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Forest Fuel Inventory in 5 and 9-Year-Old Acacia Mangium Plantations

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Abstract: This study was conducted to determine the fuel components on forest floor of two different age stands and to estimate the fuel loading of the various fuel components. This study was carried out at Bukit Tarek Forest Reserve, Hulu Selangor, Selangor Darul Ehsan, at two stand age of *Acacia mangium* of 5 and 9-year-old. Fuel components of downed woody material and duff were sampled along transects lines. Shrubs, litter, herbaceous and small trees (< 3 m height) were sampled from quadratic plots. The results showed that the forest fuel components in both stands were similar but not in term of their fuel loading. The 5 year-old stand showed 23.31 Mg ha^{-1} of total fuel (downed woody material, litter and herbaceous), 1.73 cm of duff depth, 37,030 stem ha^{-1} of shrubs density and 2,175 tree ha^{-1} of small trees. The 9 year-old stand showed 17.42 Mg ha^{-1} of forest fuel, 3.03 cm of duff depth, 39,151 stem ha^{-1} shrubs density and 3,515 tree ha^{-1} of small trees. Downed woody material made up of 89 and 74% of the total fuel weight for 5 year and 9-year-old stands, respectively. Comparison between two different age stands, showed that 5 year old stand has higher quantity of downed woody materials than 9 year-old stand with 20.66 and 12.82 Mg ha^{-1}, respectively. Based on diameter class interval, the weight of downed woody material, diameter class of 0-7.6 cm were higher compared to diameter class of >7.6 cm. The fuel weight for 0-7.6 cm diameter class was 12.48 and 9.94 Mg ha^{-1} for 5 and 9-year-old stands, respectively. Statistical analysis showed that the loading of downed woody material on 5-year-old stand was significantly greater than the 9 year-old stand. However, litter loading was greater on the 9-year-old stand than the 5-year-old stand. The study concludes that in terms of fuel loading, 5-year-old stand has higher fire risk than 9-year-old stand. This is due to the silviculture activities in the 5-year-old stand.

Key words: Forest fuel, forest plantation, *Acacia mangium*, Malaysia

INTRODUCTION

In Southeast Asia, the land area under forest plantation had increased tremendously over the last decade. In Malaysia alone, forest plantation has long been recognized as an essential part of strategic development plan for the sustainable forest resources. In 1995 the land area under forest plantations in Peninsular Malaysia has increased from 52,552 to 75,672 ha in 2001 (Krishnapillay and Ong, 2003). Most of these plantations have been planted with exotic species and fast-growing, such as *Acacia mangium*, *Gmelina arborea* and *Paraserianthes falcataria*. However, the development of plantations on large scale has raised several problems. One of the major problems encountered is the protection of the stands against fire.

Thousands of hectares of plantation of various age classes and species have been lost in the tropic due to fires. For examples, in the Philipines, about 61,807 ha of natural and plantation forest were destroyed during 1992-96 (Costales *et al*., 1996). In Thailand, damages caused by forest fires in 1984-86 have been estimated to be about 3.1 million hectares (Bhumibhamon, 1995). In Indonesia, during 1982-1983 about 3.5 million hectares of forested and plantation areas were destroyed by wildfire (Goldammer and Seibert, 1989). In Malaysia, forest fire is a great threat to the plantation forest and about 7,396.30 hectare of plantation forest had been burnt during 1975-1994. In Sabah, SAFODA particularly had lost 5,565 hectares to forest fire (Ainuddin, 1996; Thai, 1996). These forest fires causes haze and air pollution (Khandekar *et al*., 2000) and affect the economy of the region (Glover and Jessup, 1999).

Plantation forests are open to risk of fire, especially to mono species. Forest fire management plan should be established for each forest management unit, taking into account the degree of risk. Before determining an attack method or formulating fire prevention plan, it is necessary to evaluate the fuels involved. Fire managers should know the vegetative and characteristic of forest fuel.

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Knowledge of fuel management is necessary so the fire's thermal output and rate of spread can be projected (Perry, 1990). Forest fuel inventory is a way to describe the fuel components, fuel quantity and estimate its volume. Fuel inventories are also used to detect areas of hazardous fuels, to plan prescribed burning and to predict fire behavior (Stephens, 2004). Calculating carbon stocks can also be done using forest fuel inventory especially the downed woody material (Fearnside *et al*., 1998). Fire managers use fuel inventories to simplify the complexity of forest fuels. They are complex because even stands of the same kind of trees differ from one another in appearance, which means that they contain differing amounts of fuels that react differently to fire (Fuller, 1991).

Forest fuel components in *Acacia mangium* plantation are of great importance to be studied. However, information and study on this field of knowledge is minimal. An inventory of forest fuel needed to be done to determine fuel components and their characteristic. The records and information collected are required to estimate fuel loading and forest fire prevention plan. Thus this project can help fire control men and forest fire manager to anticipate burning behavior and control problem of fires in each fuel type as weather condition varies.

The objectives of this study were to investigate the components of forest fuel in *Acacia mangium* plantation and to determine fuel loading of various forest fuel components in *Acacia mangium* plantation of different age stand.

MATERIALS AND METHODS

Description of study area: The study was conducted at Bukit Tarek Forest Reserve, Hulu Selangor, Selangor Darul Ehsan. This area is located in the northern part of Selangor between longitude 101°28'E-101°38'E and between latitude 3°29'N-3° 37 'N in the Rawang district, which is about 75 km North of Kuala Lumpur. The project area encompasses about 5,000 ha which was planted with *Acacia mangium* on a 15 year-rotation.

The northern and southern boundaries of the project area are fringed by Bukit Belata Forest Reserve, while the eastern and western boundaries are bounded by Sg. Ledang and Bukit Tunggal Estates, respectively. Kerling is the nearest town. Bukit Tarek Forest Reserve, Hulu Selangor, started in 1982 and under control of Batu Arang Compensatory Forest Plantation.

Study site: Two site conditions were selected for the study, Compartment 22 (9-year-old stand) and compartment 46 (5-year-old stand). The stand in compartment 22 (154.0 ha) was established in October, 1988. The mean diameter of the stand was 23.6 cm with average height of 22.7 m. Meanwhile, Compartment 46 (131.0 ha) was established in November, 1992. The mean stand diameter of this compartment was 15.8 cm with average height of 19.4 m. Both stands were planted with planting distances of 3.7 by 3.7 m.

Generally, the topography ranges from undulating to rolling. The slope gradient ranges from 1 to 25%. The average elevation of the area is 61 m above the mean sea level. The bedrock is mainly sedimentary and composed mainly of shales and sandstones. As such, the parent material can be considered as well drained. Sg. Kerling and Sg. Belatuk provide the main drainage in the project area.

The soils consist of a combination of soil series including Telemong-Akob-Alluvium Association, Munchong-Seremban Association, Serdang-Bungor-Munchong Association, Serdang-Kedah Association and Steepland. There soils are developed from various parent materials ranging from sandstones, shale, sedementary and igneous rocks (Anonymous, 1996).

Methodology: Two stand ages, 5-year-old and 9-year-old *Acacia mangium* were chosen in the study. Four transect lines were systematically established for each categories of stands age. Sample points were located along transect lines. The plot layout was established at every sample point. Various components of forest fuel were inventoried in the plots.

Forest litters, shrubs, herbaceous and small trees were sampled using quadrat method while downed woody materials and duff depth were sampled using transect line. Slope and elevation were recorded at every sample points.

The field procedures involved counting of shrub and small tree stems and intersected pieces of downed woody material, measuring diameters, depth and height of vegetation, occular estimating percentage of cover and percentage of dead vegetation.

Sample points were systematically located along the transect lines with 15 m intervals and distance between transects line is 100 m. Forest fuels component were measured along the four transects line with distance 210 m by using the bearing of 90° and back bearing of 270°. As many as 15 samples points were located on each transect line.

The plot layout at a sample point consists of a systematically positioned line transect for downed woody material and duff measured along transect lines. Circular plots of 2.0 m radius were established for small trees sampling and the two circular plots of 0.5 m radius for shrubs sampling. Four frames of 0.5×0.5 m located parallel with the transect line for collecting herbaceous and litter were established.

Data collection of forest fuel component was recorded in the inventory form, after the subplots and line transect were established on the ground.

After the subplots and line transect were established on the ground, recording general information at the top of the inventory form was done. The general information were date, sample point number, transect number, transect length, aspect, terrain slope, elevation, cover type, area, block/compartment number, date planted and stand age.

Components of forest fuel were sampled from 6 categories by different technique within each sampling point. Parameters measured were size diameter, basal diameter, height, average weight or weight per unit area (fuel loading), moisture content of litters (dead leaves) and herbaceous (live plants).

Downed woody materials were observed and measured from the central point until 10 m along the transect lines for each sample points. The 50 m tape was used to mark the transect line. Method used to tally the downed woody material was planar intersect technique based on tallying rules (Van Wagner, 1982).

The actual diameter of the particle at the point intersection to determine its size class was by using go/no-go gage. A go/no-go gage with openings of 0.6, 2.5 and 7.6 cm worked well for training the eye to recognize size classes. Diameter classes of downed woody material was measured as follows, (0-0.6 cm) and (0.6-2.5 cm) particles intersected by the sampling line 2.0 m distance, (2.5-7.6 cm) particles intersected by sampling line 3.0 m distance and (>7.6 cm) particles intersected by sampling line 5.0 m distance were counted.

Diameters of large fuels were estimated using a ruler laid perpendicularly across the pieces. On incidents where the sampling line intersected the curved piece more than once, both intersections were counted. Sound and rotten pieces intersected separately were recorded. Volumes of downed woody material in terms of weight per hectare were determined using formula derived by Brown (1974).

The depth of duff was measured to the nearest 0.1 cm using a ruler held vertically at two points along the transect line of fixed distance; first was 0.3 m and second 1.8 m from the sample point. The duff depth along an exposed profile of the forest floor from the top of the mineral soil to the bottom of the 01 horizon was measured. A knife was used to measure the profile of the forest floor for the measurement.

Herbaceous plant was collected using four frames of 0.5×0.5 m located parallel with the transect line. The amount of herbaceous plant distribution in each frame was determined according to the established percentage code (Brown *et al*., 1982).

The set of data taken are the estimate percentage of herbaceous vegetation stand, cover and dead. Finally, the herbs were clipped and kept in the labeled plastic bag.

Four frames of 0.5×0.5 m located parallel with transect line were established for collecting litters, but only the right half of each frames was viewed. Only material qualifying as litter was examined. The quantity of litter were rated using the established percentage code in the right half of each frames. Litter was collected and placed in plastic bag with a label tag.

Shrubs were tallied on the two circles of 0.5 m radius subplots. This method involved measurements of stem diameters and tally of number of stem by basal diameter on both circle. The set of data taken in each circle are the estimate percentages of shrub cover, percentage both live and dead by using the established percentage code. Height was measured from the ground to the visually average level of the immediate woody vegetation. The record was to the nearest whole in 0.1 cm. On both circle, the number of stems by species was counted and basal diameter classes measured were as follows: (0-0.5 cm), (0.5-1.0 cm), (1.0-1.5 cm), (1.5-2.0 cm), (2.0-3.0 cm), (3.0-5.0 cm) and (>5.0 cm) were counted. A go/no-go gage was used for checking and tallying the number of shrub stems by basal diameter classes.

Small trees were observed from the largest circle of 2.0 m radius subplot. The number of trees less than 3.0 m in height by species was counted. The number of trees within each species and average their height to the nearest 0.1 m was recorded. On occasions when trees of the same species differed by more than 1.5 m in height, the data was recorded in separate form.

The fresh herbaceous and litter collected from their standard subplot were determined, respectively. Each sample was weighed before drying in the oven. The samples were dried in the oven at 95°C for a period of 24 h. The weight after ovendry was recorded on the inventory form to the nearest 0.01 g.

Data analysis was conducted using SAS statistical software to calculate means, standard deviation and percentage of means for the sample properties. T-test analysis was used to test the significance difference along transects line for different age stands.

RESULTS AND DISCUSSION

The results of loading of forest fuel components for both age stands are summarized in Table 1.

Table 1: Summary of fuel loading and density of fuel components for both age stands

Fuel components	5-year-old stand	9-year-old stand
Downed woody material	20.66 Mg ha^{-1}	12.82 Mg ha^{-1}
Litter	2.22 Mg ha^{-1}	3.88 Mg ha^{-1}
Herbaceous		
Grass	0.22 Mg ha^{-1}	0.05 Mg ha^{-1}
Forb	0.09 Mg ha^{-1}	0.26 Mg ha^{-1}
Herb	0.12 Mg ha^{-1}	0.41 Mg ha^{-1}
Total	23.31 Mg ha^{-1}	17.42 Mg ha^{-1}
Duff depth	1.73 cm	3.03 cm
Shrub	37,030 stem ha^{-1}	39,151 stem ha^{-1}
Small tree (<3 m height)	2,175 tree ha^{-1}	3,515 tree ha^{-1}

Table 2: Average loading of downed woody material based in size diameter classes

	5-year-old stand	9-Year-old stand
Diameter classes (cm)	Weight (Mg ha^{-1})	Weight (Mg ha^{-1})
0.0-0.6	0.61	0.44
0.6-2.5	3.17	2.76
2.5-7.6	8.70	6.74
Subtotal (0.0-7.6) = A	12.48	9.94
(Sound)	6.75	0.91
(Rotten)	1.43	1.97
Subtotal (>7.6) = B	8.18	2.88
Total (A + B)	20.66	12.82

Result from the study shows that the total average of fuel loading for downed woody material, litter and herbaceous was 23.31 Mg ha^{-1} in 5-year-old stand compared to only 17.42 Mg ha^{-1} in 9-year-old stand (Table 1). In 9-year-old stand, duff depth was 3.03 cm compared only 1.73 cm in 5-year-old stand. The density of shrubs in the 9-year-old stand was 39,151 stem ha^{-1} compared to 37,030 stem ha^{-1} in the 5-year-old stand. The fuel component of small trees (< 3 m height), in 9-year-old stand was greater rather than 5-year-old stand. The total density in 5-year and 9-year-old stands was 2,175 tree ha^{-1} and 3,515 tree ha^{-1}, respectively.

In Table 2, comparison between two different age stands, showed that the 5-year-old stand have higher quantity of downed woody materials than 9-year-old stand. In the 5-year-old stand downed woody material was 20.66 Mg ha^{-1} compared in 9-year-old stand was 12.82 Mg ha^{-1}. The difference due to the result of thinning on the 5-year-old stand, three months prior to the study.

Fine fuel of downed woody material components included in (0.0-0.6) cm diameter classes, will create fire control problem under the conditions of severe fire outbreak. The fine fuel loading for 5-year-old and 9-year-old stands were 0.61 and 0.44 Mg ha^{-1}, respectively. Downed woody material included in (0.6-> 7.6) cm were coarse fuel. Coarse fuel was higher compared to the fine fuel.

Judging on the weight of downed woody material based on diameter class interval, downed woody materials were higher from the diameter classes of (0-7.6) cm on both stand ages. There were 12.48 and 9.94 Mg ha^{-1} of the material found from the 5-year and 9-year stands, respectively. In the diameter class of > 7.6 cm of both stand age, there was 8.18 Mg ha^{-1} in 5-year-old stand compared to only 2.88 Mg ha^{-1} in 9-year-old stand.

The weight of sound downed woody material for > 7.6 cm diameter class of 5-year-old stand was 6.75 Mg ha^{-1} compared to 0.91 Mg ha^{-1}of 9-year-old stand for the same diameter class. However, there was 1.97 Mg ha^{-1} of rotten downed woody material in the 9-year-old stand compared to 1.43 Mg ha^{-1} on the 5-year-old stand. Table 2 showed that most of downed woody materials in 9-year-old stand were rotten and in 5-year-old stand were sound. For the total downed woody material 9-year-old stand had statistically lower downed woody material than 5-year-old stand.

Silvicultural treatments in the forest plantation stands such as weeding, slashing, thinning and pruning will increased the total fuel quantity on the forest floor. Physiological and morphological properties of the trees such as age, height and site of stand are also an influencing factor in the distribution of fuel on the forest floor.

Duff is one of the fuel components in forest floor. In the 9-year-old stand duff depth was 3.03 cm compared only 1.73 cm in 5-year-old stand. The duff containing decomposed woody and litter materials. Duff depth and bulk density were important parameters that vary with slope, site quality and exposure.

From the Table 3, the average dry weight of 3.88 Mg ha^{-1} of litter from the 9-year-old stand was statistically higher compared to only 2.22 Mg ha^{-1} for the 5-year-old stand.

In term of herbaceous components, both stands showed that forbs and herbs higher in 9-year-old stand except grass which is lower in 9-year old stand. The wet weight of grasses was calculated as 0.22 Mg ha^{-1}, forbs 0.09 and herbs 0.12 Mg ha^{-1} in 5-year-old stand, were while in 9-year-old stand was 0.05, 0.26 and 0.41 Mg ha^{-1}, respectively. The amount of grasses decreases as the stand age increased. This was due the canopy closure which reduced the amount of solar radiation reaching the forest floor. However, the amount of herbs and forbs were increasing with increasing of stand age.

Average moisture content of litter in 5-year-old and 9-year-old stands were 10.54 and 10.81%, respectively. The figures showed that both stands were quite similar in term of litter moisture content. The herbaceous moisture content of both stand were varied between each components. An average moisture content of herbaceous components in 5-year-old stand was

Table 3: Average dry weight and percentage (%) moisture content of litter and herbaceous

Fuel component	5 year-old stand Mg ha^{-1}	5 year-old stand Moisture content (%)	9 year-old stand Mg ha^{-1}	9 year-old stand Moisture content (%)
Litter	2.22	10.54	3.88	10.81
Herbaceous				
Grasses	0.22	135.94	0.05	128.86
Forbs	0.09	135.25	0.26	144.76
Herbs	0.12	137.75	0.41	150.96

Table 4: Total stem of shrubs counted based on basal diameter classes

Class diameter (cm)	5 year-old stand (Stem ha^{-1})	9 year-old stand (Stem ha^{-1})
0-0.5	4032	4987
0.5-1.0	13369	15172
1.0-1.5	11353	12308
1.5-2.0	7958	5729
2.0-3.0	318	955
3.0-5.0	0	0
> 5.0	0	0
Total	37,030	39,151

calculated as grasses 135.94%, forbs 135.25%, herbs 137.75%, meanwhile in 9-year-old stand was 128.86, 144.76 and 150.70%, respectively.

Fuel having moisture content of 100 to 125% do not contribute a serious hazard but fuels with moisture content less than 65% can increased fire hazard. Johnson (1968) reported that moisture content varies with weather conditions, compactness, fuel volume and whether they are green or cured. Moisture content of litter were influenced by many factors such as weather, soil moisture content, air humidity, temperature, habitat types, characteristics of forest itself and leaves maturity.

Total number of shrub were counted according to size basal diameter classes were summarized and shown in Table 4.

The total number of shrubs counted in 5-year-old stand were 37,030 and 39,151 stem ha^{-1} in 9-year-old stand according to size basal diameter classes (Table 4). Quantity of shrub in (0.5-2.0) cm class was higher compared to other size classes in both stands.

The information from this study will help forest fire manager develop forest fire management plan to manage, control and suppress forest fires. Since the amount of downed woody material and total fuel loading is higher in 5-year old compared to the 9-year old stand, more fire control resources should be allocated to the 5-year old stand.

CONCLUSIONS

All of the forest fuel component such as downed woody material, duff, litter, herbaceous, shrub and small trees are present in both stands of *Acacia mangium* plantation, but not similar in term of their loading and density. The estimated and calculated forest fuel components vegetation in 9-year-old stand is higher than 5-year-old stand, except downed woody material.

The presence of fuel loading and density of fuel component in 9-year-old stand is higher than 5-year-old stand, except downed woody material and grasses indicate lower. This condition occurred due to the recent thinning treatment in 5-year-old stand. The canopy closure impedes the growth of grasses in 9-year-old stand.

Forest fuel loading and density increase with an increasing of age stand of the forest plantation. However, this depends on the silivculture treatments for *Acacia mangium* plantation.

The density of shrubs and small trees differ between age stand with shrub and small tree show higher in older stand. Moisture content of litter between both of age stand is quite similar but differ in herbaceous.

The potential for fire hazard is higher in 5-year-old stand compared to 9-year-old stand, this condition due to the high total quantity of downed woody material and litter.

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