing organic matter reduces the movement and loss of some nutrients, although not nitrate-N. Management practices that synchronize nutrient availability with crop demand and uptake also minimize losses. Both application timing and the amount of fertilizer

applied are important. Splitting fertilizer application into several small applications, rather than a single, large one, is especially important to limit N leaching on sandy, well-drained soils. Split N applications can also reduce N losses in runoff or from denitrification on poorly drained soils. Excess nutrient applications can be eliminated or at least significantly reduced by soil testing on a regular basis, setting realistic yield goals and fertilizing accordingly, accounting for all nutrient sources and using plant analysis as a monitoring tool for the fertilizer program (Bierman and Rosen, 2005). In any case, knowing the residual fertility level of soil is important to determine if fertilizers are necessary for economically optimum crop production. Residual soil fertility is commonly defined as the amount of nutrient reported in the soil test plus some variable amount expected to become available during the crop season from organic, exchangeable and slowly soluble forms. The residual forms are reservoirs which can replenish the plant available

form during the growing season, as plant uptake removes nutrients from the soil solution. A high residual level can occur due to prolonged application of fertilizers beyond crop needs and naturally high levels of plant nutrients in soils. Residual soil fertility can be low due to prolonged cropping without adequate fertilization and naturally low levels of plant nutrients in soils.

Studies relating to soil nutrient management in forest soils are rather a recent trend(Balagopalan *et al.*,1998; Gupta and Prasad, 1994; Gupta *et al.*, 2006; Rashmi and Singh, 2008; Singh and Bhatnagar, 2002 and Singh and Srivastava, 2005). But studies on nutrient residues from the applied fertilizers in forest soils

are practically absent, unlike for agricultural soils (Durgadevi, 2002). This is because forest crops are long rotation ones and the high input management has been practiced only recently. In any case, knowing the residual fertility level of soil is important to determine if fertilizers are necessary for economically optimum crop production. It is in this context, this project was undertaken in order to find out the status of nutrients in the soil at different periods after the application in different years in teak plantations and to develop a protocol for evaluation of residual nutrients in the soil.

2. MATERIALS AND METHODS

2.1. Study area

The study was carried out in the teak plantations at Pariyaram and Vellikkulangara Forest Ranges in the Chalakkudy Forest Division. Teak plantations established in the years 2002 and 2003 at Pariyaram and Vellikkulangara Forest Ranges with root trainer seedlings and stumps were selected. The terrain was flat to gently undulating and elevation was 170m msl. The plantations were in second rotation stage. The teak plantations under first rotation were clearfelled in 2002 and 2001, respectively. After clearfelling, slash burning was done.

2.2. Design of the experiment

In plantations with root trainer seedlings and stumps in each range, blocks of 75m x 15m were demarcated and such 24 blocks were selected in each range for the

study. The blocks were selected in such a way that there was a gap of 2.5m between blocks. This was done in order to minimize the leaching effect of fertilizers from one block to another. Among the 24 blocks, equal number of blocks was laid out for root trainer seedlings and stump planted locations. Each block was subdivided into five plots, each of 15m x 15m size. The spacing for root trainer seedlings and stumps was 2.5m x 2.5m. As such, there were 36 root trainer seedlings and stumps in each plot. As there were 24 blocks in each range, twelve blocks each were with root trainer seedlings and stumps. In plantations with root trainer seedlings and stumps in each range, the experiment was laid out in a complete randomized block design with 5 fertilizer treatments replicated 12 times.

2.3. Fertiliser treatments

The fertilizer treatment was the one prescribed by KFRI *viz,*. 30g each of N, P, K, Ca and Mg per plant during the first year and double the dose during the second and third years (Balagopalan *et al.*, 1998). As the teak plantations at Pariyaram were established in the year 2002 and were in the second year, the dose applied was double the one prescribed for first year i.e. 60g each of N, P, K, Ca and Mg per plant. The different fertilizer treatment selected for the study were

1. Control (T0)
2. Full dose of fertilizers (T1)
3. 75% of full dose of fertilizers (T2)
4. 50% of full dose of fertilizers (T3)
5. 25% of full dose of fertilizers (T4)

The fertilizers, Urea for N, Mussorie Rock Phosphate for P, Muriate of Potash for K, Lime for Ca and Magnesium Sulphate for Mg were used for the study. The fertilizers were added in a furrow10cm away around the plant, 5-10cm deep and then filled with the soil. Unlike in agriculture where broadcast application is practiced, here spot application around the plants was followed with different dosage of fertilizers.

2.4. Method of application

The first application of fertilizers was done in June 2003 after carrying out soil working and weeding. Second application of fertilizers was carried out in October 2003. During the year 2004, first application of fertilizers with double the dose of that applied in the first year was done in June 2004 in a furrow 20cm away, 0-10cm deep and then filled with soil, after soil working and weeding. As there was no north-east monsoon in 2004, second time of application in October 2004 was not done.

2.5. Sampling pattern

In order to find out the initial N, P, K, Ca and Mg status as well as general soil characteristics, soil pits were dug in 2002 and 2003 plantations. One soil pit was dug upto a depth of 60cm in the centre of 75m x 15m of first, sixth, 12^{th}, 18^{th} and 24^{th} blocks of Vellikkulangara and Pariyaram ranges and samples collected from 0-20, 20-40 and 40-60cm layers. Three surface samples (0-20cm) were also collected from each plot of 15m x 15m and pooled into one composite sample.

Altogether, samples from 0-20, 20-40 and 40-60cm layers were taken from 10 blocks of 75m x 15m size and surface samples from 240 plots of 15m x 15m. As such there were 270 soil samples collected and these samples were processed and analysed for general characteristics and initial N, P, K, Ca and Mg status. The physical and chemical characteristics of soils at Vellikkulangara and Pariyaram ranges are given in Tables 1 and 2.

Observations on height of the plants in each plot were recorded at yearly interval. For the purpose of statistical analysis, data from only the net plot containing 8 plants from each gross plot of 36 plants were considered. To find out the residual nutrients in the soil, soils in the net plot were selected.

At Vellikulangara range, after the initial soil sampling, soils were collected around 10cm away from the plant after one, two and three months of the first application of fertilizer in June 2003 upto a depth of 20cm. This was done on the basis of the fact that the fertilizers were applied on the surface and most of the feeding roots were concentrated in the 0-20cm layer of the soil. In this way, eight surface samples were collected from each treatment in one sub plot and pooled into one composite soil sample. The surface samples from each sub plot under each treatment were then composited into one pooled sample. As there were five treatments, five pooled surface samples were collected each for root trainer seedlings and stumps. As the sampling was done in August, September and October 2003, 30 pooled samples were collected. Soil sampling was done after
the application of fertilizers in October 2003 in the months of November

and December 2003 and January 2004 in the same way as it was done after first application. As such, there were 60 pooled soil samples for analyses for N, P, K, Ca and Mg contents.

The same procedure was followed during the year 2004 for the application of fertilizers in June 2004 and 30 pooled samples were collected. As there was no north east monsoon in the year 2004, fertilizer application in October 2004 was not done and so soil sampling was not carried out. As such, there were 90 pooled soil samples for analyses.

At Pariyaram range, soil sampling was done in the same way as that in Vellikulangara range. Hence, the pooled surface samples amounted to be 90 x 2= 180. The samples were processed and analysed for total N, and available P, K, Ca and Mg contents as per standard procedures in ASA (1965) and Jackson (1958).

The data on height obtained over three years were subjected to analysis of variance for each location and separately for root trainer seedlings and teak stumps. The height values were subjected to logarithmic transformation before subjecting to analysis of variance. Mean comparison test were also carried out using Duncan's Multiple Range test(Gomez and Gomez, 1976). The analysis of variance conformed to that of a univariate mixed model analysis.

Table 1. Physical and chemical characteristics of soils at Vellikkulangara range

Layers (cm)	Gravel %	Sand %	Silt %	Clay %	Water holding capacity %	Soil pH	Organic carbon %	Exchangeable bases me/100g	Total N ppm	P ppm	K ppm	Ca ppm	Mg ppm
0-20	28	75	11	14	42	5.9	1.86	11	1901	8	92	121	69
20-40	24	70	14	16	43	6.0	0.98	10	924	5	54	69	46
40-60	15	68	17	15	42	6.0	0.79	8	674	2	47	55	31

Table 2. Physical and chemical characteristics of soils at Pariyaram range

Layers (cm)	Gravel %	Sand %	Silt %	Clay %	Water holding capacity %	Soil pH	Organic carbon %	Exchangeable bases me/100g	Total N ppm	P ppm	K ppm	Ca ppm	Mg ppm
0-20	24	78	14	8	47	6.1	1.75	14	1812	8	88	127	65
20-40	20	72	15	13	41	6.0	0.87	9	872	4	46	61	42
40-60	17	69	17	14	40	6.0	0.64	7	621	2	39	43	30

3. RESULTS AND DISCUSSION

Analysis of variance on height of root trainer seedlings and stumps for both the locations are presented in Tables 3 and 4. The height of root trainer seedlings and stumps in June 2003, June 2004 and June 2005 are depicted in Tables 5 and 6. The status of N, P, K, Ca and Mg in soils at different periods are given in Tables 7-12.

The soils at Vellikkulangara range were medium acid in all layers and sandy loam in the surface and loam in deeper layers. The organic carbon and total N as well as available P, K, Ca and Mg contents were low. At Pariyaram range, the soils were medium acid in all layers and loamy sand in the surface and loam in deeper layers. The organic carbon and total N as well as available P, K, Ca and Mg contents were also low.

The initial mean height of root trainer seedlings at Vellikulangara varied from 40.18cm to 41.68cm which increased to 157.13cm in the control to 229.90 cm in the treatment T2 after one year of application. After two years, the height of seedlings was 214.46 in the control which increased to 314.84cm in the treatment T2. In the case of stumps, there was not much variation in initial height (20.43-20.94cm). The height varied from 106.56 cm in the control T1 to 145.48 cm in the treatment T2 and from 161.93 cm to 234.70 cm after one and two years, respectively. In the second and third years, the maximum height was recorded in T2 followed by T3, T4 and T5 and the lowest was in control, T1 for root trainer seedlings and stumps (Table 5).

At Pariyaram, the initial mean height of root trainer seedlings ranged from 133.70cm to 135.96cm which increased to 183.69cm in the control to 243.03cm in the treatment T2 after one year of application. The height of seedlings was 236.96cm in the control T1 which increased to 318.88cm in the treatment T2. With respect to stumps, the initial height ranged from 116cm to 119.92cm. The height varied from 158.06 cm in the control T1 to 220.21cm in the treatment T2 after one year. The height further increased to 181.30cm in the control T1 to 254.96 cm in the treatment T2 after two years. Similar to Vellikulangara, in the second and third years, the maximum height was recorded in T2 followed by T3, T4 and T5 and the lowest was in control, T1 for root trainer seedlings and stumps (Table 6).

In both the locations, the effect due to treatment, period and the interaction between period and treatment turned out to be highly significant with regard to height in root trainer seedlings as well as in teak stumps. The interaction between period and treatment was highly significant, indicating that the treatment differed in their height growth pattern across time. Pair wise comparison between treatments at each period showed that the nutrient treatment recommended by KFRI (Balagopalan *et al.*, 1998) differed significantly from all the other treatments (Tables 3 and 4).

Pair-wise comparison between treatments at each period showed that the treatments differed significantly ($P<0.01$) from each other during second and third years (Tables 5 and 6). The treatment T2 showed higher height growth during second and third years when compared to other ones.

The total N, and available P, K, Ca and Mg contents at the time of application of fertilizers and during the following three months of application revealed that there was an increase in the nutrient status during the first three months which gradually decreased and approached close to the initial levels after three months at Vellikulangara range (Tables 7 - 9). The same pattern was followed at Pariyaram except for available P which remained same during the second and third months of application of fertilizers (Tables 10 - 12). This fact showed that there was an increase in the nutrient level in the soil after the application of fertilizers which reached at a level close to the initial levels or slightly higher than the initial levels within three months time.

Table 3. Analysis of variance on mean height of teak root trainer seedlings and stumps over three years at Vellikulangara

Source of variation	Sum of squares	Degrees of freedom	Mean sum of squares	F- ratio
Root trainer seedlings				
Treatment	10.24	4	2.56	177.35**
Block	0.38	11	0.03	2.38*
Treatment x Block	0.63	44	0.01	
Period	934.61	2	467.31	30958.28**
Period by treatment	7.00	8	0.87	57.96**
Residual	1.66	110	0.02	
Teak stumps				
Treatment	9.58	4	2.39	372.01**
Block	0.19	11	0.02	2.70*
Treatment x Block	0.28	44	0.01	
Period	1374.54	2	687.27	84743.02**
Period by treatment	4.56	8	0.57	70.30**
Residual	0.89	110	0.01	

*,** denote significance at 5 and 1% level

Table 4. Analysis of variance on mean height of teak root trainer seedlings and stumps observed over three years at Pariyaram

Source of variation	Sum of squares	Degrees of freedom	Mean sum of squares	F- ratio
Root trainer seedlings				
Treatment	6.48	4	1.62	3039.93**
Block	.04	11	0.00	6.31**
Treatment x Block	0.02	44	0.00	
Period	118.45	2	59.23	59163.28**
Period by treatment	3.24	8	0.40	404.53**
Residual	0.11	110	0.00	
Teak stumps				
Treatment	8.80	4	2.20	746.94**
Block	0.15	11	0.01	4.75**
Treatment x Block	0.13	44	0.00	
Period	97.96	2	48.98	10204.94**
Period by treatment	4.98	8	0.62	129.67**
Residual	0.53	110	0.00	

** denote significance at 1% level

Table 5. Mean height (cm) of plants belonging to five treatments under root trainer and stumps at Vellikulangara range

Period	Treatments☼				
	T1	T2	T3	T4	T5
Root trainer seedlings					
1	41.68^{b}	40.19^{a}	40.76^{ab}	40.32^{a}	41.18^{ab}
2	157.13^{a}	229.90^{e}	209.98^{d}	190.95^{c}	173.25^{b}
3	214.46^{a}	314.84^{e}	269.30^{d}	247.14^{c}	230.94^{b}
Teak stumps					
1	20.43^{a}	20.50^{a}	20.94^{b}	20.59^{ab}	20.57^{ab}
2	106.56^{a}	145.48^{e}	133.21^{d}	122.35^{c}	114.61^{b}
3	161.93^{a}	234.70^{e}	216.96^{d}	198.74^{c}	179.80^{b}

☼ - figures superscribed by different letter in a row indicate significance

Table 6. Mean height (cm) of plants belonging to five treatments under root trainer and stumps at Pariyaram range

Period	Treatments☼				
	T1	T2	T3	T4	T5
Root trainer seedlings					
1	134.86^{ab}	134.70^{ab}	135.50^{bc}	135.96^{c}	133.70^{a}
2	183.69^{a}	243.03^{e}	227.35^{d}	213.74^{c}	198.65^{b}
3	236.96^{a}	318.88^{e}	282.75^{d}	264.99^{c}	250.31^{b}
Teak stumps					
1	117.92	116.00	116.78	116.74	117.11
2	158.06^{a}	220.21^{e}	199.50^{d}	186.08^{c}	168.42^{b}
3	181.30^{a}	254.96^{e}	235.82^{d}	217.35^{c}	197.79^{b}

☼ - figures superscribed by different letter in a row indicate significance

Table 7. Mean values of soil nutrients under different reatments after the application of fertilizers in June 2003 at Vellikulangara range

Nutrients	June 2003	After (months)		
		One	Two	Three
N %	0.19	0.24 (26)*	0.23 (21)	0.21 (11)
P ppm	8	12 (50)	11 (38)	10 (25)
K ppm	92	107 (16)	97 (5)	94 (2)
Ca ppm	121	134 (11)	130 (5)	125 (3)
Mg ppm	69	81 (17)	75 (9)	73 (6)

*Values in brackets are per cent increase

Table 8. Mean values of soil nutrients under different treatments after the application of fertilizers in October 2003 at Vellikulangara range

Nutrients	October 2003	After (months)		
		One	Two	Three
N %	0.20	0.27 (35)*	0.25 (25)	0.23 (15)
P ppm	10	16 (60)	14 (40)	13 (30)
K ppm	93	110 (18)	101 (9)	97 (4)
Ca ppm	123	139 (13)	132 (7)	128 (4)
Mg ppm	72	88 (19)	80 (11)	78 (8)

*Values in brackets are per cent increase

Table 9. Mean values of soil nutrients under different treatments after the application of fertilizers in June 2004 at Vellikulangara range

Nutrients	June 2004	After (months)		
		One	Two	Three
N %	0.21	0.29 (38)*	0.27 (29)	0.25 (19)
P ppm	11	18 (73)	16 (45)	15 (36)
K ppm	94	115 (22)	104 (11)	99 (5)
Ca ppm	122	143 (15)	135 (9)	131 (6)
Mg ppm	73	88 (23)	83 (14)	80 (10)

*Values in brackets are per cent increase

Table 10. Mean values of soil nutrients under different treatments after the application of fertilizers in June 2003 at Pariyaram range

Nutrients	Initial June 2003	After (months)		
		One	Two	Three
N %	0.18	0.22 (22)*	0.21 (17)	0.20 (11)
P ppm	8	11 (38)	10 (25)	10 (25)
K ppm	88	104 (18)	95 (8)	90 (2)
Ca ppm	127	139 (9)	134 (6)	129 (2)
Mg ppm	65	80 (23)	74 (14)	70 (8)

*Values in brackets are per cent increase

Table 11. Mean values of soil nutrients under different treatments after the application of fertilizers in October 2003 at Pariyaram range

Nutrients	Initial October 2003	After (months)		
		One	Two	Three
N %	0.19	0.25 (32)*	0.23 (21)	0.22 (16)
P ppm	10	14 (40)	13 (30)	13 (30)
K ppm	89	109 (22)	97 (13)	93 (5)
Ca ppm	128	143 (12)	138 (8)	133 (4)
Mg ppm	69	87 (26)	79 (15)	75 (9)

*Values in brackets are per cent increase

Table 12. Mean values of soil nutrients under different treatments after the application of fertilizers in June 2004 at Pariyaram range

Nutrients	Initial June 2004	After (months)		
		One	Two	Three
N %	0.21	0.29 (38)*	0.26 (24)	0.25 (19)
P ppm	12	17 (42)	16 (33)	16 (33)
K ppm	90	113 (26)	104 (16)	97 (8)
Ca ppm	130	148 (14)	142 (9)	137 (5)
Mg ppm	73	94 (29)	86 (18)	81 (11)

*Values in brackets are per cent increase

Unlike in agriculture where broadcast application is practiced, here spot application around the plant was followed with different doses of fertilizers. This shows that the quantity of fertilizers applied in agriculture is uniformly distributed while in forestry sector, the fertilizers are condensed in a small area around the plant. As such, the possibility of leaching laterally as well as vertically from the high concentrated portion is high.

It has been noticed that at Vellikulangara, N, P, K, Ca and Mg contents in the soils was high after one month of application during the first and second years which gradually decreased after two and three months (Tables 7-9). The immobile nutrients were retained for a longer period as revealed by the high per cent increase over initial level.

The N content was 26% more after one month of application in June 2003 which gradually decreased and reached a level 11% higher than the initial level after three months. The N content was 35% more than the initial level after one month of application in October 2003 and was 15% more than the initial level after three months. After the first application during the second year, 2004, the level increased to 38% over initial level after one month and was 29 and 19% over initial level after two and three months, respectively (Tables 7-9).

The P content was found to be 50% more after one month of application in June 2003 and the content gradually decreased and reached a level 25% higher than the initial level after three months of application. Due to the fertilizer application in October 2003, the P content was 60% more than the

initial level after one month which decreased and was 30% more than the initial level after three months. Following the fertilizer application in June 2004, the level increased to 73% over initial level after one month and was 45 and 36% over initial one, after two and three months, respectively (Tables 7-9).

With respect to K content, it was 16% more after one month of application in June 2003. The K level gradually decreased and reached a level 2% higher than the initial level after three months of application. Following the fertilizer application in October 2003, the K content was 18% more than the initial level after one month which decreased and was 4% more than the initial level after three months. Subsequent to the fertilizer application in June 2004, the K level increased to 22% over initial level after one month and was 11 and 5% more over the initial level, after two and three months, respectively (Tables 7-9).

The Ca content was 11% more after one month of application in June 2003 which gradually decreased and reached a level 3% higher than the initial level after three months of application. The Ca content was 13% more than the initial level after one month of application in October 2003 and was 4% more than the initial level after three months. After the first application during the second year, 2004, the level increased to 15% over initial level after one month and was 9 and 6% over initial level after two and three months, respectively (Tables 7-9).

In the case of Mg, the level increased to 17% after one month of application in June 2003 which gradually decreased and reached a level 6% higher than

the initial level after three months of application. The Mg content was 19% more than the initial level after one month subsequent to the fertilizer application in October 2003, which decreased and was 8% more than the initial level after three months. As regards the fertilizer application in June 2004, the Mg level increased to 23% over initial level after one month and was 10% more over the initial level, after three months (Tables 7-9).

At Pariyaram, the N, P, K, Ca and Mg contents in the soils was also high after one month of application during the first and second years which gradually decreased after two and three months (Tables 10-12). The immobile nutrients were retained in the soil for a longer period as revealed by the high per cent increase over initial level during second and third months.

It was found that the N content was 22% more after one month of application in June 2003. The level reached at 11% higher than the initial level after three months of application. After the second application in October 2003, the N contents was 32% more than the initial level which decreased and was 16% more than the initial level after three months. After the first application during the second year, 2004, the level increased to 38% over initial level after one month and was 29 and 19% over initial level after two and three months, respectively (Tables 10-12).

The P content was 38% more after one month of application in June 2003 and gradually decreased and reached a level 25% higher than the initial level after two and three months of application. As a result of the fertilizer application in October 2003, the P content was 40% more than the initial

level after one month which decreased and was 30% more than the initial level after two and three months. Consequent to the fertilizer application in June 2004, the level increased to 42% over initial level after one month and was 33% over initial one, after two and three months (Tables 10-12).

As regards K content, it was 18% more after one month of application in June 2003 and reached a level 2% higher than the initial level after three months of application. The K content was 22% more than the initial level following the fertilizer application in October 2003, after one month which decreased and was 5% more than the initial level after three months. Consequent to the fertilizer application in June 2004, the K level increased to 26 % over initial level after one month and was 16 and 8% more over the initial level, after two and three months, respectively (Tables 10-12).

In the case of Ca, the level increased to 9 % after one month of application in June 2003 and it reached at a level 2% higher than the initial level after three months of application. It was 12% more than the initial level after one month of application in October 2003 and was 4% more than the initial level after three months. The level increased to 14% following the application in 2004 after one month and was 5% over initial level after three months, (Tables 10-12).

With regard to Mg level, it was 23% more than the initial level after one month of application in June 2003 and reached a level 8% higher than the initial level after three months. Subsequent to the fertilizer application in October 2003, the Mg content increased to 26% more than the initial level

after one month which decreased and was 9% more than the initial level after three months. The Mg level increased to 29% over initial level after one month of fertilizer application in June 2004 and was 11% more over the initial level, after three months (Tables 10-12).

It was noted that there was not much variation in the per cent dissolution of nutrients in different treatments at various periods. This could be due to the fact that only 30g or its fractions were added at a time and the soil nutrient management practices were not followed earlier. It has been reported that the residual fertility is affected by many factors, including the release of plant nutrients from the soil's mineral and organic fractions by dissolution and decomposition, past fertilization practices and past cropping history (Nottidge *et al*., 2005). In the present experiment, all the above factors being same, the residual status is being controlled by degradation, adsorption or leaching. In other words, the persistence of the fertilizers in the soils revealed that within three months time, most of them have either degraded, adsorbed orleached and reached at a level close to the initial level except for P. This situation usually happens when no additional nutrients are applied. Thus, the residual fertility was found to decrease when net nutrient removal occurred. With immobile nutrients like phosphorus, it is seen that the residual effect persisted for a longer period.

These results indicated that sufficient number of microorganisms would have been present in the soil to degrade the fertilizers and make them available. It has also been noted that the maximum height of plants was recorded in sites receiving the premier dose.

In the agricultural systems where continuous application of fertilizers either by broadcast or by plant specific application is a common pracitice, the persistence of the added fertilizers will be more. This results in subsequent residual fertility to be more. Prior to the trial, nutrient management was practically absent in this site. Hence, it will not be viable to equate the fate of added fertilizers and the ensuing residual fertility in the two ecosystems. In the forest soils where canopy is highly open and the soil is exposed to rainfall pointed to the fact that instead of applying the full dosage in single application, it would be prudent to apply in two or three split doses. Splitting fertilizer application into several small applications, rather than a single large one, is especially important to limit N leaching on sandy, well-drained soils. Split N applications can also reduce N losses in runoff or from denitrification. Though economically and administratively, this is unwieldy, from the scientific angle, this recommendation is highly worthwhile.

Thus, the etiquette for residual nutrients as well as their effect on growth revealed that the recommendation of 30g each of N, P, K, Ca and Mg in the first year and double the dose in the second and third years by KFRI (Balagopalan *et al.*,1998) and split application of fertilizers are the protocols to be followed as far as the residual nutrients are concerned. The findings of the present investigation make it clear that the present recommendation

for the first three years for teak does not cause any adverse effect in the soil, unlike other ecosystems where continuous application has led to deleterious effect on the soil.

4. CONCLUSIONS

The study in the teak plantations established in the years 2002 and 2003 at Pariyaram and Vellikkulangara Forest Ranges in the Chalakkudy Forest Division with root trainer seedlings and stumps showed that

1. the effect due to treatment, period and the interaction between period and treatment was highly significant with regard to height in root trainer seedlings as well as in teak stumps in both locations.
2. the interaction between period and treatment was highly significant, indicating that the treatments differed in their height growth pattern across time in both locations.
3. Pair-wise comparison between treatments at each period revealed that the treatments differed significantly from each other during second and third years.. The nutrient treatment of 30g each of N,P,K.Ca and Mg showed higher height growth in the second and third years compared to other ones.
4. the persistence of the nutrients in the soils except P was three months after the application of fertilizers.
5. The fertilizers have either degraded, adsorbed or leached and reached a level close to the initial level within three months of the application.
6. instead of applying the whole fertilizers at a stretch, it would be prudent to apply in two or three split doses. Though economically and administratively unwieldy, from the scientific angle, this recommendation is highly worthwhile.

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Appendix I

Height of teak stumps under different treatments in the month of June 2003 at Pariyaram range

Treatment	Block	Height of stumps (cm)							
1	I	111	121	121	117	115	118	125	126
2		116	112	111	113	110	111	112	111
3		112	115	119	117	125	115	121	123
4		117	114	125	112	118	121	125	114
5		110	111	125	111	114	119	121	125
1	II	111	112	117	112	111	115	125	121
2		111	112	111	120	125	111	114	111
3		117	110	129	118	128	121	111	125
4		112	121	125	127	121	112	117	121
5		125	111	121	115	125	114	125	117
1	III	111	121	121	112	110	127	114	110
2		110	112	117	110	115	125	118	117
3		111	111	111	121	110	115	117	111
4		110	125	114	117	125	121	114	115
5		121	112	110	114	111	125	125	123
1	IV	121	110	111	110	114	117	114	120
2		110	121	119	111	111	112	125	111
3		110	117	121	121	110	121	112	121
4		111	117	121	121	117	125	121	111
5		121	117	111	110	111	121	110	114
1	V	117	110	112	121	111	119	117	125
2		112	124	117	118	111	121	112	111
3		111	112	121	121	125	117	111	110
4		111	121	111	117	110	114	111	111
5		111	121	125	111	111	121	121	110
1	VI	112	114	110	121	117	111	117	125
2		111	121	112	111	115	111	114	111
3		121	111	111	112	111	121	119	125
4		111	111	119	110	125	110	115	117
5		117	118	111	117	117	118	118	111
1	VII	125	121	119	117	125	115	117	115
2		121	125	111	111	121	117	114	114
3		118	110	117	117	125	121	125	112
4		110	119	121	117	111	117	115	111
5		121	125	115	121	114	121	112	167
1	VIII	125	165	121	117	111	129	121	110
2		121	125	111	111	115	125	111	119
3		114	110	117	112	125	123	125	110
4		115	126	111	123	111	111	121	111
5		111	121	115	115	110	111	124	117

1	IX	112	111	123	110	111	124	121	126
2		121	111	123	121	111	117	111	117
3		114	114	125	111	117	111	117	121
4		117	120	111	110	114	125	111	117
5		111	111	110	115	111	118	117	110
1	X	111	110	126	121	115	125	115	110
2		111	123	129	125	110	123	111	111
3		120	117	114	117	111	112	125	117
4		125	110	111	111	117	115	117	125
5		110	115	121	111	112	118	114	117
1	XI	127	125	112	128	129	121	121	117
2		117	115	110	115	126	126	111	112
3		121	118	110	123	125	112	111	114
4		117	128	121	117	117	125	114	118
5		110	117	129	110	125	121	127	117
1	XII	121	110	115	118	115	111	117	129
2		122	126	129	117	125	110	115	126
3		110	125	121	118	110	115	117	111
4		114	111	115	112	125	118	121	117
5		111	125	117	112	123	110	127	118

Appendix II

Height of teak stumps under different treatments in the month of June 2004 at Pariyaram range

Treatment	Block	Height of stumps (cm)							
1	I	163	167	160	164	155	160	151	162
2		222	221	227	222	224	222	223	222
3		204	206	201	207	201	202	203	202
4		185	181	187	184	182	181	178	185
5		170	172	176	164	173	172	169	167
1	II	155	161	160	162	157	162	163	156
2		224	222	216	221	216	223	224	227
3		207	202	194	204	201	204	206	209
4		187	181	180	188	185	188	187	189
5		161	170	166	171	165	173	173	171
1	III	160	162	154	159	161	158	161	163
2		221	218	227	224	216	226	218	217
3		204	202	204	205	203	210	202	201
4		181	188	184	190	188	187	189	190
5		172	171	171	177	169	173	174	171
1	IV	161	158	161	163	161	156	162	160
2		227	221	224	219	221	216	217	216
3		206	201	203	198	203	200	202	201
4		187	181	190	182	187	185	190	187
5		165	167	171	172	170	171	173	174
1	V	167	149	161	160	164	166	167	161
2		221	224	227	229	226	219	227	223
3		202	213	198	200	195	202	203	196
4		181	189	183	187	186	191	189	184
5		170	164	173	172	173	171	176	170
1	VI	162	154	160	161	157	161	163	145
2		227	224	216	213	225	221	227	214
3		204	205	201	202	201	202	204	200
4		189	188	185	187	191	189	186	188
5		167	164	169	168	169	168	169	166
1	VII	156	155	151	157	161	162	163	161
2		218	226	222	221	225	223	224	216
3		201	200	203	204	210	208	206	209
4		186	185	187	189	191	197	191	192
5		169	167	166	170	171	173	172	174

1	VIII	146	157	161	147	162	165	161	160
2		219	216	216	221	225	221	224	221
3		201	200	207	202	210	206	198	203
4		189	181	186	190	191	194	190	189
5		161	170	168	166	171	176	173	167
1	IX	148	154	161	150	161	162	162	145
2		226	224	223	214	221	210	221	217
3		202	202	206	202	141	201	207	141
4		187	183	184	185	181	188	181	187
5		164	165	166	164	166	169	167	162
1	X	141	140	160	144	162	143	148	146
2		224	214	223	216	163	214	221	214
3		199	195	162	164	189	162	196	160
4		186	174	181	183	176	183	179	186
5		164	160	166	162	161	164	166	161
1	XI	141	161	164	145	164	148	161	167
2		226	227	216	216	225	213	214	222
3		201	204	200	202	206	199	201	201
4		187	190	185	187	189	181	186	189
5		161	167	169	163	171	169	167	172
1	XII	147	161	161	142	160	144	145	161
2		213	224	223	217	226	210	216	222
3		202	206	204	201	204	194	201	203
4		184	189	187	189	186	179	190	187
5		161	167	164	166	165	160	170	172

Appendix III

Height of stumps under different treatments in the month of June 2005 at Pariyaram range

Treatment	Block	Height of stumps (cm)							
1	I	192	195	186	188	183	191	188	189
2		261	272	254	260	263	252	260	261
3		231	236	233	257	236	233	240	238
4		222	216	226	221	216	216	223	217
5		210	201	210	209	201	202	199	196
1	II	182	190	184	182	186	182	174	170
2		258	261	253	270	262	259	270	260
3		240	243	238	247	246	241	253	241
4		221	216	216	224	230	226	235	227
5		198	205	202	200	203	199	216	203
1	III	182	190	183	192	178	186	179	186
2		252	241	258	254	251	257	247	253
3		237	229	242	240	236	233	229	238
4		216	214	224	226	216	216	213	217
5		202	201	207	220	201	200	201	204
1	IV	184	182	186	171	173	182	188	188
2		256	245	243	251	248	248	250	247
3		238	227	227	236	232	229	231	230
4		214	210	216	213	214	217	216	213
5		199	197	160	161	162	160	197	161
1	V	178	179	185	182	172	181	180	184
2		251	245	254	251	242	246	247	261
3		233	232	237	232	225	225	226	239
4		214	216	221	216	214	214	210	216
5		192	198	202	201	197	200	194	205
1	VI	171	182	176	182	183	172	190	183
2		261	244	252	261	252	261	247	255
3		242	227	237	245	234	246	232	237
4		221	213	216	227	221	227	218	224
5		206	201	204	205	200	206	206	206
1	VII	182	185	173	182	176	179	187	182
2		255	262	261	252	260	251	273	253
3		234	243	244	235	242	234	253	236
4		219	226	231	216	227	221	236	216
5		193	199	194	200	198	191	216	201

1	VIII	182	172	186	175	177	185	179	183
2		251	249	252	246	261	242	250	260
3		232	230	224	230	242	221	231	238
4		213	216	203	214	221	201	213	216
5		196	199	197	193	191	193	196	201
1	IX	176	182	172	184	179	181	176	187
2		261	254	267	252	261	254	263	250
3		243	232	243	237	241	236	242	231
4		221	217	222	221	216	221	221	218
5		197	203	198	200	190	201	197	201
1	X	172	180	181	177	174	185	182	181
2		267	272	257	254	261	259	264	249
3		241	247	235	238	242	236	242	230
4		222	226	219	216	224	216	223	216
5		191	198	195	199	203	199	206	194
1	XI	182	190	176	180	172	171	185	182
2		257	254	252	241	256	264	257	258
3		238	236	231	227	234	240	235	233
4		214	221	216	214	216	222	218	217
5		198	204	192	198	194	193	198	201
1	XII	174	182	181	170	177	181	186	189
2		257	252	241	248	257	250	249	253
3		234	235	221	222	236	232	233	231
4		216	216	169	167	213	214	214	216
5		190	194	197	189	198	200	199	203

Appendix IV

Height of root trainer seedlings under different treatments in the month of June 2003 at Pariyaram range

Treatment	Block	Height of stumps (cm)							
1	I	132	137	141	131	142	131	132	137
2		133	130	134	145	140	137	133	143
3		145	149	137	130	134	145	131	145
4		141	135	131	141	137	135	130	145
5		130	134	137	130	131	137	134	133
1	II	138	131	136	132	134	135	137	137
2		130	131	131	145	132	1313	137	132
3		131	137	135	130	131	145	137	1313
4		137	134	145	139	131	1313	132	145
5		141	131	130	134	134	145	130	134
1	III	145	132	131	133	135	137	130	130
2		137	131	134	136	131	131	131	131
3		130	136	132	135	141	131	137	131
4		137	141	136	145	131	137	138	135
5		137	135	132	134	132	131	130	130
1	IV	132	131	135	132	137	136	131	137
2		131	134	131	130	146	130	141	132
3		130	137	130	131	145	136	131	134
4		138	130	131	145	132	139	137	132
5		131	134	139	136	130	132	130	131
1	V	147	130	131	138	132	132	133	137
2		130	1313	131	135	131	132	134	145
3		141	131	130	131	130	133	136	136
4		130	132	137	137	131	132	137	135
5		131	130	132	137	132	131	136	134
1	VI	130	146	144	134	131	130	147	144
2		137	134	136	132	133	137	135	136
3		136	131	137	131	135	136	130	136
4		139	136	132	131	137	132	136	130
5		134	138	130	135	130	132	133	138
1	VII	130	131	137	131	145	132	141	132
2		131	136	141	133	130	134	131	137
3		137	130	131	138	137	141	147	134
4		130	131	141	137	145	130	133	135
5		131	133	134	145	141	132	130	141

1	VIII	137	135	131	148	132	145	134	130
2		131	136	147	137	137	131	131	141
3		139	141	145	133	131	130	137	141
4		145	141	131	137	131	132	135	149
5		139	137	131	134	130	131	134	137
1	IX	131	136	132	145	132	134	131	137
2		131	141	137	134	133	137	137	139
3		132	130	131	135	134	148	134	137
4		137	141	145	131	130	130	132	138
5		133	137	134	130	141	131	130	131
1	X	131	132	130	137	134	135	131	130
2		145	134	131	141	132	141	131	135
3		131	131	137	134	137	135	136	145
4		135	132	134	149	132	138	131	135
5		134	130	131	135	134	132	137	131
1	XI	139	137	131	137	131	134	135	132
2		133	136	134	137	131	130	135	131
3		132	130	132	131	137	133	131	130
4		130	135	137	145	131	131	137	130
5		138	131	135	130	131	134	134	131
1	XII	131	136	132	135	137	131	130	137
2		141	130	137	135	130	133	131	134
3		130	137	134	141	146	146	134	145
4		137	132	134	137	145	141	131	149
5		144	130	132	137	132	142	130	131

Appendix V

Height of root trainer seedlings under different treatments in the month of June 2004 at Pariyaram range

Treatment	Block	Height of stumps (cm)							
1	I	181	184	187	188	180	191	183	198
2		246	237	232	254	247	251	250	241
3		232	226	221	237	230	235	236	231
4		214	216	222	220	216	221	220	219
5		191	198	202	210	202	204	206	209
1	II	184	183	186	188	187	186	182	187
2		251	242	247	245	241	256	248	249
3		232	223	233	232	226	237	221	226
4		216	217	221	222	212	216	206	210
5		201	202	204	203	198	206	191	198
1	III	188	186	181	180	184	187	186	182
2		252	245	241	251	246	257	245	253
3		236	234	226	240	232	231	232	236
4		222	216	212	221	220	216	219	218
5		204	202	200	196	201	199	202	201
1	IV	179	181	184	186	180	183	179	186
2		250	245	240	237	241	245	240	236
3		231	232	227	231	232	230	226	224
4		216	215	212	216	220	216	212	209
5		201	198	200	198	196	198	200	195
1	V	182	178	181	183	184	187	186	182
2		238	241	244	252	235	244	237	251
3		221	225	226	233	222	226	223	234
4		216	212	216	218	210	213	214	216
5		201	197	201	203	198	201	200	198
1	VI	178	181	188	187	183	182	179	176
2		251	243	246	231	236	252	242	236
3		235	232	226	224	221	234	226	219
4		219	216	212	210	209	220	212	203
5		197	196	201	200	196	201	197	192
1	VII	184	176	182	189	181	186	188	187
2		247	234	241	246	250	247	243	251
3		233	221	226	229	232	230	231	232
4		216	206	212	216	217	220	215	221
5		196	191	196	201	200	199	202	203

1	VIII	188	186	185	179	187	186	182	186
2		241	251	242	241	242	236	240	238
3		232	234	230	226	229	223	227	221
4		216	218	215	216	218	212	215	204
5		202	203	200	198	201	198	197	196
1	IX	176	181	186	182	187	188	180	183
2		246	244	237	242	231	241	242	244
3		229	226	219	226	217	224	223	227
4		216	214	208	212	204	213	207	211
5		192	196	197	200	191	202	192	195
1	X	187	186	182	179	184	177	180	184
2		240	242	237	244	241	236	233	239
3		225	226	221	222	224	221	219	221
4		212	212	210	203	206	206	204	206
5		198	200	197	190	194	190	191	190
1	XI	188	187	183	181	183	180	182	186
2		242	241	239	237	234	240	235	233
3		224	226	225	221	216	222	217	221
4		216	212	212	210	203	206	204	210
5		201	200	202	197	192	192	192	200
1	XII	188	182	183	186	182	187	180	178
2		244	245	241	236	245	252	253	245
3		226	231	226	216	231	234	229	230
4		216	220	213	204	216	222	216	214
5		203	204	200	193	202	201	198	200

Appendix VI

Height of root trainer seedlings under different treatments in the month of June 2005 at Pariyaram range

Treatment	Block	Height of stumps (cm)							
1	I	232	237	235	231	230	231	239	237
2		301	322	312	316	306	314	310	316
3		271	287	289	280	283	284	279	286
4		253	266	266	259	262	259	258	264
5		247	250	246	241	244	246	253	252
1	II	234	241	231	221	230	234	232	239
2		321	320	316	319	321	318	317	321
3		286	285	282	287	288	286	285	289
4		264	267	261	266	261	263	267	270
5		246	252	248	242	243	246	251	257
1	III	236	231	233	237	232	241	242	240
2		312	316	321	325	322	320	321	316
3		281	286	288	290	285	284	291	284
4		261	263	266	276	270	266	270	267
5		246	247	248	253	252	254	253	251
1	IV	234	231	236	241	240	237	238	242
2		316	324	320	322	312	313	310	315
3		275	270	271	281	276	279	274	276
2		256	257	260	266	262	264	256	260
3		245	246	247	253	250	249	248	253
1	V	235	236	240	242	238	229	237	232
2		321	324	319	320	322	316	326	315
3		290	282	284	287	279	288	278	274
4		264	268	265	256	260	259	260	254
5		251	250	251	249	254	243	249	240
1	VI	241	231	235	239	242	237	244	232
2		326	318	323	322	321	316	320	324
3		287	280	281	282	280	275	279	286
4		266	260	259	262	263	260	261	267
5		252	248	249	247	254	246	252	250
1	VII	234	245	236	241	231	237	240	242
2		316	321	322	319	318	320	326	321
3		279	282	287	280	281	283	289	286
4		264	272	275	269	263	267	271	271
5		246	257	251	254	245	252	256	257

1	VIII	236	241	234	245	246	241	231	240
2		316	320	322	322	319	321	324	314
3		287	279	285	280	281	284	286	275
4		271	264	266	264	265	272	270	262
5		254	253	250	252	254	256	251	251
1	IX	234	242	232	231	241	240	250	243
2		315	314	321	316	321	322	314	319
3		271	282	281	276	285	284	279	281
4		257	263	262	257	268	270	266	270
5		246	253	250	246	252	251	257	256
1	X	231	237	236	246	240	232	234	241
2		316	319	320	329	321	315	318	322
3		282	281	287	284	286	280	282	283
4		263	265	270	268	271	262	263	265
5		245	251	253	253	255	248	246	253
1	XI	232	241	236	245	231	237	242	230
2		316	324	319	322	321	313	327	318
3		284	286	285	287	286	280	289	285
4		267	271	270	271	272	273	272	263
5		250	256	252	256	250	251	257	243
1	XII	241	237	232	236	242	240	235	246
2		320	316	321	319	323	325	322	315
3		285	282	284	286	289	290	287	281
4		266	263	265	271	270	275	270	264
5		251	250	248	254	253	254	252	255

Appendix VII

Height of teak stumps under different treatments in the month of June 2003 at Vellikulangara range

Treatment	Block	Height of stumps (cm)							
1	I	23	24	25	27	25	18	20	19
2		18	19	16	21	16	21	22	21
3		21	17	19	23	21	23	19	19
4		18	24	21	20	22	23	21	24
5		21	19	23	22	18	16	24	25
1	II	19	20	16	18	21	23	22	24
2		22	21	18	23	24	19	24	18
3		21	20	19	23	24	23	21	26
4		16	23	21	25	16	16	16	21
5		22	16	23	22	21	24	161	21
1	III	16	21	23	22	16	18	24	26
2		16	16	16	23	25	26	16	27
3		16	16	21	22	24	16	16	22
4		23	21	24	19	22	16	22	25
5		23	19	16	16	21	23	19	19
1	IV	16	21	23	16	24	27	24	17
2		16	16	22	21	16	23	26	24
3		16	21	25	20	18	19	22	23
4		22	27	23	23	21	24	20	20
5		19	17	21	22	21	24	22	24
1	V	16	16	16	16	19	19	16	21
2		16	21	19	19	16	16	22	16
3		21	22	19	16	19	21	22	23
4		16	19	18	21	18	22	21	23
5		16	21	16	19	20	21	23	19
1	VI	16	23	22	16	21	24	19	19
2		24	16	23	22	21	18	23	20
3		22	21	16	16	19	23	19	23
4		23	19	23	16	24	16	22	16
5		21	25	19	24	16	24	21	23
1	VII	16	21	22	19	22	16	23	19
2		21	23	16	16	19	19	21	22
3		17	22	19	18	22	21	23	16
4		23	21	17	21	21	19	18	19
5		20	21	23	19	22	21	22	16

1	VIII	19	22	19	19	19	23	23	19
2		19	19	21	23	21	24	23	21
3		23	21	24	22	23	19	16	19
4		19	22	23	19	16	24	23	16
5		24	23	19	16	23	25	26	21
1	IX	22	24	19	19	16	21	22	21
2		19	19	21	24	21	23	21	19
3		16	18	24	25	22	23	21	24
4		19	21	19	19	19	16	24	25
5		19	21	23	19	18	21	22	16
1	X	19	24	19	16	19	21	23	22
2		21	22	23	22	16	24	23	19
3		23	21	23	21	21	23	23	19
4		19	23	19	24	19	16	19	21
5		22	16	19	21	23	22	21	22
1	XI	20	24	22	19	23	22	23	19
2		22	24	19	20	21	22	23	21
3		16	22	23	21	22	19	25	24
4		19	21	22	16	22	21	21	22
5		21	23	17	19	24	17	22	19
1	XII	23	18	19	23	22	19	16	24
2		19	16	22	19	21	26	23	21
3		24	25	22	21	22	23	28	23
4		22	19	23	22	24	21	19	24
5		19	20	22	16	21	19	21	22

Appendix VIII

Height of stumps under different treatments in the month of June 2004 at Vellikulangara range

Treatment	Block	Height of stumps (cm)							
1	I	103	105	102	106	107	104	102	106
2		142	145	147	142	144	138	139	142
3		134	139	132	137	132	133	139	132
4		122	129	127	122	128	126	122	127
5		114	117	116	115	119	118	116	117
1	II	110	102	106	103	107	102	112	107
2		143	139	144	142	140	138	142	146
3		132	128	133	132	137	132	132	135
4		122	121	122	128	124	119	126	122
5		115	112	113	114	116	112	118	113
1	III	108	103	102	110	102	109	100	103
2		142	139	143	141	138	145	142	150
3		134	129	132	130	125	136	129	136
4		122	119	125	121	119	124	119	124
5		114	110	113	112	112	117	110	114
1	IV	109	101	110	107	108	109	106	101
2		147	140	154	143	149	142	138	139
3		135	130	139	131	136	131	127	126
4		124	121	126	120	124	122	116	113
5		117	113	119	113	117	113	110	108
1	V	110	102	108	107	101	112	105	107
2		142	149	144	147	151	148	142	146
3		130	132	131	130	136	134	131	130
4		121	121	120	122	124	123	122	122
5		117	113	114	115	113	118	117	116
1	VI	107	102	109	102	100	101	103	110
2		141	151	158	140	142	147	145	143
3		133	138	140	129	128	132	131	129
4		122	124	129	116	117	121	120	118
5		115	113	116	109	110	113	110	113
1	VII	101	111	102	106	109	101	112	108
2		140	151	142	149	142	152	139	148
3		129	138	130	134	131	139	125	136
4		118	124	119	123	120	126	118	124
5		109	117	109	114	111	114	115	116

1	VIII	109	102	107	110	112	102	113	115
2		149	152	148	146	144	149	157	148
3		129	140	133	130	131	130	142	133
4		118	129	122	119	123	120	127	120
5		113	115	114	115	118	113	119	117
1	IX	103	111	107	109	101	112	108	106
2		150	149	143	144	140	153	151	148
3		138	136	131	130	127	138	139	132
4		123	123	120	119	114	124	127	121
5		114	118	115	113	110	117	117	115
1	X	111	108	109	107	103	111	112	110
2		149	150	143	139	151	142	147	148
3		138	139	134	127	139	129	132	133
4		124	128	127	118	124	120	124	120
5		118	116	115	112	114	116	118	114
1	XI	108	107	109	110	106	111	108	111
2		155	144	156	147	144	149	149	144
3		141	132	143	135	131	136	134	129
4		127	121	131	122	120	123	124	118
5		114	115	118	116	114	117	117	115
1	XII	109	110	108	104	103	108	105	107
2		151	140	143	147	150	144	146	153
3		138	131	129	134	139	132	132	141
4		127	123	118	124	126	120	119	129
5		116	117	113	117	120	117	111	116

Appendix IX

Height of stumps under different treatments in the month of June 2005 at Vellikulangara range

Treatment	Block	Height of stumps (cm)							
1	I	161	164	165	167	162	159	168	169
2		232	228	227	230	234	231	239	235
3		214	209	210	211	215	214	220	218
4		201	191	196	195	194	196	206	202
5		180	176	182	181	174	177	186	184
1	II	164	160	158	161	164	156	155	161
2		237	224	228	236	223	229	230	235
3		219	213	214	220	211	214	216	217
4		201	198	197	201	195	196	198	196
5		183	182	179	184	178	176	174	179
1	III	166	155	164	161	159	168	157	158
2		241	237	232	233	230	238	236	229
3		224	219	220	218	217	221	220	215
4		207	200	202	197	189	203	201	198
5		186	176	187	183	170	183	180	177
1	IV	162	156	171	158	152	164	160	161
2		233	237	232	214	230	235	223	232
3		216	220	215	201	208	216	206	214
4		198	201	196	184	190	195	187	198
5		179	186	186	173	172	176	172	179
1	V	156	162	151	164	170	167	159	168
2		232	240	237	239	233	223	238	241
3		219	221	221	219	220	208	220	224
4		201	203	199	202	198	186	197	199
5		171	185	177	180	182	176	176	178
1	VI	164	155	161	163	168	162	154	170
2		234	231	240	236	232	229	235	232
3		216	214	224	221	214	210	218	214
4		198	196	210	205	198	194	202	201
5		187	174	183	186	183	179	179	180
1	VII	156	164	171	162	170	167	165	155
2		238	233	240	232	251	237	234	242
3		215	219	217	214	232	219	217	224
4		204	205	203	201	210	204	201	205
5		171	186	185	177	183	185	186	171

1	VIII	161	160	167	162	155	165	170	160
2		232	238	223	236	234	237	239	240
3		216	222	209	217	220	221	223	221
4		200	206	193	201	204	202	199	198
5		183	184	179	179	178	180	186	178
1	IX	160	162	166	162	170	171	157	156
2		240	234	236	232	241	239	235	242
3		219	216	214	220	224	217	215	217
4		212	200	199	201	206	202	203	204
5		183	179	180	184	188	184	179	178
1	X	156	167	162	161	164	152	170	160
2		231	237	241	234	240	238	239	234
3		214	216	222	219	217	209	211	215
4		197	195	201	196	194	192	195	196
5		172	181	185	179	177	173	181	183
1	XI	151	164	160	162	155	162	161	170
2		239	231	236	230	240	241	233	238
3		220	216	218	214	221	223	215	221
4		197	201	200	194	193	200	196	198
5		176	183	181	173	176	183	184	186
1	XII	162	155	170	156	164	161	167	159
2		241	239	240	236	244	230	234	238
3		221	216	219	221	223	211	214	216
4		202	198	196	200	202	189	192	194
5		184	171	186	176	185	171	176	177

Appendix X

Height of root trainer seedlings under different treatments in the month of June 2003 at Vellikkulangara range

Treatment	Block	Height of stumps (cm)							
1	I	42	47	35	41	36	46	42	37
2		35	36	34	36	36	34	40	35
3		36	41	37	34	44	36	40	36
4		36	45	41	36	37	45	40	36
5		41	44	47	46	34	37	36	46
1	II	50	41	46	42	44	54	46	47
2		50	35	31	36	42	46	36	52
3		41	47	45	50	41	46	47	46
4		47	44	46	36	41	36	42	36
5		43	41	50	36	44	46	40	44
1	III	46	48	49	53	36	37	36	42
2		51	41	44	60	51	41	36	36
3		40	36	42	45	33	32	47	32
4		47	35	36	36	31	34	41	45
5		37	45	46	44	42	32	36	50
1	IV	42	41	36	42	47	46	51	37
2		36	54	41	50	46	50	43	42
3		40	37	36	41	46	36	41	46
4		36	40	41	36	36	46	47	42
5		32	44	46	46	40	36	46	51
1	V	36	50	41	36	42	42	36	37
2		40	36	51	45	31	42	53	36
3		36	31	40	34	40	36	36	36
4		40	46	47	37	34	42	37	55
5		31	36	42	47	46	34	36	44
1	VI	41	36	36	43	41	36	42	36
2		36	44	36	43	41	44	41	43
3		40	45	36	32	35	36	36	46
4		36	47	36	43	36	46	36	44
5		43	50	42	36	40	44	36	46
1	VII	37	34	44	36	36	52	43	46
2		46	46	40	44	50	54	41	37
3		37	39	32	36	41	36	42	36
4		36	46	35	47	37	34	44	36
5		51	38	44	46	46	46	40	43

1	VIII	37	46	34	36	42	46	44	50
2		41	56	36	37	37	34	31	35
3		46	35	46	53	46	46	40	44
4		37	34	44	36	41	52	45	46
5		36	37	41	36	41	36	42	36
1	IX	34	46	46	40	44	50	34	37
2		41	35	47	36	37	34	44	36
3		52	30	41	55	46	46	40	44
4		37	43	36	41	36	42	52	46
5		40	47	44	40	43	41	50	32
1	X	32	36	46	46	40	44	51	40
2		36	44	31	37	34	44	36	37
3		51	41	36	36	41	38	42	36
4		45	42	44	33	42	39	41	45
5		44	50	31	25	37	34	44	36
1	XI	46	37	51	43	36	44	45	36
2		36	38	41	36	42	30	35	41
3		41	46	44	40	44	36	34	50
4		39	34	44	38	31	35	37	40
5		36	41	51	30	32	40	44	51
1	XII	34	37	52	36	41	39	42	37
2		35	35	34	44	36	46	216	36
3		50	47	36	47	45	41	44	46
4		43	36	41	37	42	43	46	36
5		46	42	40	45	36	41	38	42

Appendix XI

Height of root trainer seedlings under different treatments in the month of June 2004 at Vellikkulangara range

Treatment	Block	Height of stumps (cm)							
1	I	151	165	153	145	162	157	151	154
2		206	211	202	200	210	204	206	207
3		187	192	185	179	186	181	182	189
4		171	174	170	161	172	166	167	173
5		163	170	164	154	168	161	160	161
1	II	162	161	148	162	149	162	167	151
2		216	219	221	224	223	229	230	219
3		194	196	198	199	201	204	209	203
4		179	181	182	182	186	189	188	188
5		170	169	160	173	167	176	174	164
1	III	167	151	141	156	161	145	164	157
2		222	218	216	221	223	225	218	217
3		203	198	197	202	205	209	197	199
4		186	181	180	186	179	190	179	182
5		174	166	164	169	168	164	171	174
1	IV	155	165	152	145	164	161	167	162
2		216	228	223	219	224	220	216	218
3		200	209	206	202	205	203	198	196
4		182	186	190	185	181	186	180	179
5		168	177	173	163	173	174	173	170
1	V	160	164	161	149	154	160	156	171
2		229	224	225	227	219	228	219	223
3		208	204	206	207	197	200	198	203
4		190	186	187	189	180	182	181	186
5		172	174	176	170	169	172	169	179
1	VI	141	160	152	161	**157**	**160**	156	**158**
2		227	228	220	223	230	231	225	226
3		206	205	198	199	206	209	206	203
4		189	188	180	183	186	187	184	186
5		163	172	168	172	170	172	166	169

1		160	154	161	152	167	162	155	159
2		240	234	241	244	250	242	243	238
3		221	213	220	222	229	223	228	221
4	VII	201	195	198	199	207	200	209	203
5		182	174	178	172	182	183	174	176
1		158	161	163	152	156	145	160	158
2		241	237	242	240	232	231	240	234
3	VIII	222	218	224	221	216	215	221	220
4		207	202	204	199	196	189	204	200
5		178	180	184	176	172	161	182	179
1		160	151	167	154	160	145	162	161
2	IX	240	244	237	242	231	236	242	246
3		221	226	216	222	211	214	223	227
4		202	204	197	199	193	192	197	204
5		184	186	182	181	176	162	180	183
1		162	154	160	151	161	155	159	148
2		240	242	237	244	241	238	233	235
3	X	225	226	221	222	224	221	216	221
4		206	204	202	200	206	203	200	199
5		186	179	181	179	184	176	174	168
1		158	167	162	165	151	154	160	145
2	XI	240	241	238	244	234	240	235	233
3		221	223	219	221	216	217	216	215
4		202	203	199	200	196	194	196	196
5		180	181	182	181	174	170	175	171
1		162	160	168	145	151	161	152	157
2		244	245	238	241	235	252	253	245
3	XII	221	224	216	220	211	229	228	222
4		203	201	197	201	190	202	206	199
5		183	179	181	171	172	186	170	174

Appendix XII

Height of root trainer seedlings under different treatments in the month of June 2005 at Pariyaram range

Treatment	Block	Height of stumps (cm)							
1	I	222	217	215	211	210	219	212	217
2		306	312	316	321	319	314	320	314
3		271	264	267	262	258	255	270	271
4		246	245	250	241	239	240	256	251
5		232	230	236	231	226	230	233	234
1	II	224	221	216	220	215	214	212	222
2		309	311	316	310	321	312	317	301
3		276	269	262	263	271	257	261	256
4		254	258	246	243	247	236	247	240
5		236	242	231	232	233	224	231	233
1	III	226	216	213	217	212	211	222	215
2		311	318	316	325	326	322	310	314
3		271	261	266	264	273	271	276	266
4		251	247	246	243	252	246	260	247
5		236	233	229	230	232	228	243	231
1	IV	214	213	216	220	210	217	211	212
2		316	324	309	312	315	313	319	309
3		275	270	272	281	270	273	266	269
4		254	251	250	262	252	256	246	246
5		233	231	230	241	237	239	231	226
1	V	210	212	223	211	217	213	209	215
2		318	326	311	308	312	314	313	324
3		265	271	270	274	261	266	264	267
4		243	252	248	259	254	249	240	244
5		230	236	236	235	233	232	226	236
1	VI	214	211	226	214	201	217	214	209
2		326	313	323	310	317	308	313	318
3		267	261	271	274	275	269	268	272
4		246	240	245	242	252	247	246	251
5		226	229	233	232	234	233	226	229
1	VII	210	225	209	211	214	217	209	213
2		311	314	322	321	310	309	326	313
3		271	276	267	259	264	258	260	271
4		250	249	247	236	243	240	246	251
5		231	233	227	224	226	232	231	236

1	VIII	218	211	209	215	219	210	216	220
2		310	316	311	322	306	313	309	314
3		271	279	270	284	277	272	271	286
4		252	254	246	251	245	243	250	252
5		234	233	227	226	231	226	228	234
1	IX	214	212	202	211	220	219	210	213
2		320	314	327	318	312	322	313	319
3		269	271	280	273	277	266	272	276
4		241	243	246	247	251	252	250	252
5		230	226	222	223	230	227	237	236
1	X	211	217	210	216	212	220	221	214
2		301	318	311	315	319	307	309	322
3		270	271	277	264	267	273	266	269
4		242	244	250	248	241	240	241	247
5		225	231	233	232	237	230	231	229
1	XI	209	211	210	215	218	217	222	220
2		316	304	315	316	321	303	327	318
3		273	271	263	251	272	274	266	263
4		250	247	242	236	250	246	240	241
5		223	226	231	224	231	230	231	232
1	XII	211	207	202	213	212	209	216	220
2		320	311	313	318	303	319	306	309
3		275	271	269	270	277	279	281	269
4		246	243	242	241	250	255	256	244
5		230	221	228	224	231	230	236	234