FOREST FIRE THREATEN INDONESIA FOREST PLANTATION: A Case Study in *Acacia mangium* Plantation

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ABSTRACT

Fire in Indonesia in 1994 from August to October destroyed about five million ha of forest land including newly established forest plantations, shifting cultivation area, grass land, and land cleared for agricultural purposes. In south Sumatera of 120,000 ha of Acacia mangium planted belonging to one forest concession area which this research done, about 20,000 ha (17%) disappeared only in three months.

The results of research show that fire destroyed all of the plantations ranging from one to four years and no regeneration recognized in the forest floor under the damaging trees one year after burning. One of the reasons why so much plantations were burned was high level of fuel available because of poorly maintained. Unreasonable fire occurred in the plantation area mainly caused arson that rooted from the conflict between the forest concession area and the local people.

INTRODUCTION

Indonesia has launched a plan to establish some 6.2 million ha industrial forest plantation (Hutan Tanaman Industri, "HTI") by the year 2000. The development of industrial forest plantation is mainly to cover a lack of raw materials, especially pulp and paper, for domestic use and also for export purposes. Avoiding the decline and degradation of the tropical rain forest is of primary concern here, however, the programs are not proceeding well because of a number of disturbing activities. One of these problems is forest fire. Protection of young plantations from forest fire has become an important task because 70 to 100 thousandha are disappearing annually. Fire in 1994 (August to October), for example destroyed about five million ha of land including newly established forest plantations, shifting cultivation area, grass land, and land cleared for agricultural purposes. During that period, 120,000 ha of *Acacia mangium* was planted in South Sumatera, however, approximately 20,000 ha disappeared (Saharjo, 1995a). During research in the Subanjeriji forest block, 7,372 ha from a total five unit area of about 46,000 ha was destroyed. One of the reasons why so much of the plantations were burned was the high levels of fuels stored but poorly maintained (Saharjo, 1995b).

Research also showed that fire destroyed all the plantations of 1, 2, 3, and 4-year old *Acacia mangium*. No trees were recovered and no natural seed regeneration was recognized in the forest floor. This happened not only in research sites but also in the plantation area.

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Therefore, the objective of this paper is to show that if fire come into an *Acacia mangium* plantation which is poorly maintained, it will inevitably be destroyed by fire.

RESEARCH SITE

This research was carried out in a newly established *Acacia mangium* plantation (1, 2, 3, and 4-years) belonging to PT. Musi Hutan Persada (Figure 1), Barito Pacific Group, at the Subanjeriji forest block, South Sumatera, Indonesia (103^{0}25'E & 03^{0}05' – 04^{0}28'S) in two periods from August to September 1994 and August to September 1995.

The mean annual rainfall is about 2,800 mm, and monthly rainfall is about 208,5 mm ranging from 92 mm in July to 278 mm in February. According to the Schimdt and Fergusson system (1951), the climate of this area belongs to rainfall type A ($0<Q<0.143$). Mean maximum air temperature in this area is about 32.6°C in August, mean minimum air temperature is 22.26°C in December and mean realtive humidity is about 85.21 %. However, in 1994 monthly rainfall in July was only 3.9 mm with 2 rainy days, in August 35.55 mm with 1 rainy day and in September 63.5 mm with 6 rainy days. Those three months were extremely dry.

The soil is Red Yellow Podsolic and the soil classes (USDA) are : Haplaquox, Dystropepts, Kandiudults and Hapludox. This area has the following characteristics; acid tuff plain, acid tuff and fine felsic sediments; flat to undulating; slopes < 8 %; slightly dissected; 5 – 125 m altitude (15-50 m range); drainage varies from well drained to imperfectly drained; soil mineral depth 101-150 cm; available P (0 – 15 ppm); K-exch. (0 – 0.5 me/100g); Cation Exchange Capacity (0 – 16 me/100g); free salinity; soil acidity (pH) 3.5 – 5.5; Al toxicity and organic matter (3.1% - 16.1%) (Hikmatullah *et al,* 1990).

Tree spacing was 3m x 2m, and undergrowth vegetation are dominated by *Imperata cylindrica, Eupatorium pubescens, Clidemia hirta, Tetra cera* sp, *Artocarpus anisophyllus, Macaranga javanica* and *Dillinia grandifolia.*

RESEARCH SUBJECTS

Fire Behavior

Estimation of fuel load

Four quadrates of about 1 ha were set up in the four different ages of a newly established *Acacia mangium* (1, 2, 3, and 4 years) plantation. Representatives of the typical composition and structure of the community were chosen for the estimation of temperature in the burning process. Fifteen subplots of 2 m^2 (2m x 1m) were set aside on the subplots, floor vegetation except trees were cut, and fuel load and fuel bed depth were estimated.

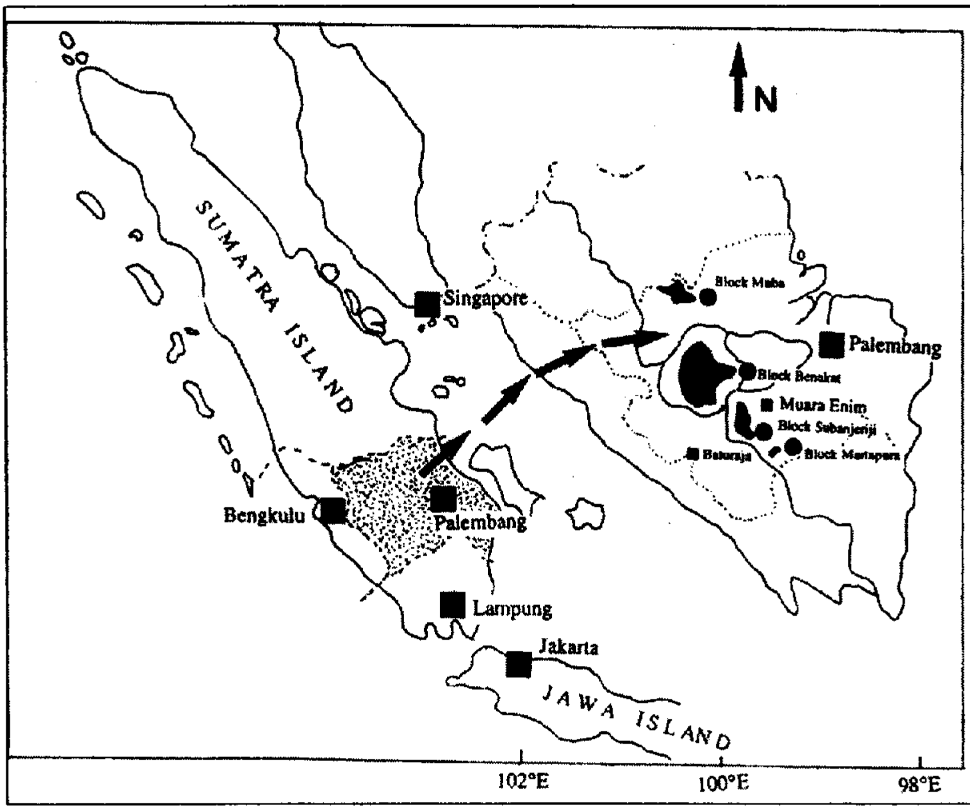

Figure 1. Research site

Estimation of flame temperature

Two subplots (20m x 15m) were burned and the fire was allowed to propagate naturally. Flame temperatures at 0 m, 1m and 2 m above the soil were measured using temperature-indicating liquid (Tempilaq), which melts at a specified temperature and provides estimates of maximum temperatures. Range temperature at 0 m was : 139^{0}C – 550^{0}C; at 1 m was : 59^{0}C – 302^{0}C, and at 2 m was : 38^{0}C – 302^{0}C. Each liquid was applied to an aluminum pipe 2 cm in diameter and 30 cm long (Saharjo, 1995c). The temperature sensors were placed in the vegetation at two locations in each of the subplots.

Estimation of fuel bed depth

Fuel bed depth was measured by the average height of the association of living and dead plant materials of various sizes and shapes that extended from mineral soil to the top of the vegetation canopy.

Rate of the spread of fire

Rate of the spread of fire was measured by the average distance perpendicular of the moving flame front per time, using a stop watch and measurement tape.

Flame height

It was very difficult to measured by the average height of the flame, so, the average height of soot marks on the trees (Pickford *et al*, 1992) was measured.

Crown scorch

Crown scorch of trees that were affected by the fire was measured by the percentage of canopy whose leaves were dark.

Fire intensity

Fire intensity was calculated by using Byram's equation (Chandler *et al*, 1983), $FI = 273\ (h)^{217}$, where FI is fire intensity (kW/m) and h is flame height (m).

Lethal scorch height

Scorch height was calculated by using Van Wagner equations (Albini, 1976), Hs (Lethal scorch height) = $63/(140\text{-}T) \times I^{7/6}/(I+W3)^{0.5}$, where, T is air temperature (^{0}F), I is fire intensity (Btu $ft^{-1}sec^{-1}$) and, W is wind speed (mil hr^{-1}).

Seed Behavior

Seed storage

One plot of 50 m x 50 m each in the 3-year (unit 46), 4-year (unit 91 and 96), and 5-year (unit 3, 5, and 32) *Acacia mangium* plantation areas were established. In these plots, seed storage was measured by using a ring sample of 400 cm^3 in volume (surface area was 100 cm^2 and ring height was 4 cm). This ring was used to take seed at the 0 – 5 cm and 5 – 10 cm levels underground. In the 3-year unit 46, 11 samples were taken both at 0 – 5 cm and 5 – 10 cm deep; in the 4-year unit 91, 9 samples and in unit 96, 8 samples; in the 5-year unit 3, 9 samples; in unit 5, 5 samples, and in unit 32, 7 samples were taken.

The means of seed stored at 0 – 5 cm and 5 – 10 cm deep from all samples, and total seed stored both at 0 – 5 cm and 5 – 10 cm deep were compared by t-test.

Germination percentage

Seeds taken from all samples both at 0 – 5 cm and 5 – 10 cm deep were germinated in germination boxes in order to study the germination rate. The medium used for germination percentage was sand that had been previously dried for 8 hours and cooled for one night. Each germination box (3 boxes used) was half filled with sand and then put in a green house. In the first box, 358 seeds were germinated, in the second box 150 seeds, and in the third box 86 seeds were germinated. Germinated seeds were monitored two weeks after treatment.

Seed lethal temperature

To study the ability of the seed to protect itself from heat effects, seed lethal temperatures were measured. 25 seeds were used in each treatment with two replications (a total of 50 seeds was used in each treatment). The medium used for germination was dried sand that had been cooled down for one night and put into the germination box. Those seeds were heated in an oven with different temperatures for treatments, after which the seeds were put in the germination box. Temperature used were: A: 100^{0}C for 5 min., B: 110^{0}C for 5 min., C: 120^{0}C for 5 min., I: 180^{0}C for 5 min., and Control: Seed placed in a germination box without any treatment. Two weeks after treatment all seeds germinated in the germination box were monitored. The mean germination rates of each treatment were compared by t-test.

Fuel and heat penetration

Different kinds of forest fuel representatives from the research sites such as tree branches, shrubs, litter, and *I. Cylindrica* were collected, and dry weight and fuel moisture content were measured. In a plot of 2 m x 2 m, fuels in different weights used as treatments were laid down and burned. In order to measure the flame temperature and heat penetration, Tempilaq (liquid indicating temperature) was applied on an aluminum pipe in diameter and 30 cm long (Saharjo, 1995c). This stick was put 1 cm under the soil surface and also on the soil surface.

Treatments used were: 1. *I. Cylindrica* + litter (1kg/m^2), 2. *I. Cylindrica* + litter (2kg/m^2), 3. Shrubs only (1kg/m^2), 4. Shrubs only (2kg/m^2), 5. Litter + *I. Cylindrica* + shrubs (2.12kg/m^2), 6. Litter + *I. Cylindrica* + shrubs only (3kg/m^2), 7. *I. Cylindrica* only (2kg/m^2).

RESULTS

Fire Behavior

Fuel load

As shown in Table 1 and Figure 2, fuel load in the second year (2.12kg/m^2) was larger than that in first (1.62 kg/m^2), third year (1,70 kg/m^2), and fourth year (1.45 kg/m^2)

Flame temperature

The highesr temperature at 0 m above soil was reached in the second year, ranging between 343^{0}C and 454^{0}C, at 1 m it ranged from 159^{0}C to 198^{0}C in the second year, and at 2 m it was between 101^{0}C and 159^{0}C in the second year.

Fuel bed depth

Fuel bed depth varied from 0.13 m in the fifth year, 0.20 m in the fourth year, 0.35 m in the third year, 0.45 m in the first year, and 0.53 m in the second year.

Rate of the spread of fire

Rate of the spread of fire was 1.15 m/min in the fourth year. 1.30 m/min in the third year, 1.50 m/min in the first year and 1.70 m/min in the second year.

Flame height

Flame height in the second year was 1.70 m, higher than the first year (1.30 m), the third year (1.20 m), and the fourth year (1.11 m).

Crown scorch

All the plot canopies were completed destroyed by fire.

Table 1. Weathes conditions and fire behavior at different plantaion ages

Parameter	Year Plantation			
	1	2	3	4
Weather condition				
Air temperature (0C)	33	35	30	33
Relative humidity (%)	60	60	65	65
Wind speed (m/s)	1.4	1.7	1.32	1.18
Fire behavior				
Fuel load (kg/m^2)	1.62(0.18)	2.12(0.15)	1.70(0.09)**	1.45(0.17)*
Fuel bed depth (m)	0.45(0.07)*	0.53(0.10)**	0.35(0.06)**	0.20(0.04)**
Rate of the spread of fire (m/min.)	1.50(0.09)**	1.70(0.15)**	1.30(0.09)	1.15(0.05)**
Flame height (m)	1.30(0.13)	1.70(0.15)**	1.20(0.15)	1.11(0.07)**
Flame temperature soil above (^{0}C)				
0 m	302-343	343-454	159-302	139-302
1 m	139-159	159-198	76-159	76-121
2 m	101-121	101-159	121	76
Fire intensity (kW/m)	482.4(105.0)	863.5(93.7)**	405.5(107.7)**	342.8(45.5)**
Crown scorch (%)	100	100	100	100

Remarks : * : Significantly different at 5% confidence level;
** : Significance different at 1% confidence level; and values within paren thesis express standar error

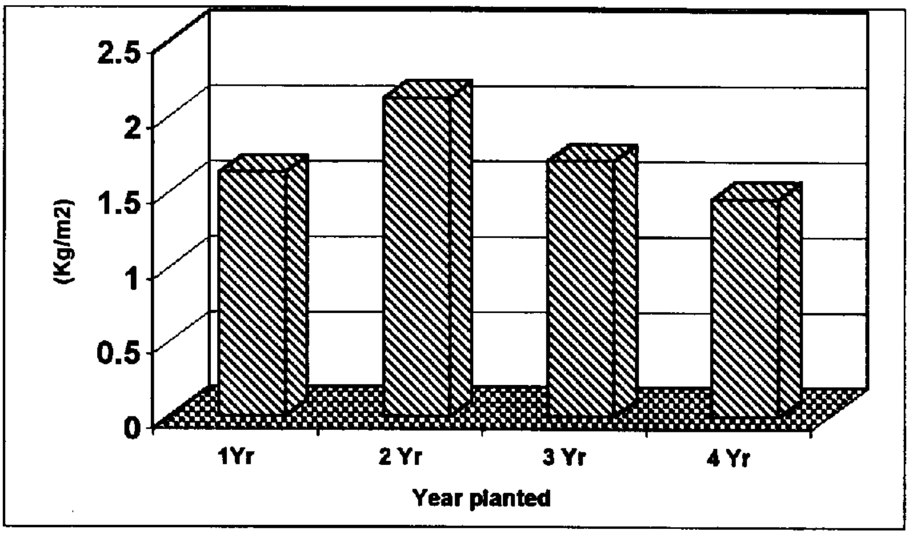

Figure 2. Fuel load at different plantation ages

Fire intensity

The highest fire intensity was 863.5 kw/m in the second year and the lowest was 342.81 kW/m in the fourth year.

Lethal scorch height

Lethal scorch height was 13.75 m in the second year, 9.3 m in the first year, 8.79 m in the fourth year and 8.29 m in the third year.

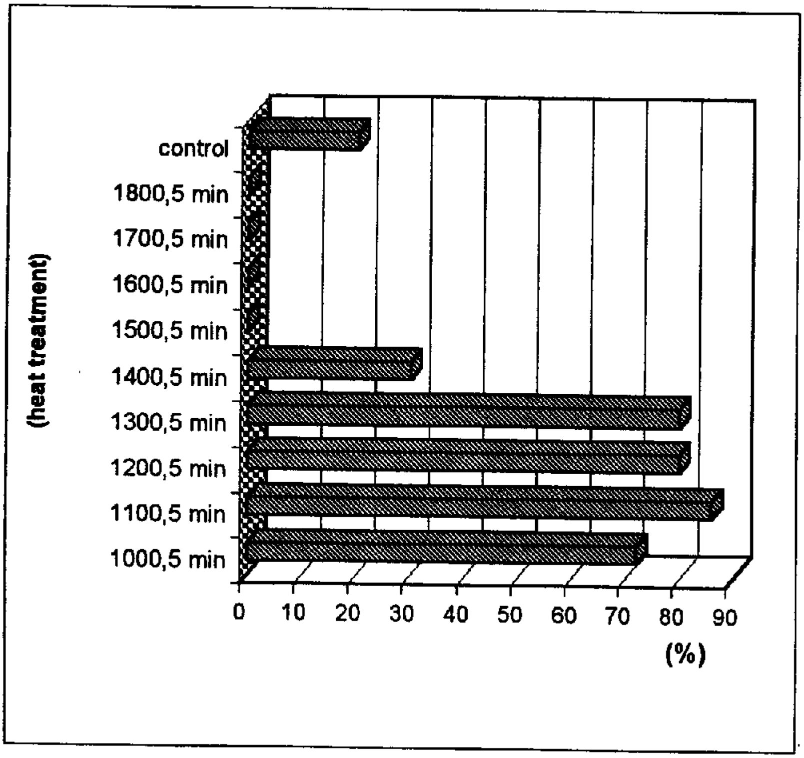

Figure 3. Seed germination percentage at different beat treatment

Seed Behavior

Seed storage

As shown in Table 2, average seeds stored per 100 cm^2 in the 5-year plot (14.43 in unit 32, 3.4 in unit 5, 2.78 in unit 3) was higher than in the 4-year plot (1.33 in unit 91, 1.13 in unit 96) and 3-year plot, 0.91 in unit 46. Total seed stored both at 0 – 5 cm and 5 – 10 cm deep in unit 32 was significantly different from that in other units in the 5-year plot. Average seed stored at 0 – 5 cm deep (Table 3) in unit 46 was significantly different from that in units 3, 5, and 32. Average seed stored at 5 – 10 cm deep (Table 4) in unit 32 was significantly different from that in units 46, 91, 96, 3, but not from that in unit 5.

Germination percentage

The seed showed good performance, with a germination of more than 90%, averaging 94,01%.

Seed lethal temperature

Figure 3, shows that at temperatures of 150^0C and 180^0C for 5 min., no more seed germinated, while between 100^0C and 140^0C for 5 min. most of the seed germinated. The percentage of germinated seed also varied from 0% in F-I treatment to 86%. Statistically, the percentage of germinated seed in control treatment was significantly different from seed dry heated from 150^0C and 180^0C for 5 min., also for seeds that dry heated at less than 150^0C for 5 min. were significantly different. Seeds that were dry heated at 100^0C and 130^0C for 5 min. showed significant differences from seeds that were dry heated at 140^0C for 5 min.

Fuel and heat penetration

The highest temperature on the soil surface (Table 5) was between 704^0C and 760^0C with fuel load of litter + *I. cylindrica* + shrubs. A potency of 3 kgm^{-2} had the highest temperature at 1 cm under the soil surface (heat penetration) at 76^0C. Shrubs with a fuel load of 2 kgm^{-2} reached a maximum temperature of 649^0C on the soil surface and 56^0C – 76^0C under the soil. *I. Cylindrica* only with fuel load of kgm^{-2} reached a maximum temperature of 593^0C on the soil surface and 56^0C under the soil surface. Litter + *I. cylindrica* (fresh fuel) with fuel load of kgm^{-2} reached a maximum temperature of 343^0C on the soil surface and 38^0 – 56^0C under the soil.

DISCUSSION

Fire Behavior

It seems that until the second year after planting, the fuel load tended to increase while it decreased in the third and fourth years. This is probably due to the fact that following the years after planting, trees canopy gradually tended to close. Closing canopy makes an impact on the shading conditions and later, inhibits *Imperata cylindrica* and shrubs growth resulting in a decrease of fuel load. This closing canopy changes wind speed in the vagetation. Changing wind speed then affects the rate in which the fire spreads. As a result, we found that rate of the spread of fire and flame height in the second year was higher than that in the first and the third years (Figure 4).

A decrease of fuel load causes a decrease in fire intensity (Figure 5). This comes from a difference in the rate of the spread of fire resulting from varying wind speed and fuel bed depths in the packing ratio. A very compact fuel bed burns slowly because airflow is impeded and there are so many particles to be ignited in a given fuel bed length. A very open or porous fuel bed burns slowly because the individual fuel particles are spaced far apart, with little heat transfer (Burgan and Rothermel, 1984).

A decreasing fuel bed depth causes decreases in the rate of the spread of fire and the flame height. In turn, a decrease in the rates of the spread of fire and flame height decreases fire intensity (Figure 6).

Increased rate of the spread of fire, fuel load, and flame height in the second year plot resulted in greater fire intensity, and a higher flame temperature was reached (4540C). Fire intensity is determined by the amount of available heat energy in the fuel. This is determined by the fuel load and the heat of combustion, or more particularly, the heat yield of a unit mass of that fuel (Trollope, 1984). Higher heat transfer (intensity) causes the adjacent fuels to be heated and burned, thereby releasing more heat and propagating fire. Plant death and injury will depend on the heat transferred to them and how much of this heat is absorbed, raising the plant temperature to lethal temperatures (Johnson, 1992). Based on observations in the field, fires causes very severe damage in the second year.

Table 2. Seed stored at different plantation ages

Sample No.	Year planted											
	3 Yr		4 Yr				5 Yr					
	unit 46		unit 91		unit 96		unit 3		unit 5		unit 32	
	5 cm	10 cm	5 cm	10 cm	5 cm	10 cm	5 cm	10 cm	5 cm	10 cm	5 cm	10 cm
1	0	0	6	2	1	0	1	0	3	0	25	2
2	2	0	2	1	1	0	3	0	0	0	23	15
3	2	0	1	0	6	1	4	0	5	0	27	20
4	0	0	0	0	0	0	9	2	2	0	2	0
5	1	0	2	0	0	0	3	0	7	0	1	0
6	0	0	0	0	1	0	0	0			21	1
7	0	0	0	0	0	0	5	0			2	1
8	1	0	1	0	0	0	0	0				
9	3	0	0	0			0	0				
10	1	0										
11	0	0										
sum	10	0	12	3	9	1	25	2	17	0	101	39

Table 3. Mean of seed stored at 5-10 cm deep

	unit 46	unit 91	unit 96	unit 3	unit 5	unit 32
unit 46	-	ns	ns	*	**	**
unit 91		-	ns	ns	ns	**
unit 96			-	ns	ns	**
unit 3				-	ns	**
unit 5					-	*
unit 32						-

Where, ns : non significant
* : significantly different at 5% confidence level
** : significantly different at below 1% confidence level

Table 4. Mean of seed stored at 5 - 10 cm deep

	Unit 46	unit 91	unit 96	unit 3	unit 5	unit 32
unit 46	-	ns	ns	ns	ns	*
unit 91		-	ns	ns	ns	*
unit 96			-	ns	ns	*
unit 3				-	ns	*
unit 5					-	ns
unit 32						-

Where, ns : non significant
* : significantly different at 5% comfidence level

Table 5. Temperature with different kinds of fuel on and under the soil surface

No.	Fuel	Potency (Kg/m^2)	Soil surface temperature (^0C)	Under soil surface temperature (^0C)
1	Litter + *I. cylindrica* + shrub	2.12	704	56-76
2	Litter + *I. cylindrica* + shrub	3	704-760	46-76
3	Shrub only	1	550	56
4	Shrub only	2	649	56-76
5	*I. cylindrica* only	2	593	56
6	Litter + *I. cylindrica* (fresh)	2	343	38-56
7	Litter + *I. cylindrica* (dry)	1	399	38-56

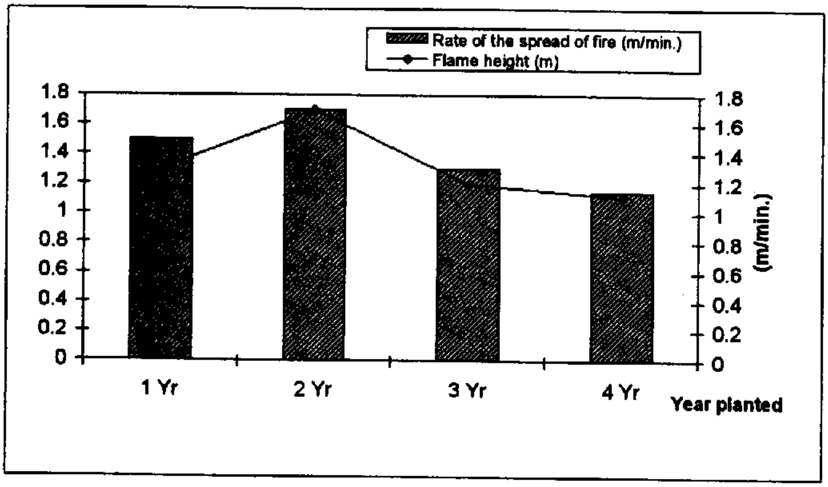

Figure 4. Rate of spread of fire versus flame height

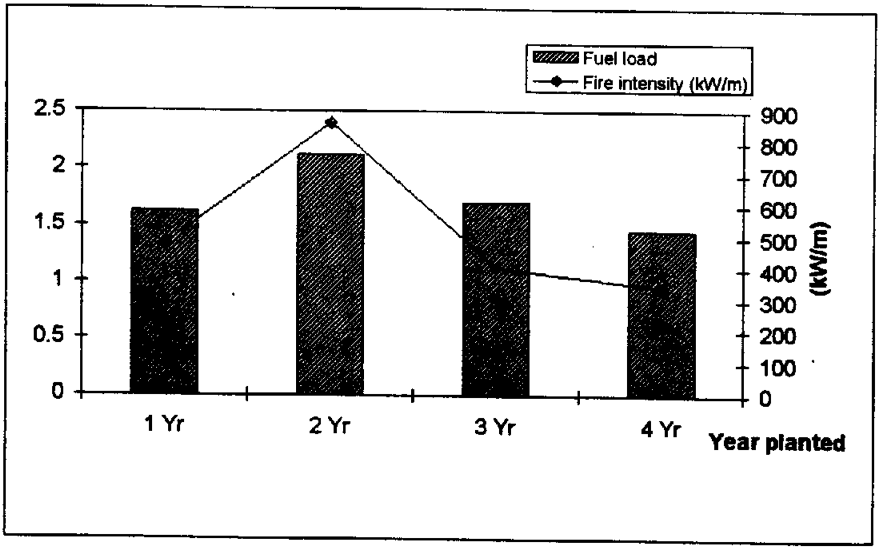

Figure 5. Fuel load versus fire intensity

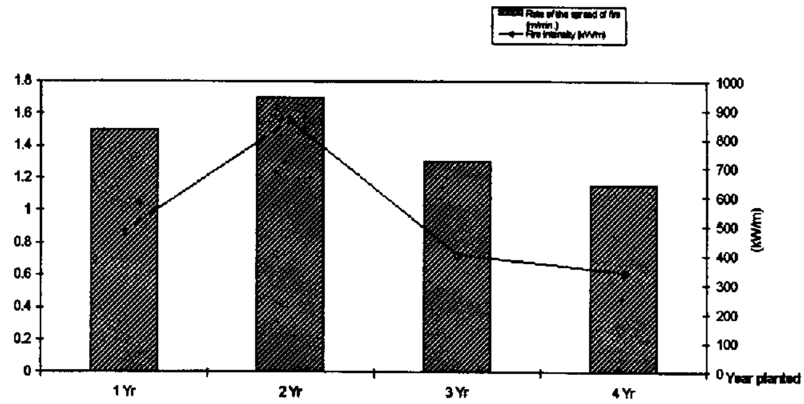

Figure 6. Rate of the spread of fire versus fire intensity

Seed Behavior

As shown in Table 2, the average amount of seed stored (per 100 cm^2) in *Acacia mangium* plantation becomes higher as the trees get older; 14.43 seeds in the 5-year, 1.33 seeds in the 4-year and 0.91 seeds in the 3-year. Seed stored in the 0 – 5 cm layer (111.86) was much higher than that in 5 – 10 cm layer (16.43), thought statistically this was not significant. Average seed stored at 0 – 5 cm especially in unit 32, was significantly different from units 46, 3, and 5. At 10 cm unit 32 was significantly different from units 46, 91, 96, and 3, but not from unit 5. Significantly different seed stored in unit 32 especially at 0 – 5 cm and 5 – 10 cm deep, compared to other plots, may have been caused by the stand quality and trees performance.

Dry heat temperatures of 150°C to 180°C for 5 min. resulted in no seed germination (0%), while dry heat temperatures of 100°C to 140°C for 5 min. resulted in a seed germination rate of between 60% at 140°C to 86% at 110°C for 5 min. Germination rates are particularly poor if the seed is not heated to more than 80°C (Adjers and Srivastava, 1993). At a temperature of 110°C for 5 min. germinated seed can reach 86%, so it seems that if the fire heats the seed at this point it means that the fire stimulates the seeds or overcomes seed dormancy (Bowen and Eusebio, 1981), because heat may increase seed coat permeability and so aid in breaking dormancy (Wright, 1931). Germination of *A. mangium,* like that with most of Acacias in inhibited by a hard and water-impermeable seed coat (Doran and Gun, 1987). While this assures seed longevity, it also makes germination slow, unpredictable and difficult (Adjers and Srivastava, 1993). The utilization of dry heat temperature treatment on seed is mainly to allow the seed receive the same treatment as when they are heated by fire. This also explains the profuse natural regeneration of *A. mangium* after fire in clear-felled areas (Adjers and Srivastava, 1993).

At a temperature of 150^{0}C for 5 min. there was no seed germination, while at a temperature of less than 150^{0}C for 5 min. most of the seed germinated. Based on this data, the seed lethal temperature of *A. mangium* can be determined as 150^{0}C for 5 min. In this way, if the heat temperature of the forest fire on the soil surface is more than 150^{0}C for 5 min., there can be no more seed germination. This was seen in all the plots for 1, 2, 3, and 4 years.

The next question to be addressed is that of heat temperatures under the soil surface. At temperatures of 704^{0}C - 760^{0}C on the soil surface, the highest temperature reached at 1 cm under the soil surface was 76^{0}C. At a the temperature of 399^{0}C on the soil surface, 38^{0}C – 56^{0}C was recorded at 1 cm under the soil surface. Different kinds of fuel, fuel potency, and fire duration cause differences in the heat temperature of the soil surface. Changes in temperatures at different depths in soil as a result of burning, are functions of the thermal conductivity of the soil, temperature and duration of the fire (Pritchet and Fisher, 1987). Temperatures below the surface decrease rapidly with depth, and the heat transmitted downward to the soil surface under and around a fire is transmitted by radiation and conduction. This limits the rate and intensity of soil heating (Brown and Davis, 1973). The ability of seeds to germinate also generally decreases with depth; influenced by soil type, seed size and species (Fatubarin, 1987).

As a result of burning on the soil surface, temperatures of 76^{0}C under the soil surface have no significant heat effect on *A. mangium* seed because it cannot break the dormancy. In addition, it cannot stimulate the seed to germinate. Germination of *A. mangium* is particularly poor if the seed is not heated to more than 80^{0}C (Adjers and Srivastava, 1993).

One of the biggest problems regarding the destruction of forest plantation is the high amounts of poorly maintained fuel stored under the vegetation.

If tree maintenance activities can be improved, there will be less fuel load stored in the plantations, and there will be no under ground vegetation with a diameter of more than 1 cm. Excessive amounts of fuel are stored in the plantation, resulting in poor tree maintenance.

With poor and randomly conducted tree maintenance activities, the potency of underground vegetation increases, resulting in a high fuel load potency in the forest floor. Presently, even though weeding, slashing, and pruning take place, these activities result in branches, leaves, and pods being deposited under the vegetation in order to add more nutrients through a decomposition process. Weed control through mulching (Setyono, 1994) is best for the growth of the trees, as its slows down the flow of run-off water and reduces soil sedimentation. Soil nutrients (N, K, Ca, Mg and organic content) increase when mulch is applied, but phosphorus content decreases. This is still a significant danger based on the view point of fire management, because a low decomposition rate, and exposure to the sun results in drier fuel, and burning is easier. Observations in the field show that, after weeding and pruning were conducted, under trees canopies were full of litter, shrubs, *I. cylindrica*, branches, pods, and leaves. Saharjo and Watanabe (1995) showed that all the plantations (1, 2, 3 and 4 years) were destroyed by fire with a fuel load consisting of about 1.45 kg/m^2 to 2.12 kg/m^2 , and no natural regeneration was recognized one year after burning. Infact, fuel load under canopies after weeding and pruning reached more than 2 kg/m^2, especially in the 2nd year of planting. This means that the fuel load was prepared for burning and fire was allowed to destroy the plantation.

From the viewpoint of silvicultural practices, it may be very difficult to clear away weeding, slashing and pruning. This, however, is one of the choices available to reduce the high potency of fuel loads in order to prevent fires. Another choice, also tree maintenance activities must be improved, reports must be followed accurately.

CONCLUSION

Fire destroyed huge young plantation areas and no regeneration was recognized in the forest floor. The reasons why the plantation disappear are the high level of fuel stored which fire easily invades, and poor maintenance, i.e. un-proper weeding or pruning branches.

In one experiment, at a temperature of more than 150^{0}C no seed was germinated due to the lethal temperature. The highest heat temperature at 1 cm under the soil surface was 76^{0}C. Low germination in the field is probably due to this low temperature, which does not break the dormancy.

To reduce fuel load in order to prevent fire invasion of the plantation, establishment of proper weeding and pruning is highly recommended.

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