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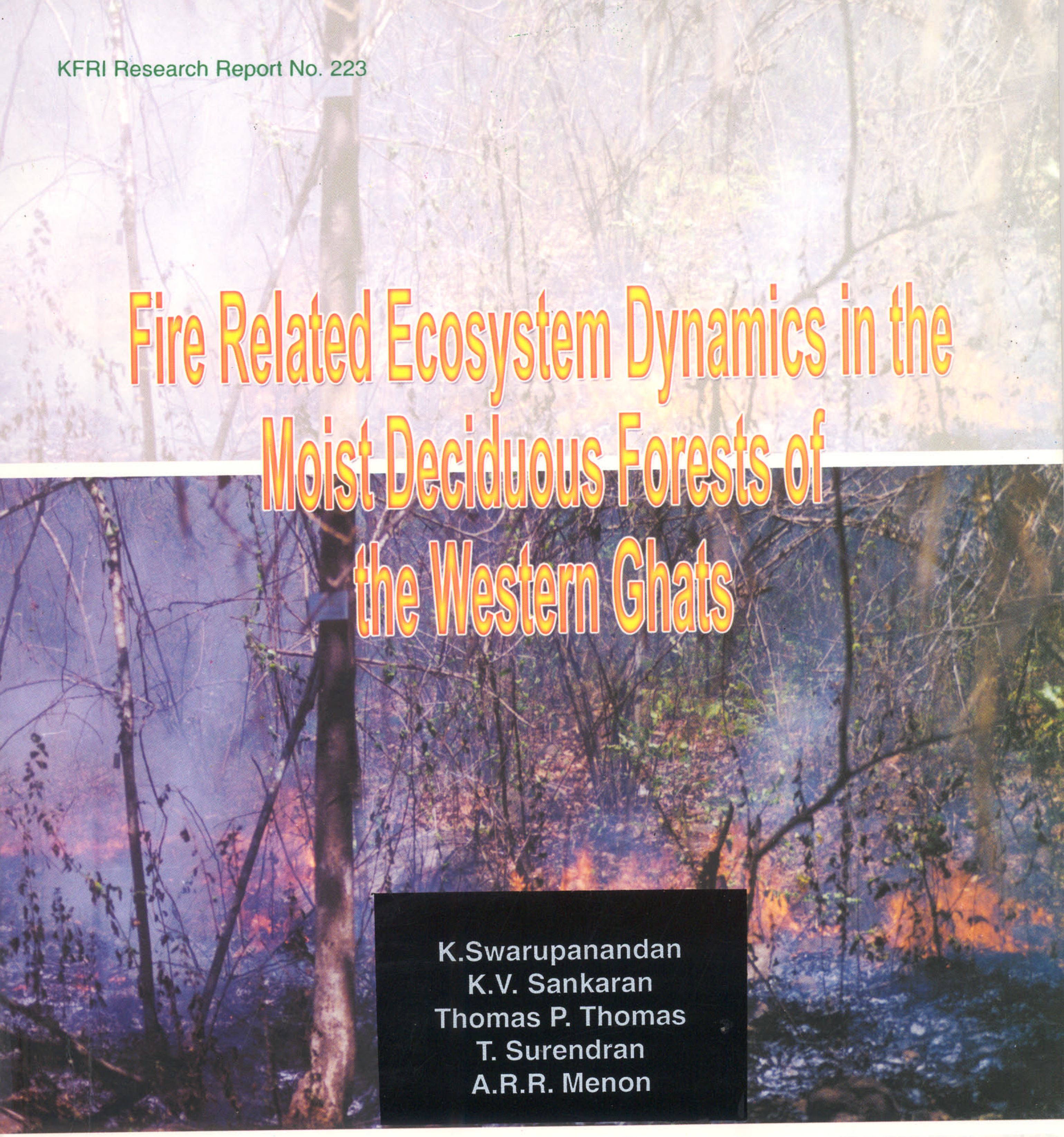

Fire Related Ecosystem Dynamics in the Moist Deciduous Forests of the Western Ghats

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CONTENTS

GENERAL INFORMATION

Title: Fire related ecosystem dynamics in the moist deciduous forests of the Western Ghats.

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Dr. K. Swarupanandan	Vegetation studies
Dr. K.V. Sankaran	Soil microbiology and litter dynamics
Dr. Thomas P. Thomas	Soil physics, soil chemistry and soil fauna
Dr. T. Surendran	Nursery and field studies on stump planting

Other project staff sanction/appointed

Jr. Research Fellow	: 2 Nos
Technical Assistants	: 2 Nos.
Field attendant	: 1 No
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FIRE RELATED ECOSYSTEM DYNAMICS IN THE MOIST DECIDUOUS FORESTS OF THE WESTERN GHATS

OBJECTIVES

1. To characterize the physical aspects of fire in moist deciduous forests

2. To study the changes brought about by fire on : soil physical and chemical properties, soil organisms (fauna, fungi, bacteria and actinomycetes), tree regeneration and litter dynamics

3. To explore the feasibility of silvicultural techniques such as stump planting to improve upon fire survival of tree seedlings.

AREA OF WORKS

Status : Kerala
District : Thrissur
Location : Pattikkad – 15 km away from Thrissur.

Plan of work for the duration of the project

	Activity	0	3	6	9	12	15	18	21	24	27	30	33	36	39	42	45	48
		Months																
I	**Preparatory activities**																	
a	Staff appointed	▨	▨	▨														
b	Procurement of equipment	▨	▨	▨	▨	▨												
2	**Field activities**																	
a	Plot establishment	▨	▨	▨	▨	▨												
b	Planning & designing of experiments	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨				
c	Tagging and enumeration			▨	▨	▨	▨	▨	▨	▨								
d	Stump trials in the nursery				▨	▨	▨											
e	Prescribed burning treatments				▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	
f	Litter dynamics & decomposition				▨	▨	▨	▨	▨	▨	▨	▨	▨	▨				
g	Re-enumeration							▨	▨	▨	▨	▨	▨	▨	▨	▨		
h	Soil sampling							▨	▨	▨	▨	▨	▨	▨	▨	▨		
i	Soil fauna sampling								▨	▨	▨	▨	▨	▨	▨			
j	Soil analyses								▨	▨	▨	▨	▨	▨	▨			
k	Stump planting				▨	▨	▨	▨	▨	▨	▨	▨						
l	Fencing	▨	▨	▨	▨	▨	▨	▨										
m	Observations		▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨		
n	Data analysis									▨	▨	▨	▨	▨	▨	▨		
3	**Preparation of report**													▨	▨	▨	▨	▨

ABSTRACT

Impact of seasonal fire on tree regeneration, litter dynamics, soil microflora and fauna (macro and meso) and physical and chemical properties of soil in a moist deciduous forest ecosystem (MD forest) in the Western Ghats was studied. The study area was located in the MD forest of Thrissur Forest Division, Kerala State. Of the 12 study plots (each 0.25 ha, in size) selected in the area, three replicate plots each were subjected to burning during different occasions in the summer season viz., early burn (burnt in early summer, mid burn (burnt in mid summer) and late burn (burnt in late summer) and observations on various parameters recorded. Unburnt control plots were maintained for each experiment. The fire survival capability of selected tree species was tested through stump planting in the experimental plots.

Observations on the behaviour and spread of fire during burning indicated that once the quantity of fuel and its moisture content were optimum to trigger an outbreak, further change in fire behaviour was controlled by factors like fuel porosity, continuity, its size and thickness, soil moisture content, wind speed and presence of grass in the forest.

Fire during early summer (early burn) caused only minimum damage to plants compared to that during mid and late summer. Impact of fire was more pronounced in plants under 5 cm dbh. Regeneration of plants with higher dbh was not seriously affected. Tree saplings in the lower diameter classes got dried up due to fire while there was an increase in the number of shrubs, herbs and grasses.

In general, burning treatments caused a temporary increase in pH and level of K, Ca and Mg in soils in the moist deciduous forest. Soil bulk density, porosity and organic carbon content were, however, adversely affected. Though some of these changes are beneficial to the acidic soil in the short term, recurrent fires may render the soil bare promoting run off and washing away of ash, which will lead to impoverishment and degradation of the soil in the long run.

Fire caused a decrease in the number of soil macro and meso fauna in the moist deciduous forest. The population recouped to its original status in an year's time after fire. Early burn did not result in a significant reduction in the density of the fauna.

A significant reduction in the density of fungal and bacterial propagules in the upper most layer of soil (0-2 cm) was observed as a result of the mid burn treatment. The population of actinomycetes was unaltered. The population of fungi and bacteria reverted to the preburn status after a week of burning. The rate of decay of leaf litter of *Xylia xylocarpa* was not affected by fire probably due to the fast recovery of the soil microbial population.

Burning (mid burn) resulted in a temporary rise in litter fall compared to unburnt plots. Premature shedding of leaves of trees and understorey scorched by fire contributed to this increase in litter production.

Search for tree species resistant to fire showed that thick barked species like *Gmelina arborea* and *Pterocarpus marsupium* have high fire survival capacity. Thicker stumps of these tree species (Collar diameter >1.5 cm and shoot height >1 m) were found promising for revegetating areas prone to recurrent fire in the moist deciduous forest.

Chapter 1

INTRODUCTION

Occurrence of fire is a regular feature in South Indian Moist Deciduous forests. It is a recurrent annual phenomenon coinciding with the drier periods of the year and hence very often regarded as a normal event in the seasonal cycle (Champion and Seth, 1968). Although uncontrolled fire is an agent of ecosystem degradation, it is considered to be an effective management tool (Brown and Davis, 1973). Planned and prescribed fire allows managers to set the timing and spatial extent of burns in advance of the event. It is in this context, the effect of fire on ecosystem function and the flora and fauna gains relevance. Concerted efforts, however, have not been made hitherto to understand the effect of fire on tree regeneration, litter dynamics and soil in the moist deciduous forest ecosystem in India.

Forest fire has been viewed upon both for and against. On the positive side, fire cleans the forest floor and thus increases accessibility. It also enables establishment of newly formed recruits (Christensen, 1991). It releases nutrients locked up in the dead and fallen litter. This helps growth of living trees and advances grass growth required for wildlife (Gruell, 1991). All the more, certain forest ecosystems continue to retain the same composition solely because of fire (Champion and Seth, 1968). On the adverse side, depending upon the type and intensity, fire can burn seed and seedlings, injure or kill trees of any age or size, affect wildlife population by depleting forage (Boyce and Merrill, 1991), consume or downgrade merchantable timber (Brown and Davis, 1973) and accelerate susceptibility of plants to decay, diseases and pests. It is estimated that in India, an average of 650 fires, affecting over 500 km^2 of forest area, occur every year (Gogate *et al.*, 1983).

Fire, when happens in the forest, will produce radical changes so rapidly that the changes in some degree are quite sufficient to maintain forest condition different from that which would eventually develop in the absence of fire. Fire, as a natural factor of environment, may play in positive ways to maintain the development of forest ecosystem (Kimmins, 1997). On the other hand, fire may cause injurious effects at any stage of plant development adversely, affect soil and animals in the forest, alter the ecosystem process including energy flow, forest biogeochemistry, and even carbon storage.

The ecological effect of fire varies greatly based on the time of the year the fire occurred, the quantity, condition and distribution of fuel, prevailing climatic conditions and the severity and intensity of fire. The slope, aspect and elevation of the area, the type of vegetation, etc. are other factors influencing the ecological effect of fire (Kimmins, 1997). Discussion on fire should always specify the type of fire and the condition of factors determining the effect of fire. However, all types of fire can occur in any combination or even altogether at the same time. A crown fire accompanied by both surface and ground fire, result in the total consumption of all organic matter above the soil surface.

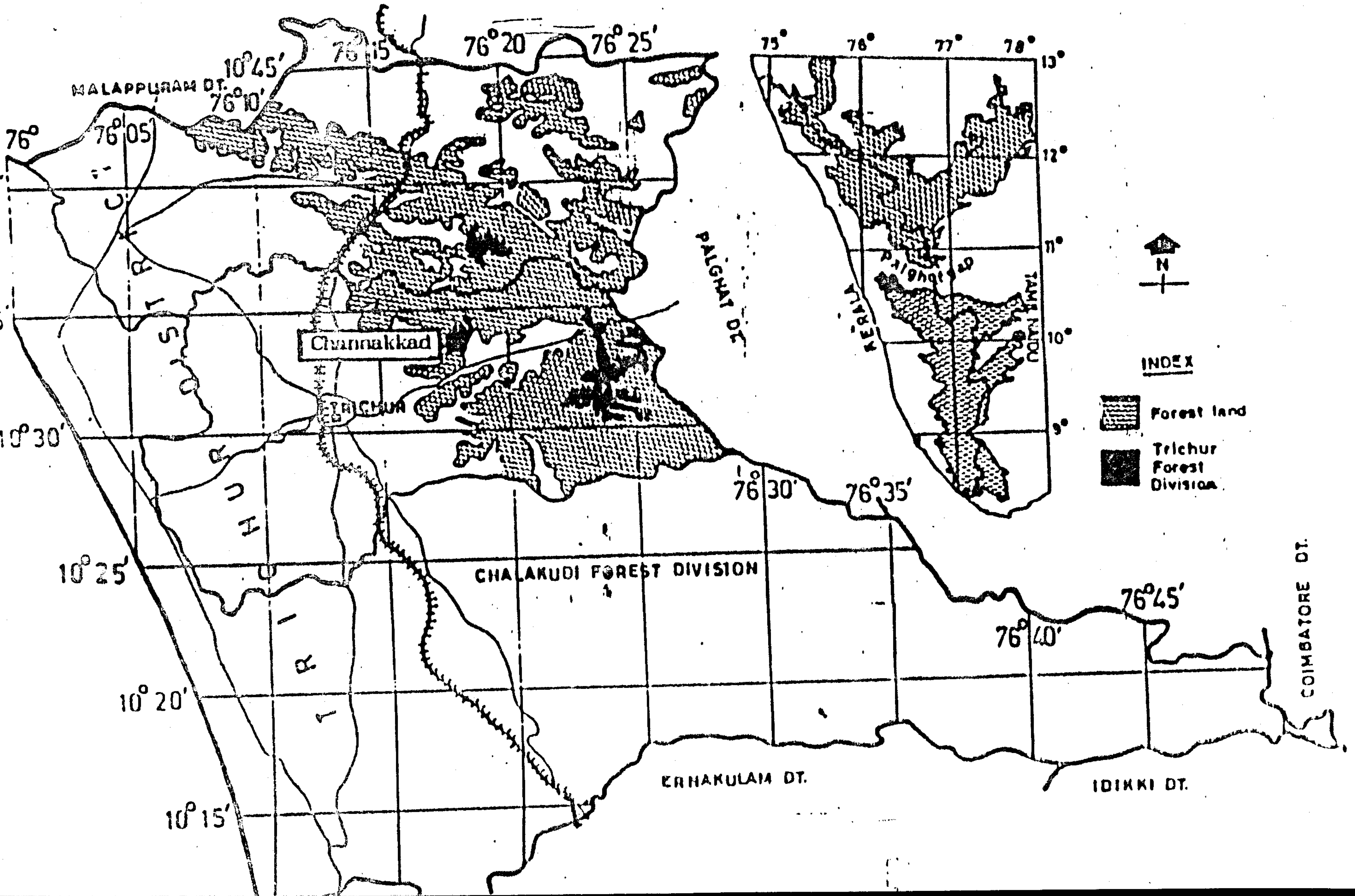
After the fire, primary production is decreased, by the reduction or elimination of plants, and where a fire has reduced the moisture and fertility status of forest, primary production may be depressed for a long time. Alternatively, primary production may be increased by fire because of the changes in species composition and more favourable soil condition. Primary production of post-burnt forest is initially by ephemeral species with little biomass accumulation. These are replaced later by herbaceous and shrubby perennials, in which much of the initial biomass accumulation may be below ground. Burning might influence litter dynamics in the forest ecosystem in the following ways: (i) by scorching the canopy (intense burns) and thus affecting the mass and nutrient content of subsequent litter fall (O'Connell *et al.*, 1979), (ii) by altering the species composition or developmental stage of understorey vegetation, (iii) by changing the species diversity and activities of soil and litter invertebrates and microflora (Springett, 1976) and (iv) by altering the microclimate (temperature and moisture) of the litter layer.

The South Indian Moist Deciduous forest (Champion and Seth, 1968) is one of the most important forest ecosystems in India. The potential areas under this forest type has been estimated to be 49,750 km^2, which is about 25% of the total forest area of the country (Gadgil and Meher-Homji, 1982). Incidence of fire is a frequent phenomenon in this vegetation type, which is characterized by a number of commercially valuable timber yielding species. Properly planned experimental studies are needed to understand the effect of fire, during different periods and varying frequencies, on the moist deciduous forest system. In order to look in to the diverse aspects of the problem, an interdisciplinary approach was taken covering various aspects dealt with. The study area was located in the moist deciduous forests of Thrissur Forest Division, in Kerala State, India (Fig. 1.1).

The objectives of the present study were

1. To characterize the physical aspects of fire in moist deciduous forests
2. To study the changes brought about by fire on soil physical and chemical properties, soil fauna, soil microflora, tree regeneration and litter dynamics in the moist deciduous forest ecosystem
3. To explore the feasibility of silvicultural techniques such as stump planting to improve fire survival of tree seedlings.

Fig. (1). Map of Trichur Forest Division showing Channakkad, the location of the Moist deciduous forest plot.



STUDY AREA

The study area lies between 10°25' and 10°45'N latitude and between 76°05' and 76°30'E longitude. The terrain is undulating with two major hills, Paravattani hill and Moodal hill. The major types of forest in the area is moist deciduous, even though semi-evergreen type covers part of the area.

Situation: The reserved forests of the Division are spread over Mukundapuram, Thrissur and Talappilly taluks of the Thrissur District.

Altitude: The altitude varies from 30 to 900 m. The highest peaks in the southern and northern halves of the Division are Ponmudi (928 m) and Munippara (521 m), respectively.

Drainage: The general direction of the drainage system is east-west with three major rivers, the Kurumali, the Manali and the Wadakkanchery draining the area. The two major dams in the area are the Vazhani and Peechi in northern and southern halves of the Division, respectively. In general, the area is well drained with no major drainage problem.

Climate: The total rainfall at Peechi, adjacent to the study site, amounted to 2601 mm during the year 1998. The southwest monsoon contributed about 2154 mm while the northeast monsoon 447 mm. The number of rainy days, when rainfall was greater than 10 mm, was 79 days. Summer showers were rare and months of January, February and March did not bring any rain. The monsoon became active from June onwards. Maximum rainfall was during July amounting to 763 mm. The temperature varied between a minimum of 19.8°C (3 January 1998) and maximum of 36.7°C (28 March 1998). Month with highest mean temperature was March (29.1°C) and the day with maximum wind speed was 4 August 1998 (9.9 m/s). With regard to sunshine, the month with maximum sunshine in the year 1997 was February (705 MJ/m^2) and that with minimum sunshine was July (357 MJ/m^2). Relative humidity varied with a minimum of 24.3% (February) and maximum of 100% (June-December) and an average minimum of 62.4% (January) and average maximum of 95.3% (July). The weather parameters were recorded using an automatic weather station, (Kallarackal and Somen, 1997).

Geology, rock and soil: The main geological formation is of the metamorphic series. On the lower slopes, laterite is also seen. There is considerable extent of rocky blanks consisting of sheet rocks in the region.

Soil: The soil type is ferralitic, dark brown to dark reddish brown in colour turning reddish yellow down the profile. It is shallow, loose, acidic and high in organic carbon and nutrients.

General nature of vegetation: The moist deciduous forests, as the name denotes, is in leafless condition, especially the upper canopy, during the dry season, i.e., from January to March. An appreciable number of trees, however, come to new leaf before the onset of rains. They occur on the lower slopes and on the ridges with rich loamy soils. Occurrence of fire is common in these areas.

The main species in the top canopy are: *Albizia odoratissima, Alstonia scholaris, Bombax ceiba, Dalbergia latifolia, Grewia tiliaefolia, Adina cordifolia, Lagerstroemia microcarpa, Miliusa tomentosa, Pterocarpus marsupium, Tectona grandis, Terminalia crenulata, Terminalia bellerica* and *Xylia xylocarpa.*

The lower canopy consists of species like *Bridelia squamosa, Caryea arborea, Cassia fistula, Gmelina arborea, Sterculia urens,* etc. *Acacia intsia, Caesalpinia bonducella, Butea superba, etc.* are the main climbers.

PRESCRIBED BURNING

Burning experiments: Early burn experiment was carried out in three replicate plots viz. T6R1, T6R2 and T6R3 during the second week of February 1997, 1998 and 1999. Mid burn experiment was carried out in T5R1, T5R2 and T5R3 plots in the second week of March 1997, 1998 and 1999. Late burn experiment was applied in T4R1, T4R2 and T4R3 plots on 25th April 1997. For two-year and three year fire frequency studies, experimental plots viz. T3R1, T3R2 and T3R3 were subjected to prescribed fire during the second year (i.e. 1998) owing to little difference with regard to fire behaviour and its ecological impacts when compared with midburn experiment.

Early burn experiment

***Treatment plots*:** T6R1, T6R2, T6R3

***Period*:** The first application of prescribed early burn was applied to the treatment plot T6R2 on 31st January 1997. But, the experiment could not be performed, as the litter moisture content was high. The trial was conducted on 19 February 1997 with the replicate sample plots T6R1, T6R2 and T6R3; subsequently repeated in the second week of February in 1998 and 1999.

Mid burn experiment

Three replicates; viz., T5R2, T5R1 and T5R3 were subjected to prescribed midburn during March 1997 and 1998 (middle of the dry season in Kerala).

Fireline clearing

Prior to burning, firelines around the plots were cleared by burning litter.

Late burn experiment

The prescribed late-burn treatment was carried out with three replicate plots viz. T4R1, T4R2 and T4R3 with the objective of comparing its impacts to that of early-burn and mid-burn treatments. The burning was conducted on April 1997. Late burn experiment has excluded in the subsequent years owing to little difference, with regard to fire behaviour and the ecological impacts when compared with mid-burn experiments.

Chapter 2

VEGETATION STUDY AND BURNING EXPERIMENTS

INTRODUCTION

The ecological effect of fire varies enormously according to the time of year, the quantity, condition and distribution of fuel, the prevailing climatic conditions, the severity and intensity of fire, etc. The slope, aspects, and type of vegetation, are yet other influencing factors ultimately affecting the ecological status of the habitat (Kimmins, 1997). It is an accepted fact that primary production is generally decreased after fire, due to reduction or elimination of plants which will cause reduction in moisture content and fertility status of soil. In some cases, an increase of primary production is also noticed, mainly due to changes in species composition and changes in the edaphic conditions. The primary production of the burnt forest is initially by the ephemeral species. The effect of forest fire on regeneration aspect of tree seedlings is not yet studied in detail. It is an accepted fact that fire alters regeneration status of vegetation, by modifying the edaphic and micro climatic conditions. It is in this context the fire related regeneration study gains relevance.

MATERIALS AND METHODS

Vegetation study: Conventional phytosociologial methods framed within proper statistical designs were used for studying different vegetational strata. The details are as follows:

a. As a follow up of the establishment of the plots for study (see Fig. 2.1) over 18,000 trees in 18 quarter hectare plots were tagged and enumerated to quantify regeneration. All damaged stems were marked, so that damage occurred after burning could be detected.

b. Trees ($\geq$ 30 cm gbh) in all the sample plots were identified, gbh measured and recorded.

c. Shrubs with height above 50 cm and gbh below 3 cm were identified and their height measured in 4 x 5 m quadrats randomly selected in each plot. Five quadrats were laid in each quarter hectare plot for this purpose.

d. For enumeration of herbs, six 1 x 1 m quadrats were laid in all sample plots. Plants with less than 50 cm height were identified, and height.

e. The enumeration data were analyzed for various ecological parameters using suitable computer programme.

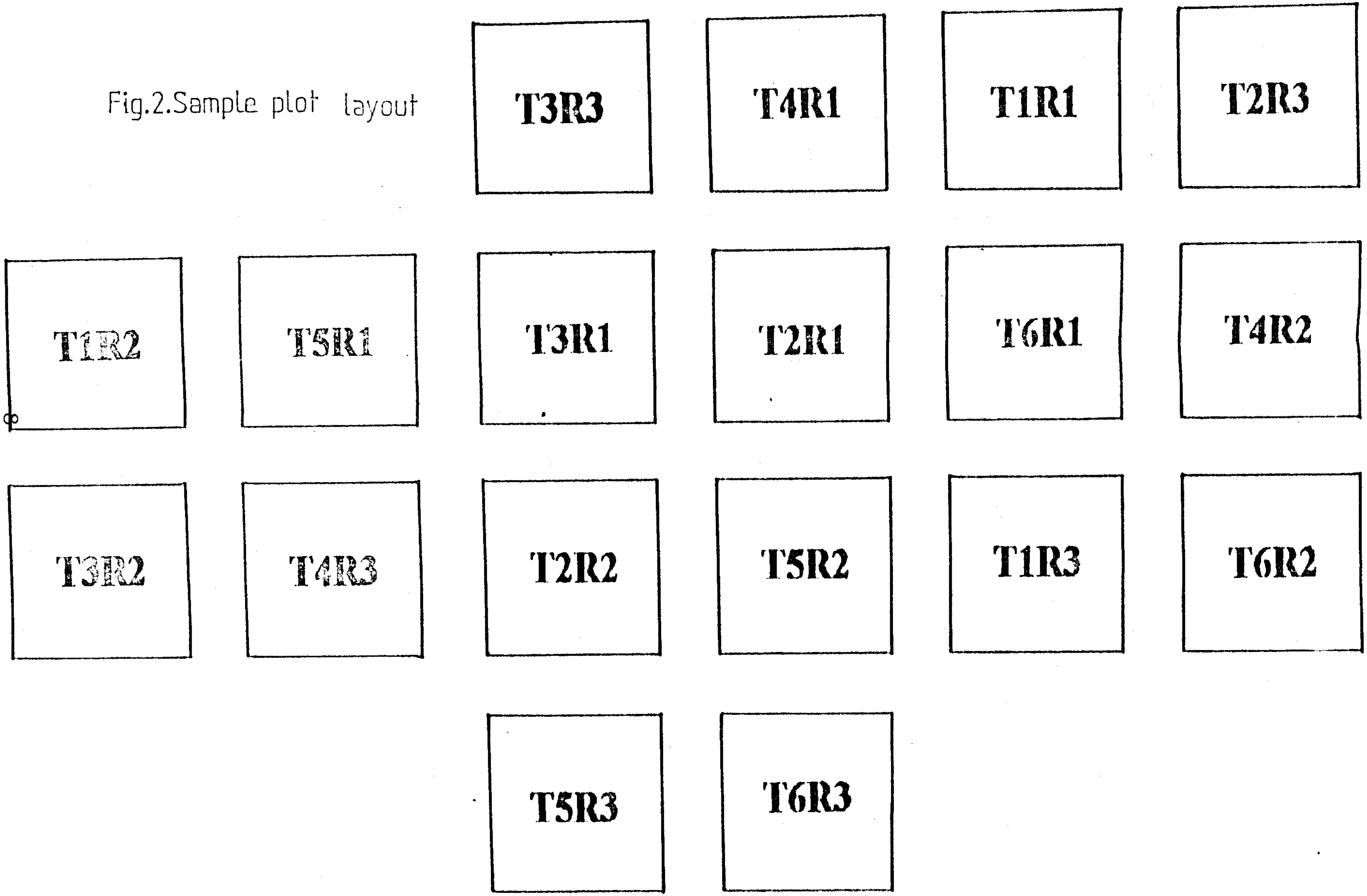


Fig.2.Sample plot layout

RESULTS AND DISCUSSION

Observations on the burning process (early burn)

Burning procedure: The burning was initiated by igniting several spots simultaneously along the down-slope base line at 12 noon, when the atmospheric humidity was at a minimum.

Moving front: Fire spreads out from individual spots and converges to a continuous moving front, thus creating a creeping ground fire spreading forward. Spatial homogenity of fuel load and topographic variation of land surface caused certain portions of the line to advance faster, thus making a rather irregular moving front.

Although the weather was calm, occasional winds swept hot gases across the moving front of the fire and contributed to heating of the fuel immediately ahead of the burning edge.

Flame height: In order to measure flame height, wooden sticks painted with yellow enamel paint were used so that charring could be detected on the clear yellow background. Sticks of 2 m length were placed randomly on 6 points in each plot. However, this method was found not very satisfactory, as the flames charred only the lower 10-15 cm portion.

The average flame height varied from 15 to 150 cm in accordance with the quality and quantity of the fuel. The ignition of grasses present in canopy openings occasionally increased the flame height at isolated points and the fire became turbulent. In the case of *Cycas circinalis*, the drooping dry leaves of the previous year carried the flame to the top of the tree. Thus, a tree of three meter height was burned at the top.

Fire spread: The rate of spread of fire changed directly with quantity and moisture content of fuel and to a lesser extent with wind velocity. In the plot T6R3, where the canopy was almost naked without any foliage, the combustible material load was comparatively high and the fire crossed 50 m, along the elevational gradient in 35 minutes.

Smoke: The smoke moved nearly vertical in the absence of wind.

Fire temperature: Thin foils of different metals, (1 x 8.5 cm size) were used for meauring fire temperature. The metals used were copper, silver, zinc, lead and tin. The metal foils were tied on to a wooden post at 10 cm height from the ground using GI wire. After burning, the metal pieces were taken out and observed (Table 2.1). The effect of burning on metal foils is given in Table 2.1. Except copper, all other metals melted away, inferring that the approximate average temperature at 1-10 cm above the ground was less than 960^{o}C.

Table 2.1. Impact of early burn on different metal foils

No.	Metal	Melting point (°C)	Impact on burning
1	Tin (Sn)	231.9	Burned out
2	Lead (Pb)	327.4	Burned out
3	Zinc (Zn)	419.5	Burned out
4	Silver (Ag)	960.8	Burned out
5	Copper(Cu)	1083	Not burned out

Fire escape islands: Interestingly, in the plots T6R1 and T6R2 occasionally fire cooled down and extinguished the flame leaving unburnt fuel in the form of several fire escape islands. In third replication plot T6R3, the area of the fire escape islands was less than one percent against 20% in the other replicates T6R1 and T6R2.

Fire persistence: As the litter load was comparatively low, and the pyrogenicity of larger and harder components of the litter was poor, the ground fire extinguished automatically as it reached the fire lines. Very rarely a piece of fallen bark continued to burn for a few minutes or continued to produce smoke for a while, even after the plot was completely burned up.

Composition of the stands: The plot T6R3 carried a total of 35 trees (gbh >30 cm) with dominance of *Grewia tiliaefolia* (34%) and *Bombax ceiba* (28%). Other important species were *Dillenia pentagyana, Lagerstroemia microcarpa, Xylia xylocarpa* and *Cordia sp.* The plot T6R2 supported 20 trees, 35% trees were of *Xylia xyloçarpa* and 20% of *Lagerstroemia microcarpa.* The plot T6R1 consisted of 23 trees with the dominance of *Xylia xylocarpa* and (26%) and *Grewia tiliaefolia* (26%). The remaining trees were composed of *Terminalia paniculata. Lagerstroemia microcarpa, Bombax ceiba. Albizia procera* and *Dillenia pentagyna.*

Phenology

Tree layer: *Grewia, Bombax* and *Dillenia* began their leaf shedding early, by the last week of December. Grewia and Bombax completed shedding of leaves by the end of January, while *Dillenia* continued the process till the end of February.

Shrub layer: The shrub layer in all the plots were thick with more than 50% green foliage on them.

Herb layer: In plots T6R1 and T6R2, owing to higher tree density much of the ground cover was comprised of herbs which remained green under the canopy. The third plot (T6R3) differed from the rest with almost naked canopy having very little of green foliage.

Litter load: Litter samples were collected from 1 m^2 areas on randomly located points in each plot with two replications. The average litter load turned out to be 535.3 g/m^2, which is equivalent to 5.5353 t/ha.

Weather: Atmospheric temperature and humidity were measured using a hygrothermograph, since January 1997. The maximum temperature recorded was 37.78°C and minimum 6°C. The relative humidity oscillated between a maximum of 97 and minimum of 45 percentage.

Observations on the burning process (mid burn)

Burning procedure: Burning was initiated by igniting several spots simultaneously along the downslope base line at 11.45 am when the atmospheric humidity was at a minimum and air temperature at ground level was at the maximum. Torches made of coconut leaf were used for the purpose.

Fire behaviour: From the point of ignition, fire radiated in all direction and met the neighbouring points of ignition and it became a continuous moving line of fire, which spread upward thus forming a slow moving surface fire.

In the first and second replicate plots, fire spread slowly, over the gently slopping terrain with constant speed. However, occasional wind swept along and across the direction of fire made either supporting and retarding effect, respectively. Interestingly, the plot T5R3 with thick layer of ground fuel (dried herbage and grasses) favoured the quick spread of fire. The fire crossed 50 m across the contour in 23 minutes.

In certain areas, flame reached up to the top of shrub layer through dried climbers and it continued for a while. The average time taken by the mid season fire to cover the distance of 50 m was only 53.6 minutes. This is far less when compared to the speed of fire in early-burn treatment (approximately 85 minutes).

The major driving force behind the rate of spread of fire appeared to be the higher volume of fuel and its continuity over the terrain. In the plots T5R1 and T5R2, a large portion of the fuel bed was composed of the leaves of *Xylia xylocarpa, Grewia tiliaefolia* and *Lagerstroemia microcarpa.* These leaves are comparatively smaller in size and on drying they became curled and brittle and thus formed a compact layer with less of arid volume within. In some isolated pockets, curling of larger leaves such as that of *Dillenia pentagyna, Terminalia bellerica, Ficus* sp. etc., after drying led to the discontinuity of fuel bed. In such areas fire intensity and speed of the spread was low. Fire was most intense and spread fast wherever fuel porosity was optimum. In certain points, sufficient fuel thickness and the presence of large sized twigs created a rugged fire front.

It is observed from the experiment that once the quantity and the moisture content of the fuel has crossed a certain level, then further changes in fire behaviour was determined by fuel porosity and its continuity. Presence of grasses and larger herbs like *Chromolaena* are other factors which created large turbulent fires.

Wind accelerated the fire spread rate when it swept along the direction of moving front, especially in areas where the fuel porosity was at the maximum. In compact litter layers wind helped burning of the entire litter by penetrating the flame into deeper layers, otherwise only a top layer was burnt. This may be due to the persistence of moisture in the bottom layers of litter. This was observed mainly in areas where litter of *Xylia* was maximum.

Flame height: The height of the flame varied between 1.5 cm and 200 cm from the ground. The vertical arrangement of the fuel and its thickness influenced the flame height in many microsystems. Burning of the partially or fully dried standing fuels permitted the flame to reach upto the height of two metres. Thick layer of litter accumulated in the depressions of ground also produced a taller flame. When the fire crossed grassy blanks and bushes of *Chromolaena*, it generated a gigantic flame reaching a height of 6 m or above from the ground. Wind was the other factor which influenced the flame height.

Fire escape islands: The percentage of fire escape islands after sufficient litter thickness and fuel discontinuity at certain points on the ground favoured the formation of the fire escape islands in the litter. In the compact litter layer, water vapour formed by fuel burning displaced air surrounding the fuel and extinguished the fire, thus forming fire escape islands. Presence of large size twigs, fuel moisture and wind direction were other factors which contributed to the formation of these islands.

Composition of the stands: The plot T5R1 consisted of a total of 32 trees, with average gbh of 151 cm. Of these, 18.7% trees were of *Xylia xylocarpa*, 15.6% of *Dillenia pentagyna* and 12% of *Grewia tiliaefolia*. The second replicate plot (T5R2) supported twenty trees with dominance of *Xylia xylocarpa* (30%), *Grewia tiliaefolia* (20%) and *Bombax ceiba* (10%). The average tree gbh was 148.7 cm. The plot T5R3 carried a minimum number of trees with average gbh 119 cm. The tree crops were composed mainly *Bombax ceiba* (29.4%), *Grewia tiliaefolia* (23.5%), and *Terminalia paniculata* (11%). Two large sized trees of *Terminalia bellerica* located near to the outer boundaries of the plot. T5R3 have also contributed considerable amount of litter at these microsites.

Phenology

Tree layer: Most of the trees had completed their defoliation and a few of them were flushing. *Xylia* and *Dillenia* had initiated flowering, after completion leaf shedding.

Shrub layer: The shrub layer was mainly composed of *Helicteres isora* and *Wrightia tinctoria*, had shed their foliage completely and remained skeletonised. In the plot T5R3, lianas covered the roof of the shrub canopy and remained green and leafy to a certain extent. *Chromolaena* sp. and *Hibiscus* sp. occupied the canopy openings up to the height of 1.5 m to 2 m. Both the species were at various stages of wilting.

Herb layer: Herbs and grasses occupying the canopy gaps had a dried-up appearance while some of the herbs under tree crown remained green.

Litter load: The total quantum of litter on the ground available for burning was calculated by drawing litter from two randomly selected of 1 m^2 area in each plot. Samples were weighed and moisture content determined after oven drying. The average litter load was estimated to be 9.3 t/ha.

Weather: Atmospheric temperature and relative humidity were measured using hygrothermograph. The average maximum temperature recorded was 37°C and the minimum temperature was 27°C. The relative humidity ranged from 51 to 98% during the burning week.

Observations on the burning process (late burn)

Burning procedure: Same as that followed for early burn and midburn treatments.

Fire behaviour: The fire lighted at several spots of the down slope baseline of plots spread upward forming a continuous line of front. Trunk and branches of fallen trees, sufficiently dry were consumed by fire. Fire took only 52 minutes to cover the distance of 50 m along the elevational gradient.

In all the three replicate plots, ground phytomass was comparatively thick and more than as seen in previous treatments. The phytomass consisting of fallen dead leaves, twigs, fruits, and seeds was completely dried up and compacted. It started to decompose at the bottom layer and led to the reduction of total fuel porosity, which retarded the rate of fire spread . Protruding rocks and freshly fallen twigs were also responsible to slow the fast moving fire.

Fire spread was a little faster than in the mid-season, in the absence of heavy fuels. When the thicker fuels ignited, fire sustained there for a longer period, where much of the surface litter was burnt and left the soil exposed. In the plot T4R1, a fallen tree of *Xylia* burnt fiercely consuming most of the fuels available at the microsite. This strong fire brought more damage to the ecosystem. A trunk of *Dillenia* remained in glowing combustion for 10 days after burning. Pealed bark of *Lagerstroemia microcarpa* which was easily consumed by flames lifted the fire from ground level to a few feet above on the trunk.

The observations recorded from plot T3R2 (burnt two years) was quite different from rest of the plots which received the same treatment. All the plots were burnt on the same day (29 April '97). The better soil moisture regime associated with thick undergrowth was the peculiarity of this plot. Though, the plot had thick litter layer on the ground it failed to produce continuous fire. The burning of these litter layer generated a mosaic of burnt and unburnt patches which gave the appearance of early burnt plots. These kind of fire appeared to be non lethal to the established tree regenerations. In this plot, fire covered 50m distance in two hours against 50 minutes in two other plots.

Flame height: The flame height varied between 20 to 200 cm. Burning of fallen trees and dried herbs lifted the flame to a height of 5 m. Fire spread with minimum flame height over the fuel bed comprised of leaves of *Xylia, Dalbergia, Lagerstroemia* etc., whereas presence of large sized leaves such as *Dillenia, Terminalia*, etc. could lift the flame to 2 m.

Fire escape islands: The percentage of fire escape islands was negligible as compared to early-burn treatment.

Fire temperature: Except copper all other metal foils used for labeling the plants got melted. Burning of wood might have produced very high temperature which could not be measured.

Composition of stands: In all the three replicate plots *Xylia xylocarpa* was the dominant species, interspersed with *Dillenia pentagyna, Grewia tiliaefolia, Bombax ceiba. Lagerstroemia microcarpa, Terminalia paniculata* and *Radermachera xylocarpa.* They contributed considerable amount of litter to the fuel bed.

The plot T4R1 supported a total of 25 trees with an average gbh of 136.3 cm. The second replicate plot also supported equal number of trees with slightly higher average gbh (166.5 cm). The third replicate plot (T4R3) consisted of 26 trees having an average gbh of 164.5 cm.

Phenology

Tree layer: Except *Dillenia pentagyna* and *Bombax ceiba* all other trees which contributed to the upper storey had started sprouting and formed a thin cover of canopy.

Plots with higher canopy closure hindered the direct of sun light to the fuel bed. Bamboos had shed down most of their leaves and left a woody skeleton.

Shrub layer: *Helicteres isora, Wrightia tinctoria* and *Holarrhena antidysenterica* which formed major part of the shrub layer, showed new flushes of leaves. Lianean community covered the shrubs remained dead, except for a very few species.

Herb layer: Herb growth was comparatively poor and most of them were dried. Very few sustained healthy aerial shoots which were under the umbrella of green conopy.

Litter load

Forest flora litter amounted to 9.17 t/ha; it was slightly less than that obtained during the mid season.

Weather: Daily atmospheric temperature fluctuated from a minimum of 29°C to a maximum of 37°C. Relative humidity varied between 57-98%. Wind was calm and did not affect much the rate of fire spread.

Vegetation

An area of 4.5 ha constituted by eighteen 0.25 ha sample plots had 33 tree species in all. According to dominance parameters six species viz., *Grewia tiliaefolia, Xylia xylocarpa, Dillenia pentagyna, Lagerstroemia microcarpa, Bombax ceiba* and *Terminalia paniculata* constituted over 75% of the importance value. From the point of view of density, *Xylia xylocarpa* was the most dominant while *Grewia tiliaefolia*, the least dominant.

Of the total of 17,534 tree seedlings tagged for regeneration studies, 62% (10,957) belonged to the size class 1-2.5 cm dbh, 29% (5,109) to the size class 2.6-5 cm dbh, 7% (1,302) to the size class 5.1-7.5 cm dbh and 1% (166) to the size class 7.6-10 cm dbh.

Of the tree seedlings tagged, 4,566 belonged to that of economically important tree species and 9,390 to the economically less important species. The dominant tree regeneration in the size class 1-10 cm dbh belonged to the species such as *Grewia tiliaefolia, Terminalia paniculata, Strychonos nux-vomica, Miliusa tomentosa, Stereospermum colais and Dalbergia latifolia.* The dominant tree regeneration in this size class of the economically less important tree species consisted of *Wrightia tinctoria, Holarrhena antidysenterica, Clerodendrum viscosum, Schleichera oleosa, Narengi crenulata, Cassia fistula, Canthium sp. and Mallotus philippensis.*

The dominant shrubs in this size class were *Wrightia tinctoria, Helictres isora, Chromoleana odorata, Hibiscus* sp., *Clerodendrum viscosum and Balliospermum* sp. The dominant climbing shrubs were: *Derris* sp., *Calicopteris floribunda, Acacia intsia* and *Caesalpinia bonducella.*

Effect of burning on vegetation (early burn): Prior to burning the ground layer of herbaceous vegetation was green, but were completely relished along with the litter, by the fire, except a few that remained in fire escape islands.

The seedlings of arborescent and other species (including that of shrubs) approximately below 3 mm in diameter were almost completely wiped out. The survival of stems with a collar diameter more than 1 cm were not affected, especially of arborescent species. The stems of trees were affected most between 1-10 cm above the ground, the bark having been charred out.

The foliage of shrubs and tree regeneration between 30 and 90 cm feet above the ground were almost completely burnt out, leaves of upper canopy dried up and curled. This created a magnificent ground clearance. The foliage of most of the shrubs were almost in tact, 1-1.5 m. above the ground. The foliage of *Strychonos nux-vomica* was seen badly affected up to a height of 2-3 m above the ground.

Effect of burning on terrestrial animals: Only two terrestrial animals and some insects could be observed in this connection. A viper (*Trimeresurus* sp.) lying in litter, was unable to sense the presence of fire, upto a distance of 1 m. or so. When the moving front of fire advanced to closer proximity of the animal it started moving and could not be traced further. A skink (*Mabuya carinata* Scneider) appeared on the ash in the center of the plot 5 minutes after the completion of the burning inferring that it was hiding somewhere. It appears that smaller terrestrial animals are not able to detect fire until it is in close proximity. Many of them perhaps take shelter in pits and holes in the soil and escape the fire, while some percentage might also be dying too, unable to find a proper shelter. Occasionally a few grass hoppers and other insects were found jumping out from the burning plot.

Effect of burning on vegetation (mid burn): All herbs and grasses burnt out together with the ground fuel. Tree seedlings with less than 50 cm height were killed by the surface fire. The foliage of younger trees and shrubs up to a height of 2 m were dried up and curled. Where the flame reached a height of 5-6 m leaves in the canopy to a height of 10 m dried up and leaves remained 2 days after burning. Dead and flapped bark, especially of *Lagerstroemia microcarpa* was found burnt.

Effect of burning on vegetation (late burn)

All herbaceous forms and tree regeneration burned out to a height of 1 m. Newly emerged leaves of shrubs and small trees dropped out and curled after fire. Burning of fallen trunk and branches in T4R1 plot wiped out all vegetal form present in the immediate surroundings and created a wide gap of about 1000 m^2.

Impact of fire on natural regeneration

Regeneration was badly affected by fire as can be seen from Tables 2.2 and 2.3. Woody regeneration with 1-10 cm dbh got dried up to various extents depending on the severity of fire. Saplings in the dbh class 1-2.5 cm was most affected; 47% dried up with early burn, 83% with mid-burn and 72% with late burn treatments. Bigger saplings were less affected. In the 2.6-5 cm dbh class 9% dried up in early burn plots, 22% in midburn plots and 21% in late burn plots, while in the 5.1-7.5 cm dbh class only 2%, 6% and 8% of plants got dried up with early, mid and late burn treatments. Very few plants dried up in the 7.6-10 cm dbh class.

Table 2.2. Effect of prescribed fire on woody regenerations (1 <dbh< 10 cm)

Treatments	DBH classes											
	1-2.5 cm			2.6-5 cm			5.1-7.5 cm			7.6-10 cm		
	Total No. of plants	Plants dried	Plants resprouted	Total No. of plants	Plants dried	Plants resprouted	Total No. of plants	Plans dried	Plants resprouted	Total No. of plants	Plants dried	Plants resprouted
Early burn	2209	1041	875	1223	112	63	276	6	36	0	0	0
Mid burn	1587	1320	1136	1023	222	151	244	14	6	37	1	0
Late burn	1404	1008	757	879	188	95	224	18	5	41	2	0
Control	1663	134	31	1014	75	9	279	12	0	33	0	0

Smaller saplings with less than 2.5 cm dbh were more in all the experimental plots at the beginning indicating healthy status of regeneration and this was found to be hampered by fire. Fire was also seen to alter the species composition (Table 2.3). There was significant reduction in saplings of tree species while the number of shrubs, herbs and grasses increased tremendously consequent to fire. This shift in species composition towards shrubs and grasses indicate canopy openings that may lead to progressive degeneration in status of the moist deciduous forest.

Of the 1663 tree seedlings tagged belonging to 1-2.5 cm dbh class in control plots, 8% dried naturally and 23% of these dried plants resprouted from the underground stem during the next growing season (rainy season) [Table 2.2].

Table 2.3. Effect of burning treatments on regeneration (< 1 cm dbh and > 50 cm height)

Burning treatments		Total number of plants	Number of species	Number of timber plants	Number of non timber plants	Number of shrubs
Early burn	Before burn	266	28	60	135	52
	After burn	452	35	36	116	292
Mid burn	Before burn	220	26	28	122	68
	After burn	401	27	20	121	270
Late burn	Before burn	205	30	51	116	21
	After burn	282	28	23	39	211
Control	First year	304	35	69	157	75
	Second year	435	31	62	176	194

In early-burnt treatment plots out of 2209 regeneration tagged, (belonged to 1-2.5 cm dbh class) 47% were dried after fire. Of these 84% of regenerated seedlings resprouted from the underground stem in the next rainy season. In mid-burn treatment plots of the 1587 regenerated seedlings, 83% got dried up, 86% resprouted. In late-burn plots, of the total of 1404 regenerations tagged belonged to the above class, 72% were dried and 75% resprouted (Table 2.4).

Table 2.4. Effect of burning treatments on regeneration (< 50 cm height)

Burning treatments		Total number of plants	Number of species	Number of timber plants	Number of non timber plants	Number of shrubs & herbs	Number of grasses
Early burn	Before burn	233	26	5	7	211	10
	After burn	475	34	17	42	337	79
Mid burn	Before burn	192	28	3	15	166	8
	After burn	338	33	2	29	260	45
Late burn	Before burn	228	28	5	5	186	30
	After burn	280	34	10	19	204	27
Control	First year	158	24	2	14	139	--
	Second year	224	22	6	15	177	23

(1st and last strips excluded to avoid edge effect)

CONCLUSION

Results of the experiment clearly indicate that impact of the fire is more pronounced in lower diameter classes (1-2.5 cm and 2.6-5 cm), whereas regenerations above 5 cm dbh were poorly affected. Prescribed burning carried out in the early summer season was found to cause minimum damage compared with the one conducted in mid and late summer months. Saplings of trees got dried up due to fire though some of them could resprout from the stump. Number of shrubs, herbs and grasses increased tremendously after burning.

Fire intensity is an important factor in fire effect analysis (Christensen, 1981; Gibson, *et al.* 1990; Williamson and Black, 1981). Fire sensitivity measurements were done from the field during control burning to estimate fire temperature using metal foils of different melting points. The study conducted on these lines reveals that the flash fire temperature in the surface layer may raise even upto 980°C for few seconds affecting the mortality rate of seedlings selected species in the area. It is also found that many small trees were killed by fire in the area where this type of "hot fire" occurred. The changes in the small tree structure were greater than that of large tree strata due to high mortality and low regeneration rate of seedlings after fire. This is in accordance with the finding of Liu, *et al.* 1977, thus emphasising the fire effects most strongly. It is also noted that the species composition and abundance of large saplings in post fire stands were altered by fire, but the recovery was also rapid probably due to high ecological efficiency of species to overcome of mortality rate. Thus there was no clear cut pattern of convergence or divergence, the net change appeared haphazard in the case of large saplings. This is a possible indication 'resilient response' of species to fire. Yet another probable reason for this phenomena observed in the area may be due to the presence of 'fire hardy' species like *Carreya arborea, Pterocarpus marsupium, Sterculia* species etc. Similarly populations of large saplings (*Lagerstroemia* spp. etc.) recovered by resprouting to a great extent with similar species composition. Again same type of vegetation may change substantially due to fire because of the hotness of flash fire and high susceptibility of selected species. Other types may change little because of rapid recovery from fire impact or low fire intensity (lice, *et al.* 1997). Hence it is highly advisable to have the structural status of the area, specially with respect to information related to floral element, their germination status and initial growth forms. These information can very well correlate to the mortality ratio of the area. Studies on fire in the dry habitats of different parts of world (Lotti, 1956; Ferguoon, 1957; Hodgkins, 1958; Komarek 1979; Uhl, *et al.* 1988) also reveals that, species of the mesic habitats growing unchecked for decades due to fire suppression, should be very susceptable to fire, particularly in the understorey. In our study area also similar susceptable species are observed in the understorey vegetation.

While hotter fire would undoubtedly result in stronger effects overall, the important point is that there is a gradient in response within a particular fire. On several occasions hot fires did occur (>400°C) but when fires burned down the mesic slope, intensity dropped and many patches were left unburned. Streng and Harcomb (1982) by examining fuel flammability of savanna communities and adjacent mesic forests suggested that some forests may effectively `escape' the influence of fire after developing a non flammable fuel bed. Nonflammability was caused by addition of hardwood litter which packs more tightly, holds moisture better and has lower heat content (Streng and Harcomb, 1982; Burgan and Rothermel, 1984). Because of the lower flammability and high moisture content of the so called `escape', it is to be expected that even under hotter conditions the gradient of fire intensity and impact would exist.

It is also observed that overstorey species composition of vegetation was relatively stable inspite of burning. Wilson and Agnew (1992) called such fire escape islands as `switches' and fire suggested that fire dependent and fire - independent types can coexist and become relatively stable, an idea proposed by Holling (1973); and Laycock (1991). Eventhough, there are difference of opinion regarding such `switches' as `rare' (Wilson and Agnew, 1992) and `common' (Schwartz, 1994); this successional stage has been common in many places and the commonness has been attributed to the fire suppression. Similar `fire escape' islands or the socalled `switches' were observed in the study area, mainly due to microclimatic variations and corresponding ground cover changes. Species of draught resistant types such as *Carreya arborea* and succulants are more in such fire escape islands and thus slowering the fire spread.

REFERENCES

Boyee, M.S. and Merill, E.H. 1991. Effects of the 1988 fires on angulates in Yellowstone National Park. Proc. Tall Timbers Fire Ecol. Conf. 17: 121-132.

Brown, A.A. and Davis, K.P. 1973. Forest fire: control and use. McGraw-Hill, New York.

Burgan, R.E. and R.C. Rothermel, 1984. BEHAVE: Fire behaviour prediction and fuel modeling system - fuel subsystem. USDA Forest Service General Technical Report INT-167.

Champion, H.G. and Seth, S.K. 1968. A revised survey of the forest types of India. Manager of Publications, Delhi.

Christensen, N.L. 1981. Fire regimes in Southeastern ecosystems. *In*: Mooney, H.L. (ed.). Fire regimes and ecosystem properties. pp.112-136. USDA Forest Service General Technical Report WO.26. Washington D.C.

Christensen, N.L. 1991. Wilderness and high intensity fire: how much is enough. Proc. Tall Timbers Fire Ecol. Conf. 17.

Gadgil, M. and Mehr-Homji, V.M. 1982. Conserving India's biological diversity. Dept. Environment. Govt. of India (mimeograph).

Gibson, D.J.; Hartnett, D.C. and Merrill, G.L.S. 1990. Fire temperature heterogeneity in contrasting fire prone habitat: Kansas tall grass prairie and Florida sandhill. *Bull. Torry Bot. Club.*, 117: 349-356.

Gogate, M.G.; Mital, R.C. and Lal, P. 1983. Fire break maintenance in India: a preliminary study on efficiency, suitability and economic of the back-pack blower (Model KW1 + 664) and Power blade fire break. *Indian For.*, 109: 91-100.

Ghosh, R.C. O.N. Kaul and B.K. Subba Rao. 1982. Environmental effects of forests in India. Indian Forest Bull. No. 275, Controller of Publications, Govt. of India, New Delhi, 20 p.

Gruell, G.E. 1991. Historical perspective: a pre-requisite for better public understanding of fire management challenger. Proc. Tall Timbers Fire Ecol. Conf. 17: 24-41.

Holling, C.S. 1973. Resiliency and stability of ecological systems. *Ann. Rev. Ecol. Syst.*, 4: 1-23.

Kimmins, J.P. 1997. Forest Ecology. A foundation for sustainable management Second edition. Prentice Hall. New Jercy.

Laycock, W.A. 1991. Stable status and threshold of range conditions on North American rangelands – a view point. *J. Range Manage.*, 44: 427-433.

Liu, C. 1994. Effects of fire on vegetation in the big thicket of Southeastern Texas, U.S.A. Ph.D. Dissertation, Rice University, Houston, Texas.

Liu; Chungxiang; Harcombe, Paul, A. and Knox and Robert, G, 1997. Effects of prescribed fire on the composition of woody plant communities in Southern Texas. *J. Vegetation Science*, 8: 495-504.

Lotti, T. 1956. Eliminating understorey hardwoods with summer prescribed fires in coastal plan lobbly pine stands. *J. For.*, 54: 191-192.

O'Connell, A.M., T.S. Grove, and D. Lamb. 1981. The influence of fire on the nutrition of Australian forests. *In*: Proc. Aust. Forest Nutrition Workshop. pp.277-289, CSIRO, Melbourne.

Pielou, E.C. 1975. Ecological diversity. Wiely, New York.

Phillipson, J. 1971. Methods for study in quantitative soil ecology. *In*: Phillipson (ed.) IBP hand book No. 18. Blackwell Scientific Publ., Oxford.

Schwartz, M.W. 1994. Natural distribution and abundance of forest species and communities in northern Florida. *Ecology*, 75: 687-705.

Shanon, C.E. and Weiner, W. 1949. Mathematical theory of communications. University Illinois Press. Urbana.

Simpson, E.H. 1949. Measurement of diversity. *Nature*, 163: 688.

Springett, J.A. 1976. The effects of prescribed burning on the soil fauna and on litter decomposition in Western Australian forests. *Aust. J. Ecol.*, 1:77-82.

Streng, D.R. and P.A. Harcomb (1982). Why don't east Texas savannas grow up to forest? *Am. Midl. Nat.*, 108: 278-299.

Wilson, J.B. and Agnew, A.D.Q. 1992. Positive feedback switches in plant communities. *Adv. Ecol. Res.*, 23: 263-336.

Williamson, G.B. and Black, E.M. 1981. High temperature of forest fires under pines as a selective advantage over oaks. *Nature*, 293: 643-644.

Chapter 3

SOIL STUDIES

INTRODUCTION

Forest fire can improve soil fertility in some cases but the impact need not be positive always. It is beneficial when the availability of plant nutrients is increased but harmful when nutrients are volatalised and lost to the atmosphere, entrapped as ash in smoke columns and carried away or lost through run off and leaching (Lock and Helvey, 1976; Biggs *et. al.*, 1996). Fire has been reported to affect adversely the species diversity, density and biomass of soil fauna also (Ahlgren, 1974; Chandler *et al.*, 1983) in forest ecosystems. Results of a study conducted in a moist deciduous forest of Kerala to reveal the impact of fire on soil properties and soil fauna are presented in this chapter.

MATERIALS AND METHODS

Soil properties: Soil samples were collected from two depths viz. 0-15 cm and 15-30 cm from the experimental plots before and after fire. The samples were air dried, passed through 2 mm sieve and subjected to various analyses. Sand, silt and clay were determined by hydrometer method, particle density using standard flask, bulk density by core sampling and porosity was calculated. Soil organic carbon was determined by Walkley and Black method, pH in 20:40 soil-water suspension and exchangeable bases using 0.1N HCL. Nitrogen was estimated by kjeldahl method, potassium by colorimetry and calcium and magnesium by versanate method.

Soil fauna: Soil fauna was estimated by sampling soil from an area of 50 x 50 cm to a depth of 20 cm and hand sorting macro-and meso fauna. Sub samples from 20 x 20 cm area to a depth of 20 cm were also taken for extraction by the funnel method.

RESULTS AND DISCUSSION

Effect of fire on soil physical properties

Sand content

Sand content of soil and its variations due to fire are shown in Table 3.1. The content of sand in the surface layer (0-15 cm) of soil was found to vary within the range of 78-80 per cent. Consequent to fire there was an increase in this coarse fraction of the soil. Early burn treatment had only a slight effect but mid burn and late burn showed more impact in increasing the sand content. Repeated fire in the three years also seemed to have a cumulative effect in this respect. In the lower layer (15-30 cm) no such influence of fire could be seen with any of the treatments. The values ranged from 76 to 78 per cent.

Table 3.1. Effect of fire on sand content

Soil depth (cm)	Observations	Sand (%)					
		Early Burn		Mid Burn		Late Burn	
		Mean	SD	Mean	SD	Mean	SD
0-15	Yr.1 BF	78	2	79	2	79	2
	AF	80	1	82	1	82	2
	Yr.2 BF	80	2	82	2	-	-
	AF	80	2	83	2	-	-
	Yr.3 BF	80	2	-	-	-	-
	AF	81	1	-	-	-	-
15-30	Yr.1 BF	76	2	78	1	78	2
	AF	76	2	78	2	78	1
	Yr.2 BF	77	1	77	2	-	-
	AF	76	2	76	2	-	-
	Yr.3 BF	76	1	-	-	-	-
	AF	76	1	-	-	-	-

BF - Before Fire; AF - After Fire.

Silt content

Table 3.2 gives the content of silt before and after fire treatments. Silt content in the surface layer was around 12% and its content decreased due to fire. Early burn, mid burn and late burn treatments could result in a reduction in the silt content. Repeated fire in the three years had a cumulative effect. In the subsurface layer no definite trend could be observed.

Clay content

Clay content of soil in the experimental plots and its variation due to fire are depicted in the Table 3.3. The content of clay was found to be around 7 to 10% in the 0-15 cm layer and no pattern of change could be observed due to various types of fire treatments in the first year. But a slight increase in clay content was found in the succeeding years. No trend was seen in the 15-30 cm layer and the values were found to lie around 9-12 per cent.

Table 3.2. Effect of fire on silt content

Soil depth (cm)	Observations	Silt (%)					
		Early Burn		Mid Burn		Late Burn	
		Mean	SD	Mean	SD	Mean	SD
0-15	Yr.1 BF	12	1	12	1	11	1
	AF	12	1	11	1	10	1
	Yr.2 BF	12	1	11	1	-	-
	AF	10	1	10	1	-	-
	Yr.3 BF	13	1	-	-	-	-
	AF	11	1	-	-	-	-
15-30	Yr.1 BF	13	1	12	1	13	1
	AF	12	1	13	1	13	1
	Yr.2 BF	12	1	13	1	-	-
	AF	12	1	14	1	-	-
	Yr.3 BF	12	1	-	-	-	-
	AF	13	1	-	-	-	-

BF - Before Fire; AF - After Fire.

Table 3.3. Effect of fire on clay content

Soil depth (cm)	Observations	Clay (%)					
		Early Burn		Mid Burn		Late Burn	
		Mean	SD	Mean	SD	Mean	SD
0-15	Yr.1 BF	10	1	9	1	10	1
	AF	8	1	7	1	8	1
	Yr.2 BF	8	1	7	1	-	-
	AF	10	1	8	1	-	-
	Yr.3 BF	7	1	-	-	-	-
	AF	8	1	-	-	-	-
15-30	Yr.1 BF	11	1	10	1	9	1
	AF	12	1	9	1	9	1
	Yr.2 BF	11	1	10	1	-	-
	AF	12	1	10	1	-	-
	Yr.3 BF	12	1	-	-	-	-
	AF	11	1	-	-	-	-

BF - Before Fire; AF - After Fire.

The increase in sand content and the decrease in silt and to some extent the clay content of surface layer points to the fact that there was a loss of finer separates of soil due to fire. It seems these are transported both down the slope and down the soil. Illuviation of silt and clay within the soil profile will lead to clogging of pores and a decrease in porosity. Those that are carried away in runoff are permanently lost to the site. Thus it can be seen that the impact of fire on soil texture seems to be adverse in the long run.

Particle density

Particle density values of soil before and after fire are given in the Table 3.4. Its value was found to be around 2.3 to 2.4 g/cm^3. Repeated annual fire was found to increase the particle density to values around 2.5 g/cm^3. In the 15-30 cm layer reverse was the observed trend; there was a decrease in the values. The treatments such as early burn, mid burn etc., did not differ in their influence on the particle density. Loss of finer separates from the surface layer and their illuvial effect in the sub surface layer might have contributed to this change of pattern.

Table 3.4. Effect of fire on particle density

Soil depth (cm)	Observations	Particle density (g/cm^3)					
		Early Burn		Mid Burn		Late Burn	
		Mean	SD	Mean	SD	Mean	SD
0-15	Yr.1 BF	2.40	0.15	2.40	0.10	2.35	0.15
	AF	2.40	0.10	2.40	0.15	2.40	0.15
	Yr.2 BF	2.45	0.10	2.45	0.15	-	-
	AF	2.45	0.10	2.45	0.10	-	-
	Yr.3 BF	2.45	0.10	-	-	-	-
	AF	2.50	0.10	-	-	-	-
15-30	Yr.1 BF	2.40	0.15	2.40	0.15	2.35	0.15
	AF	2.30	0.15	2.30	0.10	2.30	0.10
	Yr.2 BF	2.30	0.10	2.30	0.10	-	-
	AF	2.32	0.10	2.28	0.10	-	-
	Yr.3 BF	2.32	0.10	-	-	-	-
	AF	2.30	0.10	-	-	-	-

BF - Before Fire; AF - After Fire.

Bulk density

Effect of fire on soil bulk density depicted in Table 3.5 is discussed below. Soil bulk density showed a definite pattern of increase in the surface layer with the fire treatments. Its value increased from the 1.10 to 1.25 g/cm^3 in the surface layer with repeated fires. No clear trend followed in the subsurface layer of 15-30 cm though the values increased from 1.25 to 1.30 and even 1.35 g/cm^3 with some of the treatments. Mid burn had the greatest influence in this respect. All the treatments viz. early burn, mid burn and late burn had a similar effect on bulk density. Loss of organic matter as well as reduction in the diversity and abundance of organisms might have led to a reduction in the aggregate stability leading to dispersion, transport, as well as loss of finer soil separates from the surface soil which might have brought about this significant increase in bulk density. Increase in bulk density is detrimental to establishment and growth of tree saplings due to mechanical impedance and poor aeration.

Table 3.5. Effect of fire on bulk density

Soil depth (cm)	Observations		Bulk density (%)					
			Early Burn		Mid Burn		Late Burn	
			Mean	SD	Mean	SD	Mean	SD
0-15	Yr.1	BF	1.10	0.05	1.10	0.05	1.10	0.05
		AF	1.10	0.03	1.15	0.05	1.20	0.03
	Yr.2	BF	1.20	0.03	1.25	0.05	-	-
		AF	1.25	0.05	1.25	0.03	-	-
	Yr.3	BF	1.20	0.05	-	-	-	-
		AF	1.25	0.05	-	-	-	-
15-30	Yr.1	BF	1.25	0.05	1.25	0.05	1.25	0.05
		AF	1.25	0.05	1.25	0.03	1.25	0.03
	Yr.2	BF	1.25	0.05	1.25	0.05	-	-
		AF	1.30	0.03	1.35	0.03	-	-
	Yr.3	BF	1.30	0.03	-	-	-	-
		AF	1.30	0.05	-	-	-	-

BF - Before Fire; AF - After Fire.

Porosity

Porosity of soil is shown in Table 3.6. Soil porosity values were found to lie in the range of 53 to 54% in the surface and 47 to 48% in the subsurface. Fire reduced the porosity appreciably in both surface and subsurface layers. There was 4 to 5% reduction in the surface and about 4 to 7% reduction in the subsurface soil. Recurrent annual fires showed a cumulative influence while various other treatments such as early burn, mid burn etc. did not differ in their effect. Aggregate break down by rain drops consequent to loss of litter and clogging of soil pores by the dispersed finer separates might have caused the reduction in porosity.

Table 3.6. Effect of fire on Porosity

Soil depth (cm)	Observations	Porosity (%)					
		Early Burn		Mid Burn		Late Burn	
		Mean	SD	Mean	SD	Mean	SD
0-15	Yr.1 BF	54.2	3.0	54.2	2.0	53.2	2.0
	AF	54.2	2.0	52.1	2.0	50.0	2.0
	Yr.2 BF	51.1	3.0	49.0	3.0	-	-
	AF	49.0	2.0	49.0	2.0	-	-
	Yr.3 BF	51.0	2.0	-	-	-	-
	AF	50.0	2.0	-	-	-	-
15-30	Yr.1 BF	48.0	2.0	48.0	3.0	47.0	2.0
	AF	46.0	2.0	46.0	2.0	46.0	2.0
	Yr.2 BF	46.0	2.0	46.0	2.0	-	-
	AF	44.0	2.0	41.0	2.0	-	-
	Yr.3 BF	44.0	2.0	-	-	-	-
	AF	43.5	2.0	-	-	-	-

BF - Before Fire; AF - After Fire.

Effect of fire on soil chemical properties

Soil pH

Soil pH and its dynamics due to fire are given in Table 3.7 and discussed below. Soil pH values were found to be 5.5 to 5.6 in the surface layer (0-15 cm) on an average and fire did bring about a remarkable increase in pH irrespective of the treatment differences, though mid burn seems to have exerted a slightly greater influence. The pH values increased to 5.9 to 6.0 consequent to fire. This increase lasted for a few months only as was shown by the pH values next year which were coming back to the original level in an year's time. Treatments did not have any notable difference. The increase in pH might be due to easy release of bases from the ash. Activities of soil organisms and decomposition of unburnt litter and newly fallen litter seem to have counteracted the sudden increase and brought the soil pH to almost the initial levels in an year's time.

Table 3.7. Effect of fire on Soil pH

Soil depth (cm)	Observations		pH					
			Early Burn		Mid Burn		Late Burn	
			Mean	SD	Mean	SD	Mean	SD
0-15	Yr.1	BF	5.6	0.2	5.6	0.2	5.5	0.1
		AF	5.8	0.2	5.9	0.2	5.9	0.2
	Yr.2	BF	5.6	0.1	5.7	0.1	-	-
		AF	5.9	0.1	6.0	0.1	-	-
	Yr.3	BF	5.6	0.1	-	-	-	-
		AF	5.8	0.1	-	-	-	-
15-30	Yr.1	BF	5.6	0.2	5.7	0.1	5.6	0.1
		AF	5.7	0.1	5.8	0.1	5.8	0.2
	Yr.2	BF	5.6	0.1	5.7	0.1	-	-
		AF	5.8	0.2	5.8	0.2	-	-
	Yr.3	BF	5.7	0.1	-	-	-	-
		AF	5.9	0.2	-	-	-	-

BF - Before Fire; AF - After Fire.

Soil organic carbon

Effect of fire on soil organic carbon is given in Table 3.8. Soil Organic Carbon (OC) was seen to be seriously affected by fire. Its values plunged from the range of 2.2-2.3% to 1.5-1.8% in the surface layer due to fire. There was some increase in the values after a few months but the overall effect was a reduction in the organic carbon content of the soil. Mid burn and late burn treatments exerted the greatest influence in reducing the soil organic carbon. Similar was the case in the lower 15-30 cm soil layer also. The OC values got reduced from 1.2-1.4% to 0.8% after repeated fire in 3 years. The values increased slightly in one year's time and the cumulative effect was different from that of the top soil. Most of the litter had got burnt in the fire and most of the organic matter was lost as heat and light energy and as gases; the cumulative effect was always negative.

Table 3.8. Effect of fire on organic carbon

Soil depth (cm)	Observations	Organic carbon (%)					
		Early Burn		Mid Burn		Late Burn	
		Mean	SD	Mean	SD	Mean	SD
0-15	Yr.1 BF	2.2	0.1	2.2	0.1	2.3	0.1
	AF	2.2	0.2	1.7	0.2	1.5	0.1
	Yr.2 BF	2.3	0.1	2.0	0.1	-	-
	AF	1.8	0.2	1.5	0.2	-	-
	Yr.3 BF	2.0	0.1	-	-	-	-
	AF	1.5	0.2	-	-	-	-
15-30	Yr.1 BF	1.2	0.1	1.4	0.1	1.3	0.1
	AF	1.0	0.2	1.1	0.2	1.0	0.1
	Yr.2 BF	1.0	0.2	1.1	0.1	-	-
	AF	0.8	0.2	0.8	0.2	-	-
	Yr.3 BF	1.0	0.1	-	-	-	-
	AF	0.8	0.2	-	-	-	-

BF - Before Fire; AF - After Fire.

Exchangeable bases

Exchangeable bases content in the soil before and after fire are given in the Table 3.9. There was an increase of exchangeable bases in the soil consequent to fire. The surface soil which had an exchangeable bases value of 12 to 15 cmol/kg registered an increase of 3 to 5 units but this increase too could not last an year; the values returned to near initial levels. Exchangeable bases content of the 15 – 30 cm layer also increased due to fire though the increase was not as pronounced as in the top soil. The initial values of 16 cmol/kg was found to increase to 17-18 cmol/kg; the increase was only 1-2 units. Increase in exchangeable base level of soil consequent to fire can be due to release of bases from the ash which got adsorbed to soil exchange sites.

Effect of fire on soil nutrients

Nitrogen

Nitrogen content of soil is given in Table 3.10. It was observed to be seriously depleted due to fire. Its value dropped from initial levels of 2250 ppm to around 800 ppm after 3 years of fire. The effect was more marked in the mid burn and late burn treatments. The reduction was continuous over the years. Similar was the pattern of change in the subsurface (15-30 cm) layer also though to a lesser extent. The reduction in N level was from around 1500 ppm to around 850 ppm. All the treatments exerted similar impact. Fire consumes most of the litter which are the source of organic matter. The soil animals which themselves are a source of organic matter and which assist in the break down of organic matter also get reduced both in number and diversity due to fire. Reduction in organic matter and soil animals has led to a consequent reduction in nitrogen levels since nitrogen is normally released from organic matter by the action of nitrifying organisms.

Table 3.9. Effect of fire on exchangeable bases

Soil depth (cm)	Observations		Exchangeable bases (cmol/kg)					
			Early Burn		Mid Burn		Late Burn	
			Mean	SD	Mean	SD	Mean	SD
0-15	Yr.1	BF	15	1	14	1	12	1
		AF	18	2	18	2	17	2
	Yr.2	BF	16	2	15	1	-	-
		AF	18	2	18	2	-	-
	Yr.3	BF	16	1	-	-	-	-
		AF	18	2	-	-	-	-
15-30	Yr.1	BF	16	1	16	1	15	1
		AF	17	1	17	2	17	1
	Yr.2	BF	16	1	16	1	-	-
		AF	17	1	18	2	-	-
	Yr.3	BF	17	1	-	-	-	-
		AF	18	1	-	-	-	-

BF - Before Fire; AF - After Fire.

Table 3.10. Effect of fire on nitrogen

Soil depth (cm)	Observations		Nitrogen (ppm)					
			Early Burn		Mid Burn		Late Burn	
			Mean	SD	Mean	SD	Mean	SD
0-15	Yr.1	BF	2250	200	2150	100	2400	200
		AF	2100	200	2000	250	2050	150
	Yr.2	BF	2350	150	2200	100	-	-
		AF	2000	150	1000	200	-	-
	Yr.3	BF	1650	200	-	-	-	-
		AF	800	100	-	-	-	-
15-30	Yr.1	BF	1450	200	1500	200	1550	150
		AF	1400	250	1400	250	1300	150
	Yr.2	BF	1200	100	1150	150	-	-
		AF	1050	150	1000	150	-	-
	Yr.3	BF	1100	150	-	-	-	-
		AF	850	150	-	-	-	-

BF - Before Fire; AF - After Fire.

Potassium

Potassium content given in Table 3.11 is discussed below. Potassium content of top soil (0-15 cm) was seen to increase due to fire, though the rate of increase decreased in the succeeding years. There was an increase from 450 to 1250 ppm in the first year and from 850 to 1400 ppm in second year but in the third year, the change was from 400 to 850 ppm. The effect was most pronounced in the mid burn treatments; there was an increase from 500 to 1800 ppm and 500 to 1600 ppm in the first and second years respectively. The trend was similar in the sub soil (15-30 cm) also; potassium content increased from initial level of 450 to 1150 ppm in the first year, from 800 to 1250 ppm in the second year and from 600 to 1200 ppm in the third year. The impact was more pronounced in the mid burn treatment. Potassium level increased from 800 to 1400 ppm in the first year and from 600 to 1550 ppm in the second year. The late burn plot showed an increase from 300 to 1000 ppm due to fire. Release of potassium from ash and its consequent adsorption by the soil exchange complex might have led to an increase in its content in both the soil layers. This increase could not be sustained in the coming years probably because the quantity of litter for burning have been depleted due to repeated fire.

Table 3.11. Effect of fire on potassium

Soil depth (cm)	Observations		Potassium (ppm)					
			Early Burn		Mid Burn		Late Burn	
			Mean	SD	Mean	SD	Mean	SD
0-15	Yr.1	BF	450	50	500	10	450	40
		AF	1250	100	1800	20	1100	50
	Yr.2	BF	850	50	500	10	-	-
		AF	1400	150	1600	40	-	-
	Yr.3	BF	400	40	-	-	-	-
		AF	850	50	-	-	-	-
15-30	Yr.1	BF	450	40	800	30	300	10
		AF	1150	50	1400	120	1000	50
	Yr.2	BF	800	40	600	10	-	-
		AF	1250	100	1550	20	-	-
	Yr.3	BF	600	40	-	-	-	-
		AF	1200	100	-	-	-	-

BF - Before Fire; AF - After Fire.

Calcium

Soil calcium levels and the impact of fire are depicted in Table 3.12. The impact of fire on calcium content of both top soil and subsoil was not different from that of potassium content. Calcium content increased due to fire from levels of 1200 to 1650 ppm, 1300 to 1650 ppm and 1350 to 1500 ppm in the first, second and third year respectively in the early burn treatment. In the mid burn treatment, calcium increased from 1250 to 1850 ppm in the first year and from 1300 to 1550 ppm in the second year while in the late bun plot the increase was from 1350 to 1750 ppm. Calcium levels in the sub soil also followed a similar trend. The values increased from 1200 to 1350 ppm in the first year, from 1250 to 1400 ppm in the second year and from 1200 to 1300 ppm in the third year in the early burn plots. The mid burn plots also followed a similar trend; calcium levels increased from 1300 to 1500 ppm in the first year and from 1200 to 1450 ppm in the second year due to fire. Late burn plots too showed a slight increase from 1250 to 1350 ppm. Calcium dynamics also was affected by fire, the ash resulting from burning of litter supplied calcium to the soil which got adsorbed on exchange sites. But this effect could not be sustained due to reduction in combustible material after repeated annual fire.

Table 3.12. Effect of fire on calcium

Soil depth (cm)	Observations		Calcium (ppm)					
			Early Burn		Mid Burn		Late Burn	
			Mean	SD	Mean	SD	Mean	SD
0-15	Yr.1	BF	1200	50	1250	120	1350	100
		AF	1650	100	1850	150	1750	100
	Yr.2	BF	1300	80	1300	100	-	-
		AF	1650	120	1550	80	-	-
	Yr.3	BF	1350	130	-	-	-	-
		AF	1500	100	-	-	-	-
15-30	Yr.1	BF	1200	60	1300	100	1250	80
		AF	1350	70	1500	100	1350	70
	Yr.2	BF	1250	100	1200	80	-	-
		AF	1400	80	1450	50	-	-
	Yr.3	BF	1200	60	-	-	-	-
		AF	1300	70	-	-	-	-

BF - Before Fire; AF - After Fire.

Magnesium

Effect of fire on soil magnesium given in Table 3.13 is discussed below. Magnesium content exhibited a definite pattern of increase after each fire when the values of before and after fire were compared. In the early burn plots the initial value of 200 ppm increased to 500 ppm in the first year while in the second and third year the increase was from 300 to 450 and 200 to 350 ppm respectively. There was an increase in magnesium level in the mid burn plot also. The initial value of 300 ppm increased to 600 ppm in the first year and the respective change was from 350 to 650 ppm in the second year. Late burn plots followed the same trend; there was an increase in level from 300 to 600 ppm of magnesium. The subsoil also exhibited a similar pattern. The change due to fire in the first, second and third year were from 200 to 300 ppm, 300 to 4000 ppm and 200 to 300 ppm respectively in the early burn plots. The mid burn treatment produced an increase in magnesium content from 200 to 300 ppm and 300 to

Table 3.13. Effect of fire on magnesium

Soil depth (cm)	Observations		Magnesium (ppm)					
			Early Burn		Mid Burn		Late Burn	
			Mean	SD	Mean	SD	Mean	SD
0-15	Yr.1	BF	200	14	300	15	300	12
		AF	500	10	600	12	600	11
	Yr.2	BF	300	12	350	10		
		AF	450	15	650	15		
	Yr.3	BF	200	12	-	-		
		AF	350	10	-	-		
15-30	Yr.1	BF	200	12	200	12	250	10
		AF	300	15	300	10	300	12
	Yr.2	BF	300	10	300	10		
		AF	400	15	400	13		
	Yr.3	BF	200	10	-	-		
		AF	300	15	-	-		

BF - Before Fire: AF - After Fire.

400 ppm in the first and second year while the late burn plots registered an increase from 250 to 300 ppm only. Magnesium content in the soil increased due to its easy release from the ash and after two year's annual fire it seems probable that litter content also got reduced so that release of magnesium from organic matter was affected; magnesium levels decreased steadily after repeated fire. The influence of soil organisms which got depleted due to fire was also affected which in turn might have led to a reduction in mineralisation of magnesium from organic sources.

Effect of fire on soil fauna

The major macro and meso soil fauna belonged to different classes such as Oligochaeta, Crustacea, Myriapoda, Arachnida and Insecta. Crustacea was represented by Isopoda. Myriapoda by Diplopoda, Pauropoda, Chilopoda and Symphyla; Archnida by Araneida, Acari, Palpigradi and Chelonethi and Insecta by Collembola, Protura, Hymenoptera, Orthoptera, Diptera, Coleoptera and Isoptera. Highest density was observed for Hymenoptera, Acari, Collembola and Isoptera.

The results indicated that there was reduction in the density of all faunal groups due to fire (Tables 3.14 and 3.15). After an year their number was seen to increase again to a near original level. But the second year's fire was found to bring down the population of most of the groups appreciably. Animals were less in the surface soil during the mid burn season (i.e., summer) and Oligochaeta were found to have migrated to the deeper layer. Thus their number increased after fire in the surface soil since the sampling was carried out after monsoon showers during which they might have come up the soil. Hymenoptera population seemed to be unaffected while Protura was wiped out by fire. But the treatment plots being scattered within the untreated area had the chance of migration of fauna from adjacent unburned areas which was reflected in the second year's data. The results indicate a deleterious impact by recurring annual fires. The season when fire occurs was found to be most important in deciding the influence of fire. An early fire when the litter was only partly dry did not cause much harm but a fire in hot summer with plenty dry litter was definitely harmful to the soil and its fauna.

Table 3.14. Soil faunal density in first year

Class/Order	Obser-vation	Number per m^2 of 20 cm top soil							
		Early Burn		Mid Burn		Late Burn		Control	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
Oligochaeta	BF	24	7	10	3	12	3	24	8
	AF	12	4	24	2	14	1	-	-
Crustaceae									
Isopoda	BF	84	16	75	8	80	10	85	12
	AF	33	10	22	4	21	11	-	-
Myriapoda									
Diplopoda	BF	57	6	40	10	42	12	60	10
Pauropoda	AF	14	3	8	2	14	3	-	-
	BF	10	2	7	2	8	1	10	2
Chilopoda	AF	8	1	3	1	4	2	-	-
	BF	31	5	26	4	24	4	32	3
Symphyla	AF	13	3	9	2	12	3	-	-
	BF	12	2	10	3	13	1	12	2
	AF	2	1	2	1	3	1	-	-
Arachnida									
Araneida	BF	30	6	24	5	28	3	32	4
	AF	14	2	8	3	10	4	-	-
Acari	BF	240	34	164	22	172	20	234	14
	AF	53	11	50	15	46	12	-	-
Palpigradi	BF	16	3	10	2	14	3	15	2
	AF	5	1	3	1	4	1	-	-
Chelonethi	BF	20	4	12	2	11	2	25	5
	AF	6	1	4	1	4	1	-	-
Insecta									
Collembola	BF	175	24	160	20	170	28	170	31
	AF	60	15	34	11	36	6	-	-
Protura	BF	8	1	6	2	5	1	7	1
	AF	-	-	-	-	-	-	-	-
Hymenoptera	BF	420	110	430	124	418	86	434	122
	AF	420	100	400	114	404	56	-	-
Orthoptera	BF	82	9	68	12	66	9	84	11
	AF	14	4	12	3	10	3	-	-
Diptera	BF	15	7	14	3	12	2	16	4
	AF	4	2	4	3	3	2	-	-
Coleoptera	BF	12	4	14	2	12	3	15	3
	AF	4	2	3	1	3	1	-	-
Isoptera	BF	126	14	108	20	120	12	131	16
	AF	47	6	40	8	42	4		

BF - Before Fire; AF - After Fire.

Table 3.15. Soil faunal density in second year

Class/Order	Observation	Number per m^2 of 20 cm top soil					
		Early Burn		Mid Burn		Control	
		Mean	SD	Mean	SD	Mean	SD
Oligochaeta	BF	22	6	6	4	24	10
	AF	10	3	14	3	-	-
Crustaceae							
Isopoda	BF	60	11	42	8	84	12
	AF	22	6	18	3	-	-
Myriapoda							
Diplopoda	BF	43	8	34	6	60	7
	AF	11	4	9	2	-	-
Pauropoda	BF	9	2	6	2	10	2
	AF	6	1	3	1	-	-
Chilopoda	BF	22	5	20	4	32	5
	AF	10	2	8	2	-	-
Symphyla	BF	9	1	5	2	13	2
	AF	3	1	1	-	-	-
Arachnida							
Araneida	BF	30	4	16	3	30	5
	AF	15	2	4	2	-	-
Acari	BF	240	30	120	16	252	24
	AF	46	10	34	8	-	-
Palpigradi	BF	14	2	5	2	15	3
	AF	4	1	2	1	-	-
Chelonethi	BF	20	5	6	2	20	4
	AF	4	1	4	1	-	-
Insecta							
Collembola	BF	160	30	65	8	180	30
	AF	52	11	20	4	-	-
Protura	BF	6	1	2	1	8	2
	AF	-	-	-	-	-	-
Hymenoptera	BF	412	114	235	46	420	130
	AF	400	85	160	24	-	-
Orthoptera	BF	74	14	22	8	88	12
	AF	12	5	6	3	-	-
Diptera	BF	10	3	4	2	15	3
	AF	3	2	2	1	-	-
Coleoptera	BF	8	2	6	3	16	2
	AF	3	1	3	2	-	-
Isoptera	BF	102	22	64	13	93	10
	AF	38	17	14	4		

BF - Before Fire; AF - After Fire.

CONCLUSION

On the whole, it was observed that soil texture shifted to the coarser side, bulk density increased and porosity reduced due to recurrent annual fire. Soil pH increased, organic carbon declined drastically and exchangeable bases increased due to fire. Nitrogen content of soil decreased but potassium, calcium and magnesium contents were found to increase. Increase in pH, exchangeable bases, potassium, calcium and magnesium is good especially for the acidic soil under consideration. This increase is due to quick release of bases from the ash. But repeated fires will consume all the litter leaving lesser combustible material for the succeeding years. The sloping terrain of Kerala forests is susceptible to water erosion too, with the result that most of the left over ash will find its way downstream to lower lands. Thus in the long run the temporary beneficial effect of increase in bases will also be lost and the forests will shift to a poor status if the fires repeat every year. The macro and meso fauna in the soil was also adversely affected by recurring annual fire.

REFERENCES

Ahlgren, I.F. 1974. The effect of fire on soil organisms. In: Kozlowski, T.T. and Ahlgren, C.E. (eds.) Fire and ecosystems. Academic Press, New York, p.47-72.

Biggs, T.H, Webb, R.H. and Quade, J. 1996. Effects of fire frequency on nutrient lendgets of grasslands in South Eastern Arisona. *In*: Effects of fire on Madrean Province Ecosystems, Proceedings of symposium, March 11-15, 1996, Tuscson, A2., P. 276 – 277.

Chandler, C., Cheney, P., Thomas, P., Tratand, L. and Williams, D. 1983. Fire in forestry, vol.I. Forest fire behavior and effects. John Wiley & sons, New York.

Lock, G.O. and Helvey, J.D. 1976. Soil water trends following wildlife on the Entiat experimental forest. Proceedings of Tall Timbers Fire Ecology Conference, 15:193-200.

Chapter 4

EFFECT OF PRESCRIBED BURNING ON SOIL MICROFLORA AND LITTER DYNAMICS

INTRODUCTION

Burning is known to alter soil microbial population in various ways depending on fire intensity, soil type etc. (Ahlgren and Ahlgren, 1965). Some of the studies indicate an increase (Cohen, 1950) and others a decrease (Ahlgren and Ahlgren, 1965; Tiwari and Rai, 1977) in the number of soil microbes after burning. Some others, however, failed to detect any change (Jacques, 1947). Inherent limitations in the experimental techniques employed, delay in sampling of soil after burning and variation in soil environment may possibly explain some of these variations reported in the literature.

Litterfall and its subsequent decomposition account for a substantial amount of the nutrient cycling that occurs during forest stand development (Fogel and Cromack, 1977). Burning might influence litter dynamics in the following ways (i) by scorching the canopy (intense burns) and thus affecting the mass and nutrient content of subsequent litterfall (O'Connell *et. al.*, 1979) (ii) by altering the species composition or development stage of understorey vegetation, (iii) by changing the species diversity and activities of soil and litter invertebrates and microflora (Springett, 1976) and (iv) by altering the microclimate (temperature and moisture) of the litter layer.

The specific objectives of this study are: (1) to understand the effect of prescribed burning (mid burn) on soil microflora and (2) to assess the effect of prescribed burning on litter fall and litter decay in the moist deciduous forest ecosystem.

MATERIALS AND METHODS

Study site

Three replicate plots T5 R1, T5 R2, and T5 R3 (each of 0.25 ha in size) which were subjected to prescribed burning (mid burn) on 24 March 1997 were used for the present study. Unburned plots (3 plots of 0.25 ha in size) served as controls (T1R1, T1R2, T1R3). Details on the study sites, burning, intensity of fire and other details are provided in Chapter 1.

Soil microflora

A soil core sampler was used to sample soil at 0-2, 2-4 and 4-6 cm depth from burned and unburned plots. Six samples collected at random from each depth were mixed together (depth-wise) to form one composite sample. Three such composite samples were collected from individual plots. Total number of composite samples for each depth was nine for burned and nine for control plots. Sampling was done 2 days and 7 days after burning and samples stored at 4^0C before being processed for isolation of fungi, bacteria and actinomycetes. The isolation of various microorganisms was done using dilution plate technique. For isolation, 10 g of soil sample from each composite sample was transferred to 100 ml sterile distilled water in 250 ml conical flasks. The sample was shaken thoroughly and appropriate dilutions were prepared. i.e., 10^{-3} for fungi, 10^{-4} for actinomycetes and 10^{-5} for bacteria. Potato dextrose agar (PDA) and Rose Bengal agar (RBA) media were used to isolate fungi, starch casein agar (SCA) for actinomycetes and nutrient agar (NA) for bacteria. One ml of the respective soil suspension was transferred to individual Petri dishes and appropriate meida added. Five replicate Petri plates were kept in each case. The plates were incubated in the dark and colonies of different microorganisms counted after appropriate time interval. These data were used to compute microbes per gram of dry soil. Attempts were made to identify the fungi isolated using the available literature.

The limitations of the dilution plate method in supporting growth of all microorganisms in soil is well known (Parkinson and Williams, 1961). However, as plate counts can reveal the relative changes in microbial population, this method was used for the isolations.

Litterfall

Litterfall was quantified using litter traps (circular traps made of 6 mm iron rods – each of 0.28 m^2 in area) installed in burnt and unburnt plots. Twenty-five traps were installed (one litter trap each in the centre of 10 m x 10 m sub plots) in individual plots of 0.25 ha in February 1997. Thus a total of 150 traps (75 in control and 75 in burnt) were installed in all. The traps were removed temporarily from the burned plots to facilitate burning. The contents of the traps were collected at monthly intervals and the catch sorted into different components species wise. The samples were oven dried at 70°C for 24 h and the dry weight of each was determined separately. Litterfall per ha was computed from this data.

Litter decomposition

Freshly fallen leaves of *Terminalia paniculata* Roth, *Wrightia tinctoria* (Roxb.) R. Br., *Dillenia pentagyna* Roxb, *Xylia xylocarpa* (Roxb.) Theob. and *Grewia tiliaefolia* Vahl. were collected from the experimental area and air-dried. Litter bags (25 x 25 cm in size made up of nylon net of mesh size 5 mm) containing 10 g of air dried leaf litter of individual tree species were used for decomposition studies. A total of 72 litter bags were laid on the surface of soil in unburnt plots. (24 bags in each replicate plot). Since *X. xylocarpa* formed the major component of litter fall during April, only litter bags containing *Xylia* litter were laid in the burnt plots. Six litter bags containing litter of each species were sampled at monthly intervals, cleaned free of soil and other particles, dried at 70°C for 48 hrs and dry weight determined. Decay rate of litter and the annual decomposition rate constant were computed from this data.

Statistical analysis

The following exponential decay model (Olson, 1963) was used to estimate the annual decomposition rate of litter

$$x/x^{o} = e^{-kt}$$

Where, 'x' is the weight of litter remaining after time 't', x^{o} is the initial weight of litter, 'e' is the base of natural logarithm and 'k' is the decomposition rate constant. This exponential decay model was also used to calculate the time required for 90% weight loss. The significance of differences between decay rates was assessed by 't' test by comparing regression coefficients.

ANOVA and Duncans multiple range test were used to analyse the significance of differences between population of microorganisms, litter fall and litter decay rates between burned and unburned plots.

RESULTS AND DISCUSSION

Effect of burning on soil microflora

There was a significant decrease ($P > 0.05$) in the population of soil fungi (per g of dry soil) in burned plots (mid-burn) at 0-2 (62% reduction over control) and 2-4 (21% reduction over control) cm depth after 48 h of burning compared to unburned controls. The population of fungi in deeper layers (4-6 cm) was not affected (Table 4.1). After 7 days of burning, although fungal counts at 0-2 cm depth were still significantly low, the counts at 2-4 cm showed an increase and were almost equal to those in control soils at the same depth. There was a significant increase ($P > 0.05$) in the population of fungi at 0-2 m depth in burned plots after 7 days. The increase was not observed in unburned soils.

Table 4.1. Population of microorganisms (per g of soil) in burned and unburned plots in a moist deciduous forest

Fungi/g of soil x 10^3

Replicate sites	Burned soil						Unburned soil					
	After 2 days			After 7 days			After 2 days			After 7 days		
	Depth (cm)			Depth (cm)			Depth (cm)			Depth (cm)		
	0-2	2-4	4-6	0-2	2-4	4-6	0-2	2-4	4-6	0-2	2-4	4-6
R1	21.8	41.3	29.2	56.0	42.6	29.6	76.5	60.7	26.9	68.4	56.7	21.4
R2	24.9	46.7	28.8	46.2	43.0	28.4	62.3	56.7	23.8	59.2	44.3	26.2
R3	32.2	50.6	27.8	51.7	46.2	27.6	66.6	59.0	24.5	64.6	51.2	23.6

LSD value 8.635 at 5% level of significance.

Actinomycetes/g of soil x 10^4

Replicate sites	Burned soil						Unburned soil					
	After 2 days			After 7 days			After 2 days			After 7 days		
	Depth (cm)			Depth (cm)			Depth (cm)			Depth (cm)		
	0-2	2-4	4-6	0-2	2-4	4-6	0-2	2-4	4-6	0-2	2-4	4-6
R1	31.4	25.4	17.4	34.2	25.6	17.8	30.6	23.4	15.3	35.4	28.2	16.7
R2	33.4	23.6	14.3	29.4	21.2	15.8	24.4	17.0	10.6	23.7	19.3	14.2
R3	31.4	26.6	17.2	31.8	22.6	19.2	28.4	21.2	16.4	30.6	24.2	11.4

LSD value 12.603 at 5% level of significance.

Bacteria/g of soil x 10^{-5}

Replicate sites	Burned soil						Unburned soil					
	After 2 days			After 7 days			After 2 days			After 7 days		
	Depth (cm)			Depth (cm)			Depth (cm)			Depth (cm)		
	0-2	2-4	4-6	0-2	2-4	4-6	0-2	2-4	4-6	0-2	2-4	4-6
R1	20.4	19.8	17.2	29.0	22.6	16.6	29.4	20.4	17.8	31.2	23.7	12.4
R2	22.4	20.0	15.4	27.6	17.0	14.2	30.8	19.4	13.6	29.7	20.6	17.6
R3	20.6	14.8	12.4	26.2	19.3	15.4	32.6	21.2	18.2	33.0	24.3	15.3

LSD value 8.341 at 5% level of significance.

As regards the qualitative nature of the fungal flora, there was no significant reduction in number of species after burning. However, mean percentage of certain fungal species decreased drastically in burned soils. For example, the population of *Aspergillus niger* was reduced by 36% (Table 4.2). Mucoraceous fungi like *Gongronella butleri*, *Absidia cylindospora*, *Cunninghamella echinulata* and *C. elegans* were either absent or present only in low quantities in the upper 0-2 layer. There was a three fold increase in *Trichoderma* spp. and two fold increase in *Penicillium* spp. in the burned soil compared to unburned. *Fusarium* spp. also produced more number of colonies in the burned soil. The presence/absence of some of the species in burned/unburned soil may be a matter of chance rather than due to an influence of burning treatment or *vice versa*.

Table 4.2. Effect of soil burning on qualitative and quantitative nature of soil fungal flora (the number against each species represents mean percentage of the total fungal colonies) of surface soil (0-2 cm) - after 2 days of burning compared to unburned soil

Name of species	Unburned soil	Burned soil
Absidia cylindrospora Hagem	3.5	1.5
Acremonium sp. (1)	0	2.5
Aspergillus niger van Tiegham	70.3	45.2
Cladosporium cladosporioides (Fres.) de Vries	1.1	0
Cunninghamella echinulata (Thaxt.) Thaxt.	1.4	0
Cunninghamella elegans Lendner	1.0	0
Cylindrocaldium sp. (1)	1.0	1.7
Fusarium oxysporum Schltdl.	0	4.9
Fusarium solanii (Mart.) Sacc.	3.9	8.7
Geotrichum candidum Link	1.1	0
Gongronella butleri (Lendner) Peyronel & Dal Vesco	3.0	2.0
Mucor sp. (1)	0	2.4
Myrothecium roridum Tode ex Fr.	1.4	0
Rhizopus sp. (1)	2.0	0
Paecilomyces carneus (Duche & Heim) Brown & Smith	0	2.8
Penicillium spp.	6.1	14.6
Trichoderma spp.	4.2	13.6

As regards the population of actinomycetes, there was no significant difference in plate counts in burned and unburned plots at any of the depths (Table 4.1). The count of actinomycetes, however, decreased with increasing depth at both the sites. The population of these microbes did not differ significantly between the two sampling, periods in both burned and control plots.

The number of bacteria was significantly reduced ($P>0.05$) after 2 days of burning in the surface layer of the soil (0-2 cm depth). Burning apparently had no effect on the population of bacteria in the deeper layers of the soil (2-4 and 4-6 cm). After 7 days, the population got reverted to the pre-burned status. There was no significant difference in bacterial counts (at any of the depths) 7 days after burning between burned and control plots (Table 4.1).

The results of this study show that fire of moderate intensity (mid-burn in the first year) such as the one in this experiment, produce microbial changes mainly in the surface (0-2 cm) of soil ecosystem. These changes are apparently temporary and the soil may return to pre-burn condition in a couple of weeks. The more serious changes may be burning of the vegetation and the surface organic cover which will result in nutrient loss and leaching and it may take a long time for the burned site to return to its pre-fire condition (Luke and McArthur, 1978).

Ahlgren (1974) reviewed the effect of fire on soil organisms and stated that changes in microbial populations following fire are most evident in upper soil layers. According to him, the depth to which the effect can be detected increases with increased burn intensity. Fungi include species with highly specialized and diverse physiological needs and there are many contradictions in behaviour of fungi in burned soils. Post-fire decrease of fungi in the upper layers of soil as observed in this study has been reported by several workers (Wright and Tarrant, 1957; Wright and Bollen, 1961; Neal *et al*,, 1965 Ahlgren and Ahlgren, 1965; Tiwari and Rai, 1977; Theodorou and Bowen, 1982). In general, the reduction in the number of fungi and other microbes immediately after fire can be attributed to the direct effect of heat. The post-burn increase in the population is evidently due to the increased availability of energy source released through the effect of heat, increased pH etc.

The observation that (i) fungal population in deeper layer of the soil was not affected (ii) the population reverted back to pre-burned status at 2-4 cm depth in 7 days and (iii) species richness was not affected, indicate that the intensity of the burn was not high enough to cause long term changes. The speedy reversion of the fungal population to the original status in the upper layer of the soil (0-2 cm) confirms the observation. Results of a host of other studies conducted in India and elsewhere (Wright and Tarrant, 1957; Rai and Tiwari, 1977; Theodorou and Bowen, 1982), indicated that it took several months and some times a few years after burning for restoration of the fungal population to its pre-burn status. At the same time, some other studies have shown that burning has no influence on population of fungi. For example, Ahlgren and Ahlgren (1965) reported that in jack pine forests in Northern Minnesota no post-fire decrease in fungi was detected in the upper soil layer. Likewise, in South Eastern US, Jorgensen and Hodges (1970) found no significant difference in numbers of fungi cultured from periodically burned and unburned soil. The delay in sampling soil after the occurrence of fire, the suitability of the isolation techniques used and variation in the soil ecosystem and environment may possibly explain some of these contradictory results.

The fungal species comprising the population in a burned site is reported to differ from those on unburned site and this vary with age of the burn (Ahlgren, 1974). The hygrophilous discomycetes and higher basidiomycetes are reported to be the early post-fire species. (Hintikka, 1960). However, as none of these fungi would grow on culture plates, colonization of burned sites with these fungi could not be ascertained. A significant reduction of *Aspergillus niger* in burned site may be ascribed to the killing of spores in the surface layer. Wright and Tarrant (1957) have reported that on severely burned sites, no aspergilli were found. But, in contrast to their observation on the low frequency of *Fusarium* on burned sites, this study showed an increase in *Fusarium*. The absence of some mucoraceous fungi from the burned site may be due to the inability of these fungi to withstand extremes of temperature. The number of *Pencillium* and *Trichoderma* were more in burned soil which is contradictory to the observations of Jalaluddin, (1969) and Tiwari and Rai (1977). According to Ahlgren (1974), temperature, acidity and nutrient source are the three factors influencing species selectivity of fungi in burned sites.

Several workers have reported that (Wright and Bollen, 1961; Jorgensen and Hodges, 1970; Ahlgren, 1974), soil actinomycetes and bacteria behave similarly in response to fire. Ahlgren and Ahlgren (1965) noticed a significant decrease in Streptomycetes in the upper layer of soil immediately after fire. In the present study actinomycete population was found unaltered after burning at all depths. Neal *et al.*, (1965) found that in Oregon, USA, burning of Douglas fir slash did not markedly influence Streptomycete population. Actinomycetes are generally known to be more resistant to heating than bacteria and fungi. This may be one of the reasons why actinomycetes in soil were unaffected by burning.

A post-fire decrease in soil bacterial population has been reported by Theodorou and Bowen,. (1982), Ahlgren and Ahlgren (1965) and Meiklejohn (1953). Results of this study are in agreement with the findings of these authors. In areas where moisture is a limiting factor, bacterial population declines soon after the fire lasting only until the first rainfall. In most cases, the population increased after an initial decrease and reverted to original status or exceeded those of unburned soil in a few months time depending on the intensity of the fire (Renbuss *et al.*, 1973; Wright and Tarrant, 1957). The intensity of fire also decides the extent of damage caused to the surface and deeper layers. As discussed earlier, the initial decrease in the population of bacteria may be due to the direct influence of heat. The population gradually increased in response to the suitable ecological condition like increased pH, moisture, etc. and availability of ash minerals in the burned soil.

It may be noted that despite the complete burn of surface organic matter and under storey vegetation, complete sterilization of the soil did not occur even in the upper 2 cm layer of the soil. The effect of more intensive fire may be quite different from what has been observed during this study.

Effect of burning on litter decomposition

The data on litter decay in unburned soils showed that leaflitter of *Wrightia tinctoria* decomposed the fastest compared to other species (Table 4.3).

Table 4.3. Loss in weight of different leaf litters (%)

Species	May 1997	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan. 1998	Feb.
Wrightia tinctoria	53.0	83.1	92.1	96	-	-	-	-	-
Terminalia paniculata	22.0	28.0	72.4	74	86.1	91	92.7	95.4	-
Dillenia pentagyna	22.8	38.2	63.8	72.9	83.4	90.8	92.2	97.1	-
Grewia tiliaefolia	21.3	40.0	55.8	74.6	83.5	90.2	92.3	97.1	-
Xylia xylocarpa	18.3	21.3	23.8	31.3	56.2	63.3	72.6	76.3	80.9
Xylia xylocarpa (In burned plots)	14.4	25.8	28.3	31.8	41.5	60.8	69.7	83.1	87.5

The decay rate of the leaf litters of *Terminalia paniculata*, *Dillenia pentagyna* and *Grewia tiliaefolia* fell almost in the same range. Leaf litter of *Xylia xylocarpa* decomposed the slowest compared to the rest.

There was no significant difference between decay rate of leaf litter of *Xylia* between burned and unburned plots. An overall analysis of the data indicated that the time required for 90% decomposition of the leaf litters of the six dominant tree species (used in this study) in moist deciduous forests of Kerala was 3-10 months and that litter decay rate apparently was not affected by mid burn treatment (Fig. 4.1).

Primary factors affecting litter decomposition are composition of the decomposer organisms, the physical environment (principally the microclimate of the forest floor) and the chemical composition of the material (Swift *et al.* 1979). As burning affects the physical environment and the composition of the microflora and microfauna a change in decay rate of litter in burned sites was expected.

Stark (1973) reported that in Missoula, USA, the rate of decomposition in dry Jeffrey pine forest differed appreciably between burned and unburned sites during the dry summer. In-sub-alpine eucalypt forests in Australia, Raison *et al.* (1986) recorded a reduction in decay rate of leaf litters of *Eucalyptus delegatensis* R. Baker and *Eucalyptus pauciflora* Sieber ex A. Sprangal after prescribed burning. Rate of decay of leaves of *E. dives* Schauer was however, unaffected. Likewise, Grigal and McColl (1977) recorded no significant difference in the decay rate of aspen and aster leaf litter between burned and unburned sites in St. Paul, USA. The results of the present study is in agreement with these observations. Although burning resulted in temporary changes in the physical environment and the composition of the microflora, these do not appear to have affected the rate of litter decomposition. A rapid recovery of soil microflora following burning may be one of the reasons for the lack of impact on decay rates. It also shows that fires of moderate intensity will not cause any lasting effect on litter break down.

The decay rate of leaf litters of *Terminalia paniculata, Dillenia pentagyna* and *Grewia tiliaefolia* recorded during the study generally agrees with the decay rate of these litters reported by Kumar and Deepu (1992) in moist deciduous forests of Kerala. However, the decay rate of *Xylia* leaf litter reported by these authors is much higher than that recorded during this study. The slow rate of decomposition of *Xylia* leaves compared to leaves of other species can be ascribed to the high lignin content of the leaves.

Litterfall

Litterfall is estimated to be 8.49 t ha^{-1} on the unburned and 9.06 t ha^{-1} in the burned site. *Xylia xylocarpa* contributed to the major portion of litterfall in both the study plots. (Table 4.4 and 4.5). This was followed by *Dillenia pentagyna* and *Terminalia paniculata.* In general monthly litterfall in the study sites followed a monomodal pattern with its peak during February–March (Fig. 4.2). The litter yield increased gradually from September in both burned and unburned sites attaining a peak in February–March. There after it decreased in the subsequent months reaching a minimum in May. Leaf litter constituted a major share (68%) of the litter fall. Monthly litter fall of major tree species like *D. pentagyna, X. xylocarpa* and *T. paniculata* showed a monomodal pattern with the peak in litterfall occurring during Feburary-March in both burned and unburned plots (Figs. 4.3-4.5). As regards *G. tiliaefolia,* the peak in litterfall was during January in the unburned plots (Fig. 4.5). The litter fall showed a significant ($P<0.05$) increase during April-May in the burned plots compared to the unburned. The major species which contributed to the increase in litterfall during these months were *X. xylocarpa, D. pentagyna, T. paniculata, Macaranga peltata* and miscellaneous sp. (includes herbs and shrubs). This increase resulted in a high litter fall in the burned plots compared to control. The total litterfall however, was not significantly different between the two sites.

Table 4.4. Monthly litterfall (kg/ha) in a moist deciduous forest in Kerala - contribution of major species (sampling period 1997-1998)

Species	March	April	May	June	July	August	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Total
Dillenia pentagyna	325.31	116.77	34.91	31.72	18.51	8.13	32.43	36.68	48.12	81.85	196.03	467.54	1398.00
Xylia xylocarpa	878.48	203.35	11.91	33.61	39.16	57.08	29.13	50.24	92.60	200.04	346.19	749.81	2691.60
Terminalia paniculata	262.56	39.51	11.44	20.89	19.11	23.00	25.59	94.00	102.50	89.76	218.21	314.93	1221.50
Grewia tiliaefolia	54.49	12.97	20.17	31.13	73.01	17.22	23.47	25.47	82.33	117.71	189.07	139.06	786.10
Wrightia tinctoria	19.96	16.84	4.71	3.77	5.86	0.23	12.62	8.37	1.06	17.71	52.71	14.36	158.20
Helicteres isora	69.00	12.62	4.36	8.49	0.49	1.29	1.53	1.88	9.07	15.68	22.64	61.57	208.62
Pterocarpus marsupium	24.65	13.56	3.59	2.06	1.55	0	1.29	1.36	2.35	3.18	6.18	18.13	77.90
Schleichera oleosa	0.05	1.29	6.13	0.59	0	0	0.11	0	0	0.11	0	0	8.28
Lagerstroemia microcarpa	74.66	19.34	9.70	0.47	19.93	5.30	10.49	5.42	16.04	58.15	69.45	229.95	518.90
Bridelia retusa	15.21	9.55	0	2.94	0	0.82	1.65	0.48	0.35	0.35	6.70	2.71	40.76
Terminalia bellerica	131.60	13.09	9.90	14.39	2.47	0	0	0	4.71	21.11	53.07	87.50	337.84
Strychonos nux-vomica	3.65	13.45	2.71	0.19	0.24	0	0.12	1.42	1.42	1.29	0.71	6.48	31.68
Macaranga peltata	103.32	37.27	5.54	3.18	0	0.11	2.12	2.83	15.33	31.49	23.35	47.16	271.70
Cassia fistula	2.83	4.25	0	0	0	0.11	0.15	1.06	0.35	0.11	2.59	1.65	13.10
Bombax ceiba	0	0	0	0	0	0	0	0	0	0.48	8.02	10.10	18.60
Miscellaneous	233.69	100.40	82.60	12.30	11.01	9.60	10.70	21.90	12.48	66.50	85.01	69.91	716.10
Total	2199.46	614.26	207.67	165.73	191.34	122.89	151.4	251.11	388.71	705.52	1279.93	2220.86	8498.80

Critical difference between months – 24.68.

Critical difference between species – 46.43.

Table 4.5. Monthly litterfall (kg/ha) after prescribed burning treatment in a moist-deciduous forest in Kerala - contribution of major species (sampling period 1997-1998)

Species	March	April	May	June	July	August	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Total
Dillenia pentagyna	317.45	222.62	39.51	11.78	8.62	7.63	10.28	9.65	31.62	53.25	158.68	601.01	1472.10
Xylia xylocarpa	912.85	321.75	32.62	11.61	0.82	1.02	6.07	59.85	162.30	208.20	416.53	678.66	2812.40
Terminalia paniculata	165.28	96.25	12.86	11.63	16.82	19.60	37.40	82.5	112.68	107.20	116.28	200.26	978.76
Grewia tiliaefolia	94.28	48.90	22.68	0.73	1.68	2.28	16.84	26.28	59.73	68.20	97.20	153.13	591.93
Wrightia tinctoria	29.68	36.41	6.27	3.61	3.58	2.62	16.83	9.70	8.4	11.91	32.68	30.48	192.17
Helicteres isora	16.28	18.51	6.51	0	0	0	1.29	10.14	1.29	10.02	74.08	77.25	215.37
Pterocarpus marsupium	21.23	9.62	7.68	1.69	3.25	0	0	2.28	2.61	1.07	3.68	7.15	60.26
Schleichera oleosa	2.83	4.71	7.33	0.23	0.11	0.12	0	0.47	0	0.11	0.86	1.88	18.65
Lagerstroemia microcarpa	112.68	27.92	9.70	0.13	0	5.60	6.73	11.64	13.05	32.68	151.77	249.45	621.35
Bridelia retusa	0.94	8.72	4.60	0	0	0	9.67	13.56	17.1	35.03	24.88	85.39	199.89
Terminalia bellerica	128.91	52.76	2.42	1.62	0.90	0	0	0	2.63	7.26	46.86	74.16	287.52
Strychonos nux-vomica	1.90	4.71	9.83	0.24	0.11	0.12	0	0.47	17.33	0.11	0.82	1.88	37.52
Macaranga peltata	216.81	187.4	5.63	0.64	0	0	0	0	1.82	0.68	0.19	24.01	437.18
Cassia fistula	12.46	8.76	2.75	0.92	0.67	0	0	0.11	1.32	3.65	6.72	6.63	43.99
Bombax ceiba	62.68	16.71	4.28	0.39	0	0	0	0	0	6.28	12.73	22.90	125.97
Miscellaneous	262.11	168.72	102.10	7.50	10.90	6.28	1.40	9.70	6.2	23.50	58.63	106.86	963.90
Total	2358.37	1404.67	276.77	52.72	47.46	45.27	106.51	236.35	438.08	569.15	1202.59	2321.10	9058.90

Critical difference between months – 22.68.
Critical difference between species – 53.29.

Fig. 3.2. Monthly litterfall (kg/ha) in the moist deciduous forest

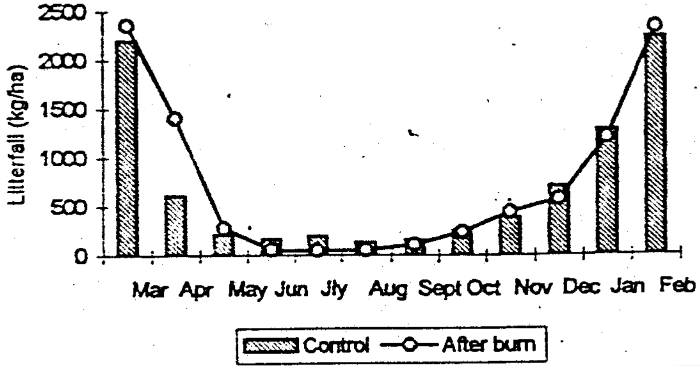
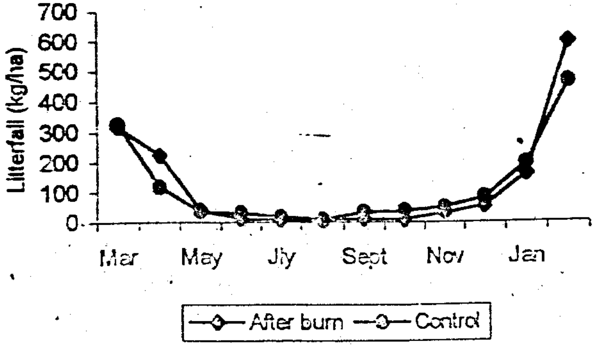


Fig 3.3. Monthly litterfall (kg/ha) - *Dillenia pentagyna*



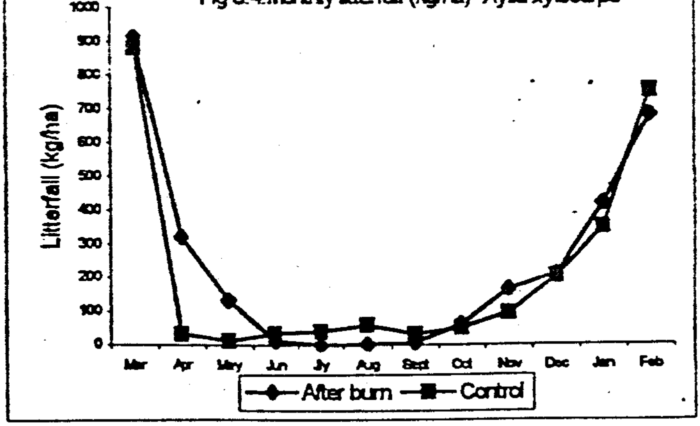


Fig 3.4. Monthly litterfall (kg/ha)- *Xylia xylocarpa*

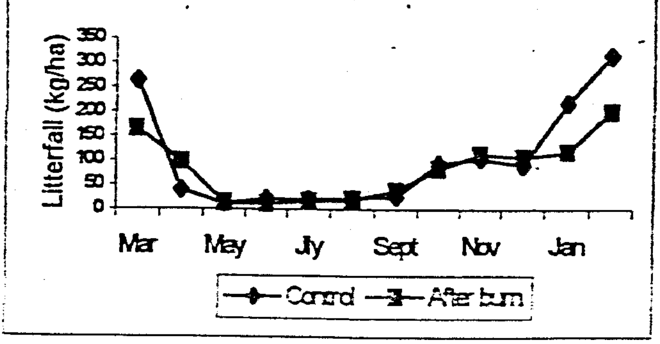


Fig. 3.5. Monthly litterfall (kg/ha) - *Terminalia paniculata*

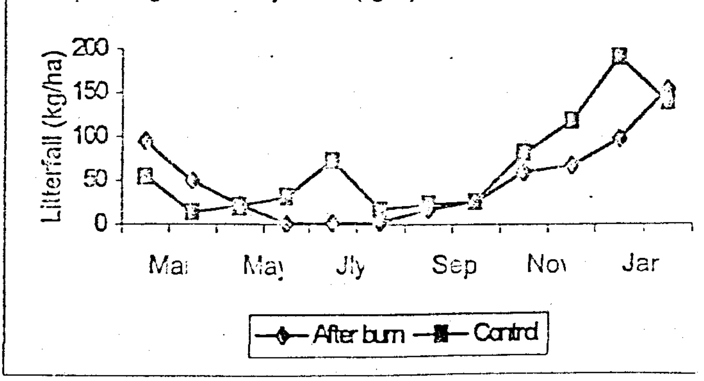


Fig. 3.6. Monthly litterfall (kg/ha) - *Grewia tiliaefolia*

Annual litterfall in tropical forests is estimated to range between 5.5 and 15.3 t/ ha^{-1} (Laudelot and Meyer, 1954; Williams and Gray, 1974). The annual litter yield in moist deciduous forests of Kerala falls within this range. The data agree with the litterfall predicted from Bray and Gorhams (1964) inverse relationship between annual litter production and latitude of the region (9.8 t/ha^{-1} at 10° N latitude). Litterfall in moist deciduous forests of Kerala was recorded as 12.2 to 14.4 t/ha^{-1} by Kumar and Deepu (1992). Litter fall estimated through this study is lower than this. This difference may be due to the difference in stand basal area and density at each site. (Stohlgren, 1988). Leaf shedding was more pronounced during summer months. (January – April) for all the major species. Tree water stress and rise in temperature due to recurrent fires are probable reasons for a high litter fall during summer months (Kumar and Deepu, 1992). Data from deciduous plantations also indicate maximum litter production during summer months (Ghosh *et al.*, 1982; Kikuzawa *et al.*, 1984).

A significant increase in litter fall during April-May in burned plots is probably due to scorching of canopy of some of the major tree species and miscellaneous understorey.

CONCLUSIONS

The following conclusions could be drawn from the results of the study:

Prescribed burning (of moderate intensity) can temporarily reduce the soil microbial population mainly in the upper most layer (0-2 cm) of the soil. The population of fungi and bacteria reverts back to the pre-burn status in a few weeks time depending on the intensity of fire.

Moderate intensity fires appear to have no effect on rate of leaf litter decay of selected species as recovery of the microflora and the physical environment of the soil occurs rapidly.

Burning can result in a temporary rise in litter fall in moist deciduous forests. Leaves of trees and understorey scorched by the flames contributed to this increased litter production.

REFERENCES

Ahlgren, I.F. 1974. The effect of fire on soil organisms In: T.T. Kozlowski and C.E. Ahlgren (Eds.). Fire and Ecosystems. Academic Press, New York. pp. 47-72.

Ahlgren, I.F. and C.E. Ahlgren 1965. Effect of prescribed burning on soil microorganisms in Minnesota jack pine forest. *Ecology*, 46: 304-310.

Bray, R.J. and E. Gorham. 1964. Litter production in forests of the World. *Adv. Ecol. Res.*, 2: 121-157.

Cohen, C. 1956. The occurrence of fungi in soil after different burning and grazing treatments in the field of Transvaal. *S. Afr. J. Sci.*, 46: 245-246.

Fogel, R, and K. Cromack 1977. Effect of habitat and substrate quality on Douglas fir litter decomposition in Western Oregon. *Can. J. Bot.*, 55: 1632-1640.

Ghosh, R.C. O.N. Kaul and B.K. Subba Rao 1982. Environmental effects of forests in India. Indian Forest Bull. No. 275. Controller of Publications. Govt. of India, New Delhi, 20 p.

Grigal, D.F. and J.G. McColl, 1977. Litter decomposition following fire in north eastern Minnesota. *J. Appl. Ecol.*, 14: 531-538.

*Hintikka, V. (1960). Zur Okologie einiger on Brandplatzen Vorkommender Blatterpilzarten. *Karstenia*, 5: 100-106.

*Jacques, F.H. 1947. L'agriculture des noirs du cameronn, une forme particuliere de l'econbage. *Agron. Trop.*, 2: 180-182.

Jalaluddin, M. 1969. Micro-organic colonization of forest soil after burning. *Plant and Soil*, 30: 150-152.

Jorgensen, J.R. and C.S. Hodges 1970. Microbial characteristics of a forest soil after twenty years of prescribed burning. *Mycologia*, 62: 721-726.

Kikuzawa, K.,T. Asai and M. Rukuchi 1984. Leaf litter production in a plantation of *Alnus inokumae*. *J. Ecol.*, 72: 993-999.

Kumar, B.M. and J.K. Deepu 1992. Litter production and decomposition dynamics in moist deciduous forests in the Western Ghats of Peninsular India. *For. Ecol. Manage.*, 50: 181-201.

Laudelot, H. and J, Meyer. 1954. Mineral element and organic material cycles in the equatorial forest of the Congo.*Oecol. Plant.*, 7: 1-21.

Luke, R.H. and McArthur, A.G. 1978. Bushfires in Australia, AGPS, Canberra.

Meiklejohn, J. 1953. The effect of bush burning on the microflora of some Kenya soils. Proc. Int. Conf. Microbiol., 10: 317-319.

Neal, J.L. E. Wright & W.B. Bollen 1965. Burning Douglas fir slash. Physical, chemical and microbial effects on soil. Res. Paper. Oregon. State Univ. Forest Research Laboratory 1: 32 p.

O'Connell, A.M. T.S. Grove, and D. Lamb 1981. The influence of fire on the nutrition of Australian forests. *In*: Proc.Aust. Forest Nutrition Workshop. pp. 277-289, CSIRO, Melbourne.

Olson, J.S. 1963. Energy storage and balance of producers and decomposers in ecological systems. *Ecology*, 44: 322-331.

Parkinson, D. and S.T. Williams 1961. A method for isolating fungi from soil microhabitats. *Plant and Soil*, 4: 347-355.

Raison, R.J., P.V. Woods and P.K. Khanna 1986. Decomposition and accumulation of litter after fire in Subalpine eucalypt forests. *Aust. J. Ecol.*, 11: 9-19.

Renbuss, M.A., G.A. Chilvers, and L.D. Pryor. 1973. Microbiology of an ash bed. Proc. Linn. Soc. N.S.W., 97: 302-311.

Springett, J.A. 1976. The effects of prescribed burning on the soil fauna and on litter decomposition in Western Australian forests. *Aust. J. Ecol.*, 1: 77-82.

Stark, N. 1973. Nutrient cycling in a Jeffrey pine ecosystem. Montana Forest Expt. Sta., Missoula.

Stohlgren, T.J. 1988. Litter dynamics in two Sierran mixed conifer forests. I. Litter fall and decomposition rates. *Can. J. For. Res.*, 18: 1127-1135.

Swift, M.J., O.W. Heal and J.M. Anderson. 1979. Decomposition in Terrestrial Ecosystems. Blackwell Scientific Publications, Oxford, 372 p.

Theodorou, C. and G.D. Bowen 1982. Effects of a bushfire on the microbiology of a South Australian low open (dry sclerophyll) forest soil. *Aust. For. Res.*, 12: 312-327.

Tiwari, V.K. and Bharat Rai 1977. Effect of soil burning on microfungi. *Plant and Soil*, 47: 692-697.

Williams, S.T. and T.R.G. Gray 1974. Decomposition of litter on the soil surface *In*: CH. Dickinson and G.J.F. Pugh (Eds.). Biology of plant litter decomposition Vol.II. Academic Press, London, pp: 611-632.

Wright, E. and W.B. Bollen 1961. Microflora of Douglas fir forest soil. *Ecology*, 42: 825-828.

Wright, E. and R.F. Tarrant 1957. Microbial soil properties after logging and slash burning. US Forest Service. Pac. Northwest Forest Range Exp. Sta. Res. Notes, 157.

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* *Original not seen.*

Chapter 5

NURSERY AND FIELD STUDIES ON STUMP PLANTING

INTRODUCTION

The stump - 'the root and shoot pruned seedling' - is a potential planting material used in raising plantations of many forest tree species. Though the stump planting technique is well established in species like teak, many economically important tree species are yet to be systematically studied for the feasibility of this method.

The stump, as a planting material is successfully used in raising plantations of many forest tree crops (Troup, 1921; Champion and Pant, 1931; Joshi, 1981). Stump planting has its own inherent advantages over conventional method of planting seedlings. Stumps are easy to plant, convenient to transport and are endowed with quicker initial growth and deep root development (Khanna, 1984).

Champion and Pant (1931) conducted a series of experiments using stumps of nearly 50 tree species of India and the results revealed that stump planting offers greater certainty of successful stocking in hostile areas compared to direct sowing and transplanting seedlings. Stumps were found to yield higher survival percentage, better shoot growth and were more resistant to the insect pests compared to seedlings.

The size and age of seedlings are two important factors which determine the survival and growth of stumps (Marcel, 1970; Joshi, 1981); Joshi (1981) reported better survival and growth of many moist deciduous tree species using stump prepared out of 1-2 year old seedlings having a collar diameter of 2.5 cm and tap root length of 10-20 cm. In *Terminalia crenulata*, a study carried out by Marcel (1970) showed higher rate of survival and faster growth with stumps having 3-4 cm collar diameter than stumps with a collar diameter less than 3cm.

Bombax ceiba Linn., *Gmelina arborea* Roxb., *Grewia tilaefolia* Vahl., *Lagerstroemia microcarpa* Wight., *Melia dubia* Cav., *Pterocarpus marsupium* Roxb., *Tectona grandis* L.f., *Terminalia bellirica* Roxb., *Terminalia crenulata* Heyne *ex* Roth, *Terminalia paniculata* Roth and *Xylia Xylocarpa* (Roxb.) Taub. are some of the dominant, fast growing and commercially important timber trees found in the moist deciduous forests of the Western Ghats (Chandrasekharan, 1962; Champion and Seth, 1968; Swarupanandan and Sasidharan, 1992).

Considering the growing economic and ecological importance of these species in several parts of the tropics, attempts have been made to raise plantations using stumps made out of six month old seedlings of some of these species (Rai, 1990). Many of these plantation attempts met with little or no success, especially in degraded lands, because of poor initial growth, which made them more susceptible to the seasonal fires and various diseases (Dadhwal and Singh, 1983). Champion and Pant (1931) had experimented the possibilities of stump planting with a few of the above mentioned species: *Gmelina arborea*, *Grewia tiliaefolia*, *Pterocarpus marsupium*, *Terminalia crenulata* and *Xylia xylocarpa* with partial success. The planting techniques for teak (*Tectona grandis*) has been pioneered with planting of stumps (Champion and Pant, 1931). The present investigation on stump planting was undertaken on some selected tree species, including some species not attempted by Champion and Pant (1931) and are important in South Indian moist deciduous forests. The study was carried out to understand the regeneration capability of the selected moist deciduous tree species when they are planted as stumps. The potential of stumps of these species for survival and growth in fire prone areas was also subjected to study.

MATERIALS AND METHODS

Nursery studies

In order to understand the regeneration capacity of stumps of selected moist deciduous tree species and to study the possibility of employing stump planting technique for fire survival, seedlings of the selected species were raised in nursery beds by sowing seeds. The species were *Anogeissus latifolia, Bombax ceiba, Dalbergia sissoides, Gmelina arborea, Grewia tiliaefolia, Lagerstroemia microcarpa, Melia dubia, Pterocarpus marsupium, Tectona grandis, Terminalia bellerica, Terminalia crenulata* and *Xylia xylocarpa*. Seeds of these species were procured and sown in standard nursery beds (12 m x 1.2 m) to obtain sufficient number of seedlings. Shading was provided using coir-mats over the nursery beds. Watering and other nursery care were also provided to the germinating seeds so that uniform lots of seedlings of these species were made available for carrying out nursery experiments on stump regeneration.

When seedlings attained 1-2 year growth in the nursery, they were uprooted, without damaging the tap root. Stumps were made from these seedlings and using these stumps regeneration trials were carried out in the nursery. The stumps were sorted into two groups according to their collar diameter as 1-2 cm and 2-3 cm. The prepared stumps were planted in polybags (18 cm x 12 cm) filled with soil and sand (1:1) and were kept under partial shade. Watering was done regularly and observations on sprouting and rooting recorded.

Field studies

Selection of site

An area of approximately 0.70 ha was surveyed and demarcated in a poorly stocked moist deciduous forest, which is subjected to seasonal fires. This area was divided into two equal plots of 0.35 ha (70 m x 50 m). Both the plots were planted with stumps of different deciduous species. One plot was treated as control, while the other one served as the experimental plot for the survival study of stumps from fire.

Selection of species

The following eleven moist deciduous species were selected for stump planting trial in the field plots based on their performance on regeneration capacity in nursery trials.

Anogeissus latifolia
Bombax ceiba
Gmelina arborea
Grewia tiliaefolia
Lagerstroemia microcarpa
Melia dubia
Pterocarpus marsupium
Tectona grandis
Terminalia bellerica
Terminalia crenulata
Xylia xylocarpa

Preparation of stumps

Stumps were prepared out of one to two year old seedlings raised in the nursery. Seedlings from the nursery beds were uprooted, carefully without causing damage to roots. The seedlings were then grouped as follows:

1. Seedlings with stem diameter >1.5 cm at the collar region.
2. Seedlings with stem diameter < 1.5 cm at the collar region.

The stumps having different diameters, shoot heights and tap root lengths were prepared as shown in the Table 5.1. using these seedlings.

Table. 5.1. Table showing the measurements of various groups of stumps

Treatment No.	Collar diameter (cm)	Height of shoots (cm)	Tap root length (cm)	Total length
1	> 1.5	100	30	130
2	>1.5	2.5	30	32.5
3	<1.5	2.5	30	32.5

One-year-old bare root seedlings were also kept ready for planting along with the stumps for comparative study.

Design and lay out for planting

A linear design of planting was followed with three replicates. A planting line having 1.5 m width was cleared of all vegetal forms and pits of size 30 cm x 30 cm x 30 cm were taken at 1 m spacement. A three meter spacing was also provided between the lines of planting (Fig. 5.1).

Fig. 5.1. Diagrammatic plot chart showing the line of planting stumps

C1		A1		C3		A2
C1		A1		C3		C3
C1		A1		C3		C3
C1		C2		C3		C3
C1		C2		C3		C3
C1		C2		B2		C3
B1		C2		B2		B3
B1		C2		B2		B3
B1		A2		B2		B3
B1		A2		B2		B3
B1		A2		A2		B3
A1		A2		A2		A3
A1		A2		A2		A3

A,B,C, etc- Species names; 1,2,3, etc-Treatment.

Planting

Planting was started in the second week of June (immediately after the onset of South West monsoon) and was completed by the end of the month. Pitting was completed sufficiently prior to planting and the pits were treated with 0.05% Chloropyriphos solution as a prophylactic measure against termite attack. Stumps were planted vertically and were labelled individually. Soil manipulation was carried out around each planted stump to avoid any possible water logging, during the heavy monsoon period.

Maintenance

The planted stumps were carefully maintained by providing barbed wire fencing and by carrying out necessary silvicultural operations like weeding etc. whenever needed.

Prescribed burning

One of the two experimental plots maintained was subjected to prescribed burning during March, 1998. All the stumps and seedlings present in the plot were subjected to fire.

Observations

Observations on sprouting and survival of each stump in the nursery trial as well as in the field trial were recorded regularly. Observations on sprouting and fire survival of each stump and seedling were recorded before and after fire in both the experimental as well as in control plots. Observations on height of shoot, diameter, number of new leaves produced on sprouted shoots of stumps and seedlings were recorded at monthly interval.

RESULTS AND DISCUSSION

Nursery studies

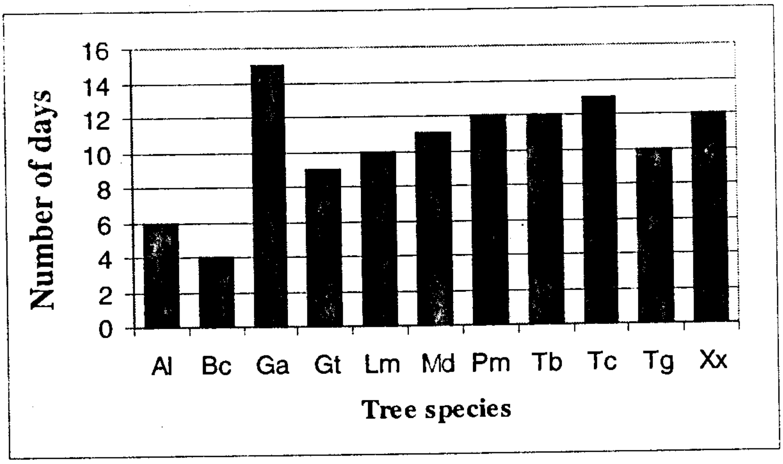
Response of stumps

The results of stump regeneration trials carried out in the nursery are presented below. The response of stumps of different moist deciduous species, to regenerate and establish was studied. Their readiness and speed to sprout (time-taken in days) and produce new shoots and roots have been evaluated. The height and diameter of shoots produced on stumps and number of new leaves produced on shoots were also recorded.

Speed of sprouting (Number of days taken for sprouting)

Speed of sprouting of stumps of various deciduous species in terms of number of days taken to produce first sprout after planting is presented in the Fig. 5.2. Maximum speed of sprouting i.e. minimum number of days taken for sprouting (4 days) was recorded in the case of *Bombax ceiba*, while the speed of sprouting was minimum in *Gmelina arborea* which took 15 days to produce sprouts on the stumps. All other species exhibited speed of sprouting in between these values (4-15 days) with most of the species producing sprouts within 7 days.

Fig. 5.2. Speed of sprouting (Number of days taken to sprout) of stumps of various deciduous tree species

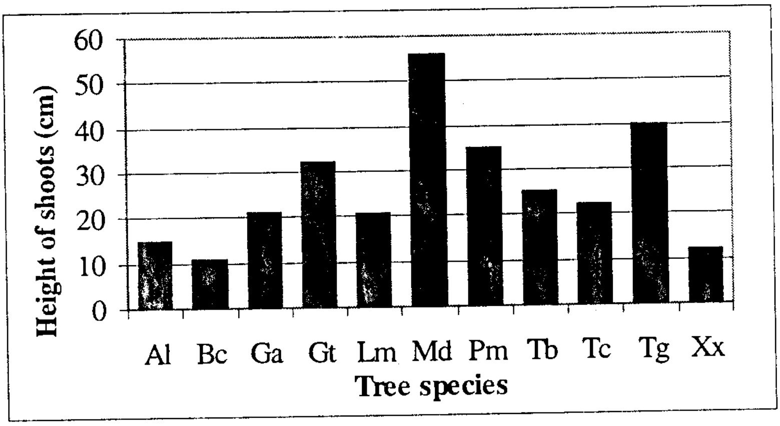


Al- *Anogeissus latifolia* Bc- *Bombax ceiba*; Ga- *Gmelina arborea*; Gt- *Grewia tiliaefolia*; Lm- *Lagerstroemia microcarpa*; Md- *Melia dubia*; Pm- *Petrocarpus marsupium*; Tb- *Terminalia bellerica*; Tc- *Terminalia crenulata*; Tg- *Tectona grandis*; Xx- *Xylia xylocarpa*.

Height of shoots

The height of shoots produced on stumps was measured after 60 days of planting. The Fig. 5.3. shows the mean values of shoot heights obtained for

Fig. 5.3. Mean height of shoots produced on stumps 60 days after planting



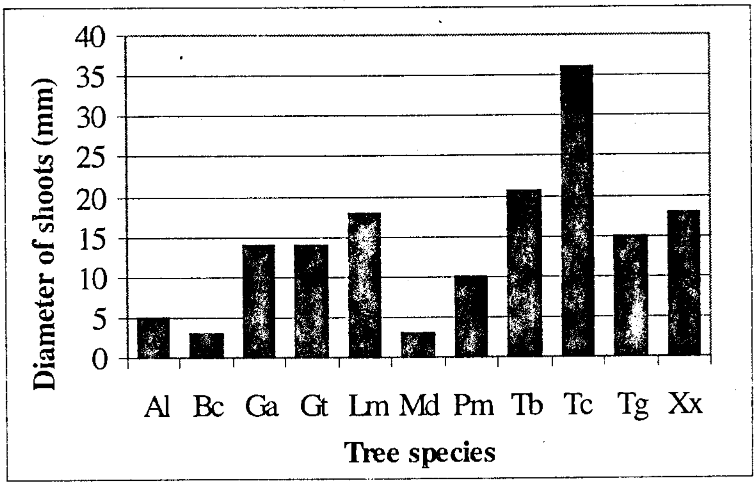
Al- *Anogeissus latifolia* Bc- *Bombax ceiba*; Ga- *Gmelina arborea*; Gt- *Grewia tiliaefolia*; Lm- *Lagerstroemia microcarpa*; Md- *Melia dubia*; Pm- *Pterocarpus marsupium*; Tb- *Terminalia bellerica*; Tc- *Terminalia crenulata*; Tg- *Tectona grandis*; Xx- *Xylia xylocarpa*.

various species tried. The mean height was maximum (56 cm) in the case of *Melia dubia* while it was minimum (10.5 cm) in stumps of *Bombax ceiba*.

Diameter of shoots

The diameter of the tallest shoot produced on the stump was measured in all the species tried and the mean values obtained are presented in the Fig. 5.4.

Fig. 5.4. Mean diameter of shoots produced on stumps
60 days after planting



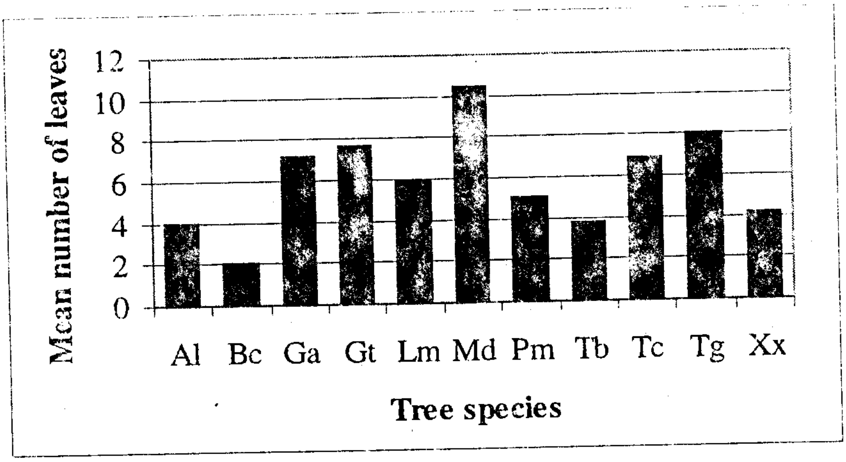
Al - *Anogeissus latifolia* Bc- *Bombax ceiba*; Ga- *Gmelina arborea*; Gt- *Grewia tiliaefolia*; Lm- *Lagerstroemia microcarpa*; Md- *Melia dubia*; Pm- *Pterocarpus marsupium*; Tb- *Terminalia bellerica*; Tc- *Terminalia crenulata*; Tg- *Tectona grandis*; Xx- *Xylia xylocarpa*.

Maximum mean diameter (36 mm) was obtained in *Terminalia bellerica* while minimum mean value (3 mm) for diameter of shoot produced on stumps was recorded for *Melia dubia* and *Bombax ceiba*.

Number of leaves

The number of leaves produced on shoots of stumps in each species were recorded and the mean values are presented in Fig. 5.5. The number of leaves produced in general, were proportional to the height of the shoots. Shoots of *Melia dubia* had maximum mean number (10.5) of leaves, while it was minimum in the case of *Bombax ceiba* (2.0).

Fig. 5.5. Mean number of new leaves on shoots produced on stumps 60 days after planting



Al - *Anogeissus latifolia* Bc- *Bombax ceiba*; Ga- *Gmelina arborea*; Gt- *Grewia tiliaefolia*; Lm- *Lagerstroemia microcarpa*; Md- *Melia dubia*; Pm- *Pterocarpus marsupium*; Tb- *Terminalia bellerica*; Tc- *Terminalia crenulata*; Tg- *Tectona grandis*; Xx- *Xylia xylocarpa*.

Field studies

The stumps of *G. arborea*, *B. ceiba*, *P. marsupium*, and *L. microcarpa* exhibited maximum percentage of establishment whereas, the success percentage was less with *Anogeissus latifolia*, *G. tiliaefolia* and *T. crenulata*. Stumps of *G. arborea microcarpa*, *P. marsupium* and *B. ceiba* showed better performance when compared with seedlings (Table 5.2). Among the different treatments tried, first treatment (1 m stem and 2.5 cm root portion) showed maximum percentage of fire survival compared to smaller size stumps and seedlings.

In general, stumps planted in control plots exhibited higher percentage of survival (Table 5.3) since these were not subjected to prescribed burning. Stumps with 100 cm stem and 30 cm root having collar diameter of above 2.5 cm was found to withstand prescribed fire. Among the different deciduous tree species tried, thick barked species such as, *Gmelina arborea* and *Pterocarpus marsupium* were found to be more suitable for planting in fire prone regions.

Table 5.2. Survival of stumps and seedlings before fire (BF) and after fire (AF)

Sl. No.	Treatments	Species										
	Particulars	Al	Bc	Ga	Gt	Lm	Md	Pm	Tb	Tc	Tg	Xx
1	No. of stumps planted	15	15	15	15	15	14	15	15	15	15	15
	% of stumps established BF	0	100	93	13	93	64	100	60	33	80	47
	% of stumps survived AF	0	10	50	0	7	0	25	0	0	25	14
	% of stumps resprouted AF*	0	80	50	100	79	100	75	78	60	75	86
2	No. of stumps planted	15	15	15	15	15	13	14	15	15	15	15
	% of stumps established BF	20	20	100	40	93	100	100	93	27	60	60
	% of stumps survived AF	0	0	27	0	0	0	0	0	0	0	0
	% of stumps resprouted AF*	0	0	60	80	100	100	100	79	11	78	78
3	No. of stumps planted	15	15	15	15	15	10	15	15	15	15	15
	% of stumps established BF	40	73	80	0	87	75	80	93	0	87	80
	% of stumps survived AF	0	0	0	0	0	0	0	0	0	0	0
	% of stumps resprouted AF*	100	100	83	0	92	20	67	36	0	85	80
4	No. of seedlings planted	10	15	10	15	15	10	15	15	15	15	15
	% of seedlings established BF	80	93	70	80	73	80	93	100	67	87	87
	% of seedlings survived AF	0	0	20	0	0	0	0	7	0	0	0
	% of seedlings resprouted AF*	75	100	70	40	73	40	86	73	80	85	77

Note: *- Percentage of stumps and seedlings resprouted from the underground portion of the stem after drying above ground portions during prescribed fire.

Treatment 1- Stumps with collar diameter > 1.5 cm and stem of 100 cm height

Treatment 2- Stumps with collar diameter > 1.5 cm and stem of 2.5 cm height

Treatment 3- Stumps with collar diameter < 1.5 cm and stem of 2.5 cm height

Treatment 4- Six-month-old to one-year-old bare root seedlings

Al- *Anogeissus latifolia*; Bc- *Bombax ceiba*; Ga- *Gmelina arborea*; Gt- *Grewia tiliaefolia*; Lm- *Lagerstroemia microcarpa*; Md- *Melia dubia*; Pm- *Pterocarpus marsupium*; Tb- *Terminalia bellerica*; Tc- *Terminalia crenulata*; Tg- *Tectona grandis*; Xx- *Xylia xylocarpa*.

Table 5.3. Survival of stumps and seedlings in control (no burning) plot

Sl. No.	Treatments	Species										
	Particulars	Al	Bc	Ga	Gt	Lm	Md	Pm	Tb	Tc	Tg	Xx
1	No. of stumps planted	15	15	15	15	14	12	10	15	15	15	15
	% of stumps established in 1st season	0	100	100	7	100	46	100	67	7	33	33
	% of stumps survived in 2nd season	0	100	100	100	100	100	100	100	100	100	100
2	No. of stumps planted	15	12	12	13	15	13	15	15	15	15	15
	% of stumps established in 1st season	20	67	67	23	93	67	100	73	53	80	33
	% of stumps survived in 2nd season	100	100	100	100	100	100	100	100	100	100	100
3	No. of stumps planted	15	15	15	15	14	15	15	15	15	15	15
	% of stumps established in 1st season	27	73	73	0	36	0	0	0	0	73	80
	% of stumps survived in 2nd season	100	91	91	0	100	0	0	0	0	91	100
4	No. of seedlings planted	10	15	15	14	15	15	15	15	11	15	15
	% of seedlings established in 1st season	40	66	66	71	60	0	86	92	36	86	73
	% of seedlings survived in 2nd season	100	100	100	100	100	0	100	100	100	100	100

Note: 1st season represents March 1998 (*ie.* before burning season)
2nd season represents July 1998 (*ie.* after burning season)

Treatment 1- Stumps with collar diameter > 1.5 cm and stem of 100 cm height
Treatment 2- Stumps with collar diameter > 1.5 cm and stem of 2.5 cm height
Treatment 3- Stumps with collar diameter < 1.5 cm and stem of 2.5 cm height
Treatment 4- Six-month-old to one-year-old bare root seedlings

Al- *Anogeissus latifolia*; Bc- *Bombax ceiba*; Ga- *Gmelina arborea*; Gt- *Grewia tiliaefolia*; Lm- *Lagerstroemia microcarpa*; Md- *Melia dubia*; Pm- *Pterocarpus marsupium*; Tb- *Terminalia bellerica*; Tc- *Terminalia crenulata*; Tg- *Tectona grandis*; Xx- *Xylia xylocarpa*.

For all the parameters studied, in general, thicker stumps showed better growth performance with regard to survival, height and diameter growth of shoots and number of leaves produced. Griffith (1941) observed similar trends for *Azadirachta indica, Feronia elephantum, Pterocarpus santalinus* and *Wrightia tinctoria.* It appears that the thickness of the stump is an important parameter to be considered for the early growth and survival, when stumps are used for planting.

Generally, stumps have more carbohydrate storage and this may be responsible for the quicker initial growth, as has been already pointed out by Shiroya *et al.* (1962). It has also been suggested that the accumulation of the carbohydrates close to the root collar region facilitate development of profuse lateral roots (Hay and Woods, 1978). For better early growth, an extensive lateral root system might be advantages than a strong tap root system with sparse lateral roots.

The stump has greater food reserves which enables it to maintain a live shoot over the dry period, but which can be fatal in the case of seedlings in many hostile situations. In the case of stumps, even if the shoots dry up during the dry season or in the adverse situations like ground fire, because of the stored food reserves, they can regenerate in the succeeding favorable season (Champion and Pant, 1931). Thus the stumps are at an advantageous position over the seedlings, in using food reserves needed for the growth and therefore in competing with the environment and surviving. Because of these factors stump planting should be prescribed increasingly in revegetation attempts on denuded or degraded areas so that the efforts may bring forth high rates of success. In areas where fire is an annual phenomenon, prescribed burning in the early summer would be an ideal management choice, except for areas in high altitudes and in very steep slopes.

CONCLUSIONS

The stumps of *Gmelina arborea, Bombax ceiba, Pterocarpus marsupium* and *Lagerstroemia microcarpa* exhibited maximum percentage of establishment, whereas, the success percentage was less with *Anageissus latifolia, Grewia tiliaefolia* and *Terminalia crenulata.* Stumps of *Gmelina arborea, Lagerstroemia microcarpa, Pterocarpus marsupium* and *Bombax ceiba* showed better performance when compared with seedlings. Among the different treatments tried, first treatment (1m stem) showed maximum percentage of fire survival compared to smaller size stumps and seedlings. Out of 11 tree species tried *Gmelina arborea* exhibited higher fire survival capability.

REFERENCES

Champion, H.G. and Pant, B.D. 1931. The use of stumps (root and shoot cuttings) in artificial regeneration. *Indian For. Rec.* 16 (6): 157-158.

Champion, H.G. and Seth, S.K. 1968. A revised survey of the forests types of India. Government of India Press, Nasik.

Chandrasekharan, C. 1962. Forest types of Kerala State, pt. 2. *Indian Forester,* 88 (11): 837-847.

Dadhwal, K.S. and Singh, B. 1983. Rooting behavior of different plant species in limestone mined area. *Indian Forester,* 119(1): 71-74.

Griffith, A.L. 1941. Investigations into artificial regeneration details of the dry fuel forests of Madras. *Indian For. Rec.*, 4(4): 178-179.

Hay, R.I. and Woods, F.W. 1978. Carbohydrate relationship in root system of planted lobolly pine seedlings. Proc. Symp. On root forms of planted trees. pp 73-84. British Columbia Ministry of Forests/Canadian Forest Services Joint Report 8.

Joshi, H.B. 1981. Troup's Silviculture of Indian trees, vols. 1-4. ICFRE, Dehra Dun.

Khanna, L.S. 1984. Principles and practice of silviculture. Khanna Bandhu Publ., New Delhi.

Marcel, L. 1970. Tree planting practices in tropical Asia. FAO Forestry Development Paper 11.

Rai, S.N. 1990. Reforestation of degraded tropical rainforests. Proc. MAB Regional Training Workshop on Trop. For. Ecosyst. Conserv. Develop. S & SE Asia. Pages 98-105. Kerala Forest Research Institute, Peechi.

Shiroya, T., Lister, G.R., Slankis, V., Drolkov, G. and Nelson, C.D. 1962. Translocation of products of photosynthesis to roots of pine seedlings *Can. J. Bot.*, 40 : 1125-1135.

Swarupanandan, K. and Sasidharan, N. 1992. Regeneration studies on some important trees in a natural moist deciduous forest ecosystem. KFRI Research Report 83.

Troup, R.S. 1921. The silviculture of Indian trees, vols. 1-3. Clarendon Press, Oxford.

Chapter 6

GENERAL CONCLUSION

One of the major causes of degradation and desertification of forest areas, particularly the moist deciduous forest in India is the recurrent incidence of fire. It is well known that fire causes extensive damage in the forests, not only affecting regeneration and stocking, but also interfering in various ways the functioning of these valuable ecosystems. However, the problems of forest fire has never been the subject of serious scientific research in the country and it is more so with the South Indian Moist Deciduous Forests. It was in this context that the present study was initiated. It deals with the impact of seasonal fires in moist deciduous forests on, i. Tree regeneration, ii. Litter dynamics, iii. Soil flora and fauna, iv. Physical and chemical properties of soil and, v. ability of selected tree species to survive fires.

The following conclusions were drawn based on the field observations recorded during the study.

1. The availability and nature of fuel (litter) in terms of its moisture content controlled by the external temperature is the main reason for triggering an out break of fire in moist deciduous forests. Further spread and behaviour of fire in general, are controlled by factors like fuel porosity, its size, quantity, continuity, soil moisture, wind speed in the forest area.

2. Incidence of fire during early summer months (up to February in South India) caused minimum damage to the flora and fauna as well as to the soil properties. It has a favourable effect on germination of seeds of many tree species and grass. Prescribed burning, in early summer months could be practised as a potential management tool except in high altitude areas and steep slopes.

3. The impact of burning treatments (prescribed fire) during mid and late summer months (February to May) was more pronounced in plants of small diameter class (under 5 cm dbh) compared to trees. Small saplings of trees got dried up due to fire, while shrubs, herbs and grasses regenerated and increased in number. Regeneration of plants was poor in plots subjected to late burn compared to other treatments.

4. The intensity and season of occurrence of fire could bring forth varied impacts on forests. Fire caused a temporary increase in particle density, pH, exchangeable bases and levels of K, Ca and Mg in soils. Most of these

changes were apparent in early, mid and late burn treatment plots. Silt content, porosity and level of organic carbon were adversely affected. Though, the preburn status was restored in a year's time, recurrent fires may render the soil exposed due to lack of litter cover and resultant washing away of ash and other accumulated nutrients, especially in slopes. This could lead to soil run off and thus degradation of soil.

5. There was a temporary decrease in the density of all macro and meso fauna in the soil as a result of fire, irrespective of the time of occurrence. This adverse affect was more pronounced during fires in mid and late summer.

6. Fire of moderate intensity caused a temporary reduction in population of soil fungi and bacteria in the upper most layer (0-2 cm) of soil. The population of fungi and bacteria reverted to the pre burn status in a few week's time.

7. A temporary rise in litter fall was observed following fire in the moist deciduous forests. Premature shedding of leaves, scorched due to the flames, contributed to this increase in litter production. The rate of litter decay was unaffected by fire of moderate intensity.

8. Planting fire resistant species in frequently fire prone areas, appears to be a practical proposition to reduce adverse effect on vegetation. Thick barked species were found more fire resistant than other tree species. The practice of planting stumps could be adopted, instead of conventional method of planting seedlings. Healthy stumps (collar diameter > 1.5 cm and shoot height >1 m) of relatively more fire resistant species (eg. *Gmelina arborea*, *Pterocarpus marsupium*, etc.) may be planted for successful revegetation of moist deciduous forests prone to recurrent fire.

The study revealed that, more details and systematic approaches are necessary to understand the various impacts of fire on moist deciduous forest ecosystem.

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Plate 1: Vegetation and ground litter before different burning treatments. A: Before early-burning. B: Before mid-burning.

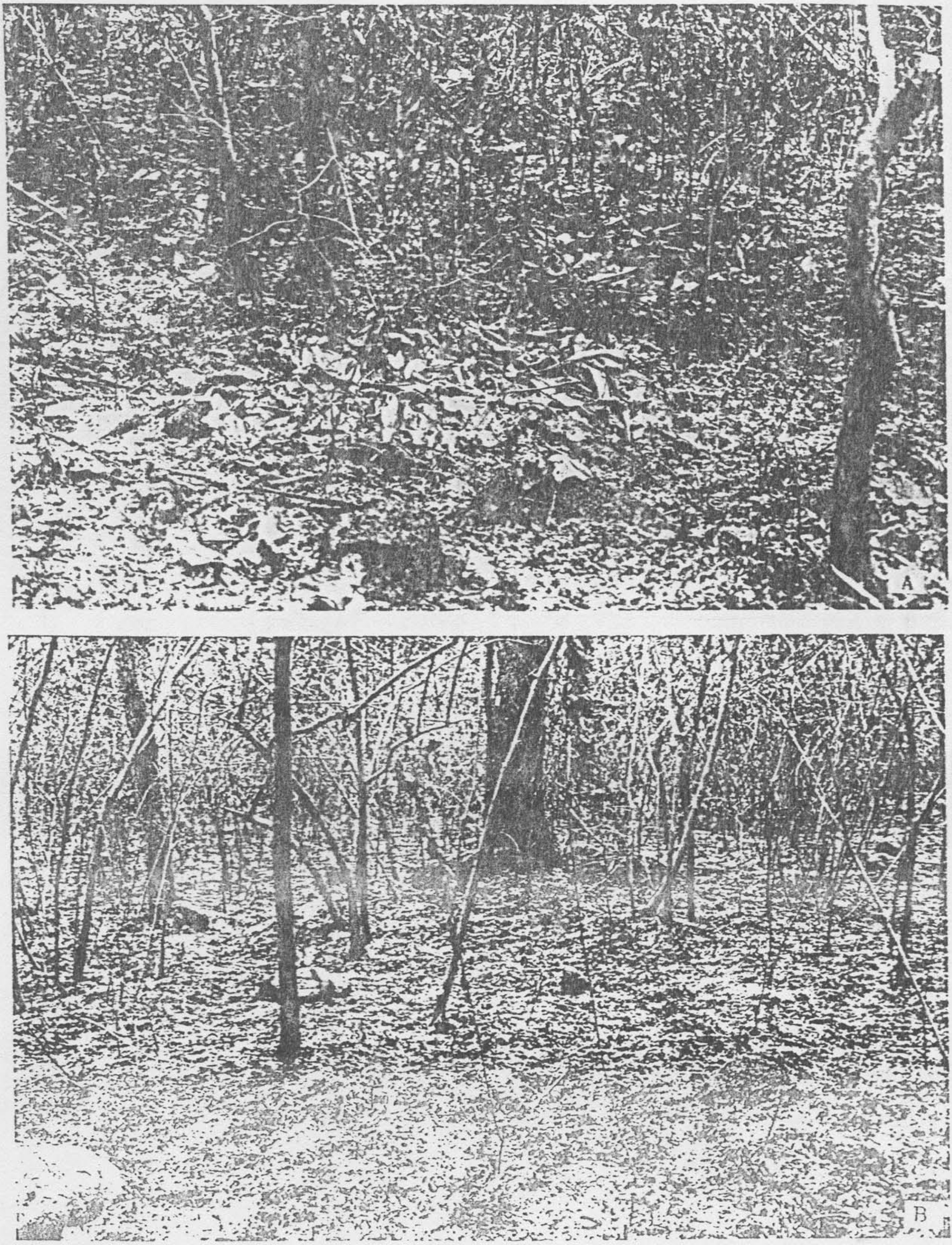
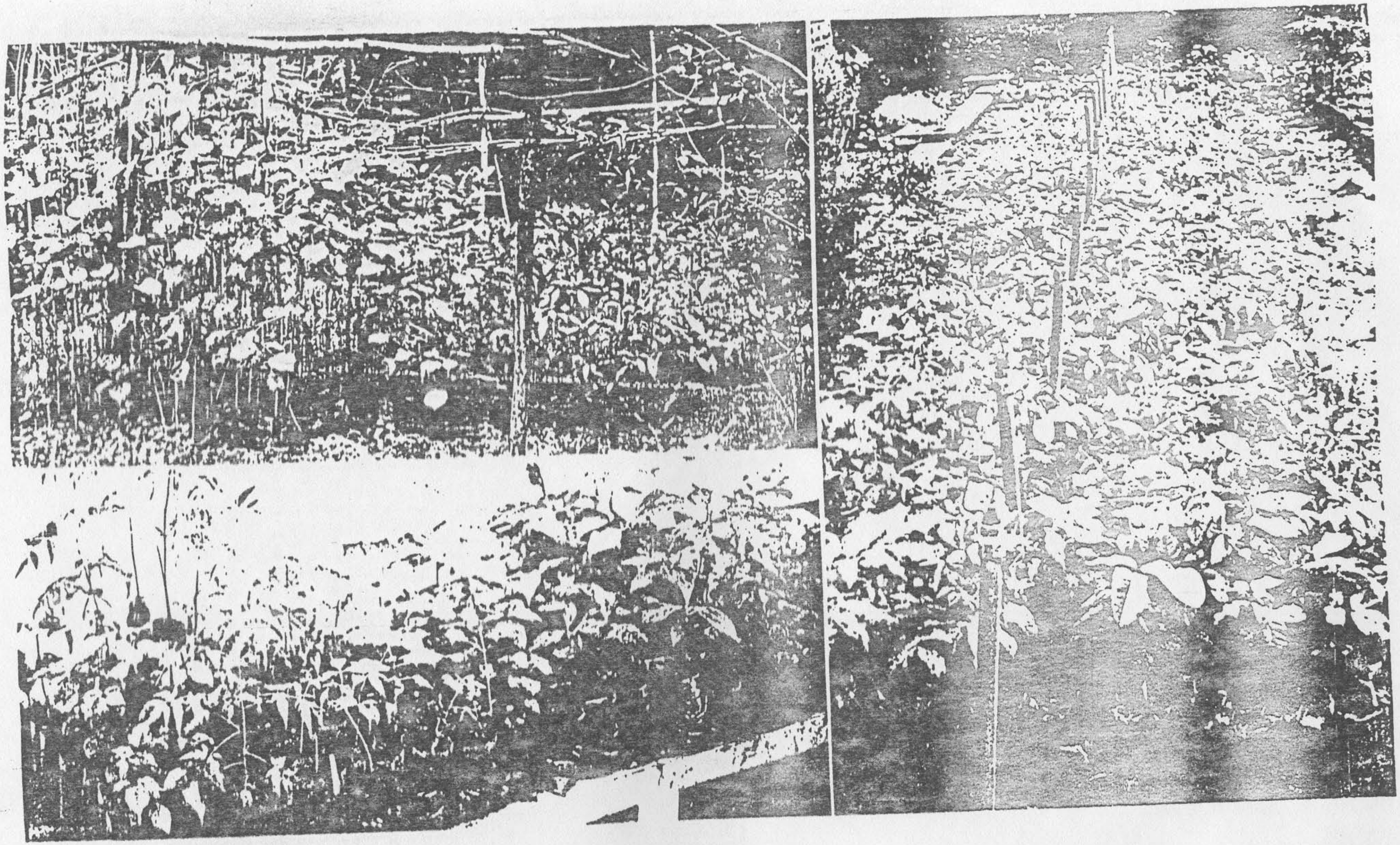


Plate 3: Post burn forest floor in different burning treatments. A: After early-burn treatment; note the many fire escape islands here. B: After mid-burn treatment, here the littercarpet has been completely burnt, leaving no fire escape islands.

Plate 4: Set up for the fire temperature and flame height measurements. A: Thin foils of several metals differing in melting point were tied on to a wooden post so that after burning, looking at the melted foils, approximate temperature of fire could be determined. The yellow painted posts were used to get an indication of flame height, but the technique was found less effective. B: A close up of stand after burning; note that established seedlings and larger once not killed even in mid-burns

Plate 5: Stump regeneration trails of different moist deciduous tree species. Top left: *Bomax ceiba*. Top right *Melia dubia*. Bottum left *Gmelina arborea* and *Tectona grandis*. Bottom right *Lagerstroemia microcarpa*.



[illegible] 3) (Clockwise from top). Different views of the nursery (1 & 2) and stump regeneration trial (3).