Journal of Tropical Forest Research 1 (2) : 33-44 (2017)

Original article

Fuel Characteristics and Fire Behavior in Highland Corn Farm and Mixed Deciduous Forest at Nan Province

Pairin Palasak* **Kobsak Wanthongchai**
San Kaitpraneet

Faculty of Forestry, Kasetsart University, Bangkok, 10900 THAILAND
*Corresponding Author, E-mail: ployb13@hotmail.com

Received: Oct 20, 2017 Accepted: Dec 1, 2017

ABSTRACT

Several highland areas in the Nan province have long been intensively applying slash and burn techniques for land preparation. However, fuel and fire information for slash and burn techniques is very limited. This research aimed to study the fuel characteristics and fire behavior in a highland corn farm and mixed deciduous forest located in the Na Noi district, Nan province. Each site consisted of 3 replication plots of 40 m × 40 m size each. Fuel characteristics (type, loads, and fuel residues) and fire behavior descriptors (rate of fire spread, flame length, and fire intensity) were evaluated. Burning experiments were carefully conducted in April 2017 under the watchful eye of forest fire guard officers.

The results showed that the total fuel load in the corn farm (3.86 t ha^{-1}) was higher than in the mixed deciduous forest (3.57 t ha^{-1}). The total residues (ash, charred, and unburned materials) left after burning in the corn farm and mixed deciduous forest were 0.25 and 0.35 t ha^{-1}, respectively. The total fuel consumed by fire, therefore, was 3.61 and 3.22 t ha^{-1}, for the corn farm and mixed deciduous forest, respectively. The rate of fire spread was 5.61 m min^{-1} in the corn farm, and 4.68 m min^{-1} in the mixed deciduous forest, though the numbers were not significantly different ($p>0.05$). Burning intensity was classified as medium in both the corn farm (562.06 kW m^{-1}) and mixed deciduous forest (463.83 kW m^{-1}) . The results could be applied in fire management during the selection of appropriate methodologies, tools, and the number of officers.

Keywords: Fuel loads, Prescribed fire, Highland fuel, Fire behavior, Nan province.

INTRODUCTION

Thailand is predominately an agricultural society. Agriculture has had a long history in contributing to the livelihood of a majority of the Thai population (Saihu, 2009) through rice farms, fruit farms, livestock and fisheries. With a steady increase in the population (The Bureau of Registration Administration, Department of

Provincial Administration, 2015), the demands on the land for living have been intensifying. In particular, in highlands in the northern part of Thailand have had people encroaching into the forests, resulting in a change of land cover to agriculture and shifting cultivation areas. In Thailand, the area under the forest has reduced from 43.21% in 1973 to only 31.61% in 2015. During this period, deforestation has taken place at a rate of 864,902 rai yr^{-1} (Office of Forest Land Management, 2015).

Changes in land use and land cover in the Nan province can be clearly seen in many areas, where the protected forests have been gradually invaded by agriculture. A majority of agriculture practices in the highlands have been shifting to cultivation and domestication. During 2014-2015, a total of 4,788 rai of forest cover was cleared for such purposes (Office of Forest Land Management, 2015). Due to shortage of spaces in the flat lands, some villagers use highland area for shifting cultivation and corn farms. In 2015, an area of 849,018 rai in the Nan province was occupied by corn farms. This area accounted for 11.86% of all the corn farms in the country. The crop residues are usually burned after the harvesting season ends, to clear and prepare the land for the next planting season, leading to harmful effects on the environment. In addition to corn farms, mixed deciduous forests are also found in the area. It is likely that the fire starting out in the corn farms could expand into the mixed deciduous forest and vice versa. Therefore, a study of the fire characteristics and the effects on both the areas is critical.

Such crop residue burning practices cause forest fires and smog, which negatively affect the soil, water, air, and living organisms. Moreover, the air pollution and small dust particles emanating from the fires can impact human health and reduce visibility for land and air transportation. Therefore, studying the fuel characteristics and forest fire behavior in highlands is critical for our understanding, and can further contribute to an efficient fire management in terms of protection and mitigation.

This study aimed at describing the fuel characteristics which is a major component in the fire triangle and fire behavior in highland corn farm and natural forest. The results of this study can help increase our present knowledge about forest fires and can be used for future forest fire management purposes.

MATERIALS AND METHODS

1. Data collections

1.1 Pre-burned fuel characteristics: 40 m × 40 m plots were selected in a corn farm and mixed deciduous forest of Ban Chetawan, Santa sub district, Na Noi district, Nan province, Thailand. Three of these plots were studied in the two habitat types, using completely randomized design (CRD). Sixteen sub-plots of 10 m × 10 m were then constructed in each of the 40 m × 40 m plots. Pre-burned fuel samples were collected from grids of 1 m × 1 m in the subplots. The fuels were characterized as grass, undergrowth, litter, and corn stubble. The heights for each fuel type were measured. Fuel loads were estimated by using harvesting techniques and the fuel samples were taken

to the laboratory to determine fuel moisture content and hence the fuel loads.

1.2 Fire behavior: Iron poles were used to study the rate of fire spread. The poles were placed at 10 m intervals in the experimental plots. As to the campaign named '60 days no burning' starts in the Nan province from mid February 2017, the prescribed fires were ignited in late April 2017 with assistance from the landowners, officers, and villagers from the Forest Fire Control Network of the Nan province. During the experiments, air temperature, wind speed, and relative humidity were measured. Thermal images and fire temperatures were recorded in 15 random spots in the experiment plots, using the spot infrared technique (MINOLTA TA 510).

1.3 Post-burned fuel characteristics: After the prescribed fire subsided, residues were collected from the 40 m × 40 m experimental plots. Four of 50 cm × 50 cm sub-plots were used to collect post-burned fuel samples. All post-fire residues in the small sub-plots were trimmed and vacuumed. The residues were categorized as either: burned material (ash and charcoal) or unburned material. The post-burned remaining residue was weighed and oven-dried.

2. Data analysis

2.1 The moisture content of each fuel type was calculated from the difference between wet and dry weights. Pre-burned and post- burn fuel loads were also calculated in the units of t ha^{-1}

2.2 Fuel consumption was estimated by subtracting pre-burned fuel load and post-burned fuel load.

2.3 Rate of fire spread was determined from the distance which the flame spread past the iron poles.

2.4 Fire intensities and flame lengths were calculated using the Byram's equation by Byram (1959) as

$$I_B = 0.007HWR,$$

where I_B = fire line intensity (kW m^{-1}),
H = heat yield (cal g^{-1}),
W = loading of available fuel (t ha^{-1}),
and
R = rate of fire spread (m min^{-1}).

Heat yield (H) of 4,457.23 cal g^{-1} was applied to the all fuels derived from mixed deciduous forest (Sompoh, 1998), while H = 4,122.48 cal g^{-1} was used for the corn stubble (Lizotte *et al*., 2015).

3. Statistical analysis

The data collected to determine the fuel characteristics and fire behavior from the highland corn farm and the mixed deciduous forest were averaged and compared using the independent-Sample t-test at a 95% confidence level.

RESULTS AND DISCUSSION

1. Pre-burned fuel characteristics

The study demonstrated that aboveground pre-burned fuel structures from the corn farm and the mixed deciduous forest consisted of litters and undergrowth. The fuel loads in the corn farm were composed of 3.59 t ha^{-1} of stubble litter and 0.27 t ha^{-1} undergrowth, with fuel heights of 0.34 and 0.41 m, respectively. On the other hand, fuels in the mixed deciduous forest comprised of 3.34 t ha^{-1} of litter and 0.23

t ha^{-1} of undergrowth, with an average fuel height of 0.30 and 0.43 m, respectively. The statistical analysis comparing these parameters between the two land uses suggested that there was no significant difference between the fuel loads and fuel heights ($p>0.05$) (Table 1).

Results of the study were also compared with other studies carried out in similar environments and are presented in Table 2. Wanthongchai and Wongsawat (2012) reported that the fuel load from a short-rotation farming system at the Doi Phu Kha national park was 19.54 t ha^{-1}. This higher fuel load in a short-rotation farming system was a result of longer fuel accumulation over time as the rotation farming area was left for two years during the planting seasons, which allowed seedling, undergrowth, and weed to grow in the agricultural area. Fuel load of the mixed deciduous forest in the Nan province estimated in this study was similar to the fuel load reported in the same type of forest reported by Sangthong (2006) and Nhoochaiya (2008), who study site was located at the Huai Kha khaeng wildlife sanctuary (3.54 and 3.34 t ha^{-1}, respectively) and Jongkitwiwat (2010) in the Chiang Mai province (3.92 t ha^{-1}). However, fuel load of a mixed deciduous forest in Nakhon Ratchasima, recorded by Akaakara (1994), was comparatively higher (5.49 t ha^{-1}).

Table 1 Average fuel height and pre-burned fuel loads in the corn farm and mixed deciduous forest (MDF) at Na Noi district, Nan province.

Study Site	Fuel height (m)		Pre-burned fuel (t ha^{-1})		
	Litter	Undergrowth	Litter	Undergrowth	Total
Corn farm	0.34±0.12	0.41±0.02	3.59±0.49	0.27±0.50	3.86±0.47
MDF	0.30±0.04	0.43±0.14	3.34±0.29	0.23±0.15	3.57±0.39
p-value	0.67^{ns}	0.77^{ns}	0.38^{ns}	0.72^{ns}	0.26^{ns}

Remarks: ^{ns} = non-significant difference ($p>0.05$)
± = standard deviations are indicated in parentheses.

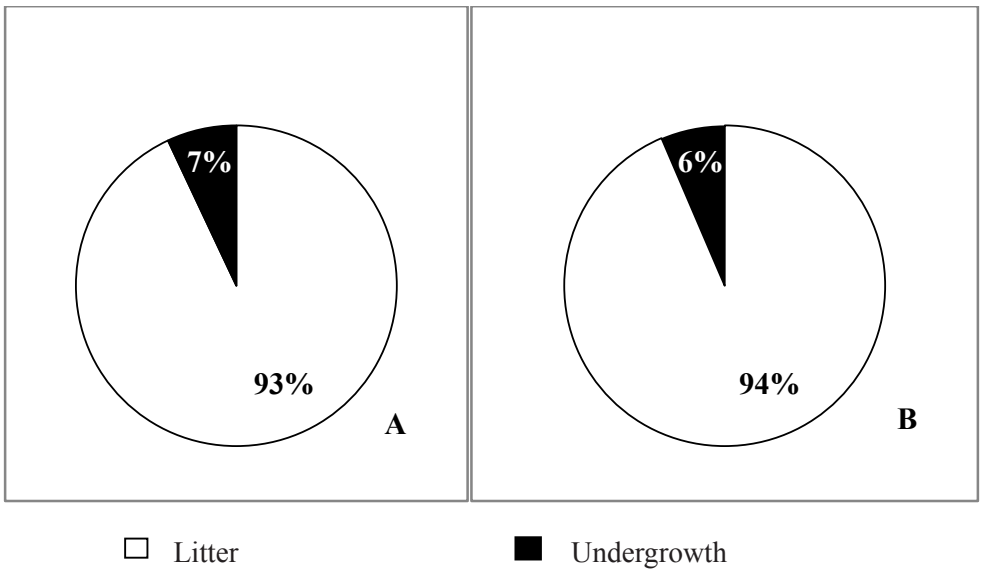

Figure 1 Portions of pre-burned fuel load in corn farm (A) and mixed deciduous forest (B).

Figure 1 revealed that the portions of pre-burned fuel, in the corn farm, consisted of litter (corn stubble) and undergrowth (93% and 7%, respectively), which were similar to the portions of pre-burned fuel in the mixed deciduous forest consisting of litter and undergrowth (94% and 6%, respectively). However, the litter composition in the mixed deciduous forest mostly comprised of leaves and branches of vegetation, including bamboo, whereas corn stubble was the main litter at the corn farm.

Table 2 Fuel loads from other studies.

Fuel bed	Study site	Fuel load (t ha^{-1})	Source
MDF	Nakhon Ratchasima	5.49	Akaakara (1994)
MDF	Huai Kha Khaeng	6.85	Akaakara *et al*. (2005)
MDF	Huai Kha Khaeng	3.54	Sangthong (2006)
DDF	Huai Kha Khaeng	8.10	Wanthongchai (2008)
MDF	Huai Kha Khaeng and Salak Phra	3.34	Nhoochaiya (2008)
MDF	Chiang Mai	3.92	Jongkitwiwat (2010)
LS	Doi Phu Kha	30.84	Wanthongchai and Wongsawat (2012)
SS	Doi Phu Kha	19.54	Wanthongchai and Wongsawat (2012)
P-DF	Ban Watchan	5.30	Chokeprasombat *et al.* (2013)

Notes: LS: long swidden farm, SS: short swidden farm, MDF : mixed deciduous forest, DDF: deciduous dipterocarp forest, P-DF: pine-dipterocarp forest.

2. Weather conditions during the burning experiment and fuel moisture content

The weather conditions during the burning experiment from the two habitats were recorded. The average temperature in the corn farm was 39.05°C while the relative humidity was 39.80%, and the wind speed was 1.11 m s^{-1}. In the mixed deciduous forest, the average temperature was measured at 36.38°C, the relative humidity was 45.79%, and the wind speed was 1.51 m s^{-1}. Statistical analysis suggested that the weather conditions in the two areas were not significantly different (Table 3)

Fuel moisture content of litter in the corn farm (5.23%) was higher than in the mixed deciduous forest (10.20%), as most of fuel in corn farm was dried corn stubbles. The fuel moisture content of undergrowth in the mixed deciduous forest (107.21%) was higher than in the corn farm (32.32%), as the mixed deciduous forest consisted of live fragments and the statistical analysis suggested that the fuel moisture content in the two areas was significantly different (Table 3).

Table 3 Weather conditions and fuel moisture content in the corn farm and the mixed deciduous forest (MDF) during the experiment.

Study Site	T (°C)	RH (%)	WS (m s^{-1})	Fuel moisture content (%)	
				Litter	Undergrowth
Corn farm	39.05±2.55	39.80±4.45	1.11±0.37	5.23±2.74	32.32±10.59
MDF	36.38±2.57	45.79±4.71	1.51±0.05	10.20±2.27	107.21±23.00
p-value	0.45^{ns}	0.37^{ns}	0.16^{ns}	0.14^{ns}	0.04^{*}

Notes: T: air temperature, RH: relative humidity, WS: wind speed
Remarks: ^{ns} = non-significant difference (p>0.05).* = significant difference at p=0.05.
± = standard deviations are indicated in parentheses.

3. Fire behavior

Rate of the fire spread, fire intensity, and flame length were measured to describe the fire behavior. The results revealed that the rate of fire spread in the corn farm (5.61 m min^{-1}) was higher than in the mixed deciduous forest (4.68 m min^{-1}). The lower relative humidity in the corn farm directly contributed to a relatively dry fuel. This property allowed the fuel to be ignited more easily with a fast burning rate (Akaakara and Kittisuttho, 1992). Studies on the rate of fire spread by Chokeprasombat *et al.* (2013) in highland pine-dipterocarp forest (2.44 m min^{-1}), Panuthai *et al.* (2009) in a mixed deciduous forest, Maeklong Watershed Research Station (3.62 m min^{-1}), and by Junpen *et al.* (2013) at the Doi Sutep-Pui national park (0.51-2.55 m min^{-1}) reported a lower rate of fire spread compared to that estimated in this study in the Nan province. Nevertheless, the rate of fire spread reported by Panuthai *et al.* (2009) in the dry dipterocarp forest (7.89 m min^{-1}) in Chi Watershed Research Station was higher than in this study (Table 5).

Rate of fire spread measured from the experiment was used to estimate the fire line intensity, according to Byram's equation (Byram, 1959). It was found that the fire intensity in the corn farm was higher than in the mixed deciduous forest (562.06 and 463.83 kW m^{-1}, respectively). Average flame length was also higher in the corn farm compared to the forest (1.42 and 1.34 m, respectively). The higher fire intensity in the corn farm could be explained by a higher fuel load, higher temperature, and lower relative humidity during the prescribed fire experiment. A comparison of standard deviation demonstrated that the corn farm had higher than the mixed deciduous forest. This was due to the fact that the piles of post-harvest residues, left in the farm, were not uniformly distributed throughout the area, while fuels in the mixed deciduous forest were more uniformly distributed on the forest floor. The fuel distribution was also a factor in contributing to a higher rate of fire spread, intensity, and flame length. However, the fire behavior parameters estimated in the corn farm and deciduous forest in this study were not statistically different (p>0.05) (Table 4).

According to the fire intensity scale recommended by Andrew (1980), the fire intensity observed in the study was categorized as medium. In contrast, when applying forest

fire rating scales of Akaakara (1996), the fire intensity of more than 301.03 kW m^{-1} from the corn farm and mixed deciduous forest in Nan province was classified as highly dangerous. Fire intensities calculated from this study were also compared with other study in similar areas. Wanthongchai *et al.* (2013) reported that the fire intensity in a degraded pine forest of Nam Nao national park, Petchabun province was 626.60 kW m^{-1}, which was higher than this study. This was because the degraded pine forest had more fuel load mainly composed of grass and leaves (45.40% and 44.35%, respectively). In contrast, Junpen *et al.* (2013) reported a fire intensity of 166.30 kW m^{-1} in a deciduous forest of Doi Suthep-Pui national park, which was lower than the study, despite the fact that the fuel load in Junpen's paper was similar to the fire intensity number obtained from the mixed deciduous forest in this study (3.88 t ha^{-1}). This may be due to the lower relative humidity and high wind speed in this study which assists fuel combustion and increases fire intensities. Moreover, slope of the terrain in Junpen's study was not mentioned, which can highly influence the fire behavior. The study, however, located on a very steep slope (>35% slope), would positively impact the rate of fire spread and hence the fire intensity.

Interestingly, the study by Molina *et al*. (2017) in a heavily thinning maritime pine forest (*Pinus pinaster*) of the Mediterranean plains, with a higher fuel load (9.87 t ha^{-1}), reported a lower rate of fire spread (0.59 m min^{-1}), fire intensity (55.17 kW m^{-1}), and flame length (0.25 m) than that reported in the corn farm and mixed deciduous forest in this study. The differences in slopes between these two studies could explain the differences in numbers as suggested by Akaakara (1989) who stressed that the slope has a direct impact on the direction and rate of fire spread. The study demonstrated that fire intensity was higher on the mountains than in the plain areas. Moreover, fire spread on the mountain slopes could be impacted by valley breeze and receive faster and higher heat compared to those spread in the flat plains at the same altitude. In addition, this lifting of hot air around the mountain slope could create wind (Learning Center of Earth Science and Astronomy, 2017), which assists in an efficient heat dispersal and so increase the rate of fire spread on mountain slopes.

Table 4 Fire temperature and fire behavior descriptors in the corn farm and mixed deciduous forest (MDF).

Study Site	Fire Temperature (°C)	Rate of fire spread (m min^{-1})	Fire intensity (kW m^{-1})	Flame length (m)
Corn farm	544.90±180.06	5.61±4.26	562.06±367.22	1.42±0.46
MDF	793.77±50.96	4.68±1.72	463.83±137.68	1.34±0.18
p-value	0.19^{ns}	0.80^{ns}	0.77^{ns}	0.86^{ns}

Remarks: ^{ns} = non-significant difference (p>0.05)
± = standard deviations are indicated in parentheses.

Table 5 Fire behavior from other studies.

Fuel bed	Fuel load (t ha^{-1})	Rate of fire spread (m min^{-1})	Fire intensity (kW m^{-1})	Flame length (m)	Source
Huai Kha Khaeng	6.86	0.47	66.17	0.45	Himmapan *et al.* (2006)
Khon Kaen	4.00	7.89	1,016.13	1.93	Panuthai *et al*. (2009)
Kanchanaburi	3.21	0.72	55.52	0.51	Panuthai *et al*. (2009)
Nam Nao	12.92	1.20	626.60	1.40	Wanthongchai *et al.* (2013)
Nam Nao	13.32	1.89	362.62	1.20	Tarusadumrongdesh (2013)
Ban Watchan	5.30	2.44	291.50	1.06	Chokepra sombat *et al*. (2013)
Northern Thailand	3.88	0-51-2.55	39.33-379.79	0.39-2.03	Junpen *et al.* (2013)

4. Post-burned residue and fuel consumption

The post-burned residues were categorized into burned (ash-charcoal) and unburned material. The results indicated that average post-burned residues of fuel in the corn farm were 0.25 t ha^{-1}, comprising of 0.12 and 0.13 t ha^{-1} of burned and unburned material, respectively. The post-burned material remaining from fuel in the mixed deciduous forest was 0.35 t ha^{-1}, consisting of 0.25 t ha^{-1} of burned and 0.10 t ha^{-1} of unburned material (Table 6). The post-prescribed fire material in the mixed deciduous forest was more than that in the corn farm, due to higher relative humidity in the forest which resulted in a higher moisture in the fuel and causing incomplete combustion. In addition, the fact that when corn was harvested, the farmer left the corn stubble on site. Therefore, these stubble were air-dried and ready to be combusted. However, the statically analysis suggested that the post-burned residues between the corn farm and the mixed deciduous forest were not significantly different.

Results of the experiment demonstrated that the combustion of fuel load in the corn farm was higher than that in the mixed deciduous forest (3.61 and 3.22 t ha^{-1}, respectively). A factor contributing to the result was the physical conditions in the two areas. As the highland corn farm was an open area while the mixed deciduous forest was covered with tree canopy, the relative humidity and fuel moisture content from the corn farm was lower than the mixed deciduous forest (Table 3). This relatively lower fuel content allowed the fuel in the corn farm to undergo a more complete combustion (Akaakara, 1989). In addition, the results showed that rate of fire spread of the fuel in the corn farm was 5.61 m min^{-1} which was higher than that in the mixed deciduous forest (4.68 m min^{-1}). The fire intensity in the corn farm were also higher than in the mixed deciduous forest, although the statistical analysis suggested no significant difference of this parameter in the two habitats of interest ($p>0.05$) (Table 6).

Table 6 Post-burned and consumed fuel loads in the corn farm and mixed deciduous forest (MDF).

Study Site	Post-burned fuel (t ha^{-1})			Consumed (t ha^{-1})
	Burned material	Unburned material	Total	
Corn farm	0.12±0.05	0.13±0.08	0.25±0.06	3.61±0.52
MDF	0.25±0.09	0.10±0.13	0.35±0.07	3.22±0.32
p-value	0.07^{ns}	0.78^{ns}	0.35^{ns}	0.15^{ns}

Remarks: ^{ns} = non-significant difference (p>0.05)
± = standard deviations are indicated in parentheses.

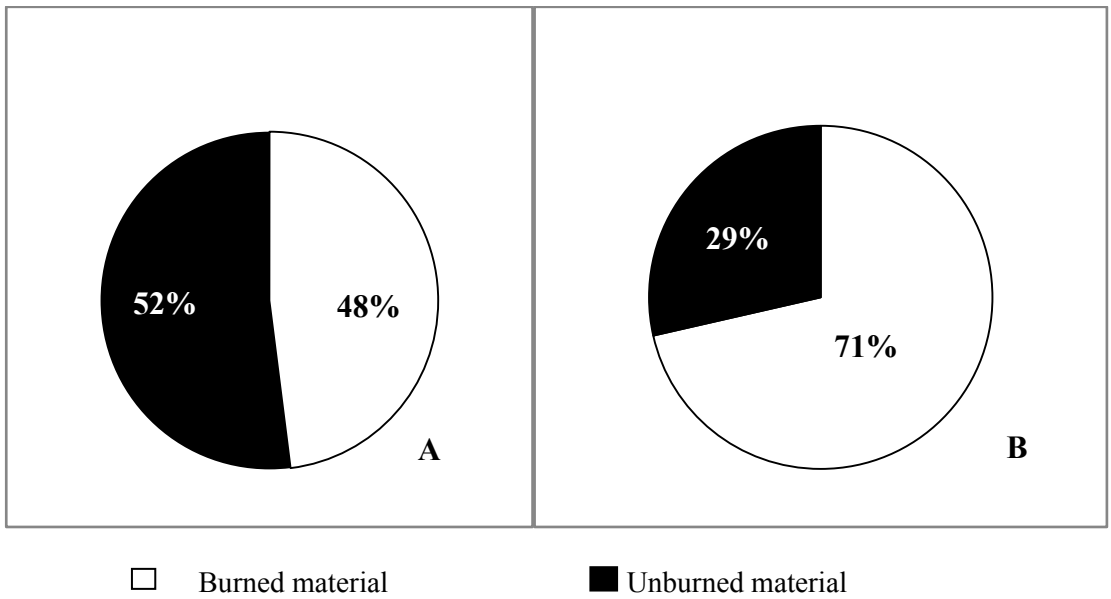

Figure 2 Portions of post-burned residual material in corn farm (A) and mixed deciduous forest (B).

Portions of post-burned residual material revealed that burned material (ash-charcoal) in corn farm were similar with unburned material while portion of unburned material in mixed deciduous forest was lower burned material. This result reflected the rate of fire spread in mixed deciduous forest which was slower than in corn farm, and hence more fuel was consumed during burning experiment. (Figure 2)

CONCLUSION

Fuel load in the corn farm was higher than in the mixed deciduous forest (3.86 and3.57t ha^{-1}, respectively). Rate of fire spread (5.61 and 4.68 m min^{-1}, respectively) and flame length in the corn farm was higher than the mixed deciduous forest (1.42 and 1.34 m, respectively) and fire intensity in the corn farm and mixed deciduous forest was medium. The results reveal that the fuel structure, composition, and fire behavior in the corn farm and the mixed deciduous forest of highland, Chetawan village, Santha sub district, Na Noi district, Nan province were similar. However, it is likely that the fire occurring in the corn farms could expand to the mixed deciduous

forest and vice versa. Therefore, studies of fire characters and response of both areas to such fires are critical with regards to a better fuel and fire management.

Recommendations

1. Even though the fuel loads in both areas were similar, it should be considered that the high fuel load in corn farms was difficult to relocate as the farms were located on the mountain slopes. Also, the fact that burning agricultural area to prepare for the next cropping season has been done traditionally and so it was recommended that firebreaks be created before the post-harvest burning to control spread of fire beyond the desired areas.

2. Early burning should be considered in as a fire management strategy in mixed deciduous forest to reduce accumulated fuel load and potential fire intensity. The post-burned fuel accumulations should be studied in order to estimate a suitable burning frequency.

3. More attention should be paid on studies of fuel loads and fire behavior in other highland corn farms in order to allow for a more robust comparison.

ACKNOWLEDGEMENTS

The authors thank Thinnakorn Panpan and Soraya Kumkeaw, the farm owners, for their kind permission to use the farm for this study; the officers from the forest fire control and support division of the Royal forest department, Na Noi, and villagers from the Nan province and Forest Fire Control Network for providing assistance though out the field data collection.

REFERENCES

Akaakara, S. 1989. **Study of fire pattern and rate of fire spread in dry dipterocarp forest, Chiang Mai province**. First Report from Phu Ping Fire Control Project, Fire Control Department, Office of Forest Management, Royal Forest Department, Bangkok. (In Thai)

_____. 1994. **Fuel characteristics in mixed deciduous forest, Khao Yai national park**. Division of Forest Fire and Natural Disaster, Office of Protection and Enforcement, Royal Forest Department, Bangkok. (In Thai)

_____. 1996. **Forest fire danger levels in a dry dipterocarp forest Doi Suthep-Pui national park**. Royal Forest Department, Bangkok. (In Thai)

_____ and S. Kittisuttho. 1992. **Fuel characteristics in a dry dipterocarp forest Doi Suthep-Pui national park, Chiang Mai province**. Office of Natural Disaster Victims Assistance report. Royal Forest Department, Bangkok. (In Thai)

_____, K. wiriya and P. Nhoochaiya. 2005. **Fuel characteristics in a mixed deciduous forest, Huai Kha Khaeng wildlife sanctuary. Huai Kha Khaeng Fire Research Center Report, Uthai Thani province**. Forest Protection and Fire Control Office, Department of National Park, Wildlife and Plant Conservation, Bangkok. (In Thai)

Andrew, P.L. 1980. Testing the fire behavior model. pp. 70-73. *In* **Proceedings sixth conference on fire and forest meteorology**. Society of American

Forester, Seattle, Washington Margaret Altemus.

Byram, G.M. 1959. Combustion of forest fuels. *In* Davis, K.P., ed. **Forest fire; Control and use.** McGraw-Hill, New York.

Chokeprasombat, T., K. Wanthongchai and D. Marod. 2013. Fuel characteristics and fire behavior in pine-deciduous dipterocarp forest. Banwatchan Royal Project, Chiang Mai province. *In* **Thailand Forest Ecological Research Network Academic Seminar and Presentation Report**. At Maejo University, Chiang Mai province. 24-26 January 2013. (In Thai)

Himmapan, W., S. Kaitpraneet and S. Boonyawat. 2006. Behavior of burning fire in dry deciduous dipterocarp forest at Huai Kha Khaeng wildlife sanctuary, Uthai Thani province. **Thai Journal of Forestry** 25: 112-114. (In Thai)

Jongkitwiwat, S. 2010. **Fuel characteristics in mixed deciduous forest, Chiang Mai province**. Forest Protection and Fire Control Office, Department of National Park, Wildlife and Plant Conservation, Bangkok. (In Thai)

Junpen, A., S. Garivait., S. Bonnet and A. Pongpullponsak. 2013. Fire spread prediction for deciduous forest fires in Northern Thailand. **ScienceAsia**. 39 (2013): 535-545.

Learning Center of Earth Science and Astronomy. 2017. **Valley breeze and mountain breeze**. Available source: http://www.lesa.biz/earth/atmosphere/wind, 23 July 2017. (In Thai)

Lizotte, P.L., P. Savoie and A.D. Champlain. 2015. Ash content and calorific energy of corn stover components in Eastern Canada. **Energies** 8: 4827-4838.

Molina, J.R., J.P. Garcia, J.J. Fernandez and R.Y. Silva. 2017. Prescribed fire experiences on crop residue removal for biomass exploitations. Application to the maritime pine forests in the Mediterranean Basis. **Science of the Total Environment** 612: 63-70.

Nhoochaiya, P. 2008. **Fuel characteristics in mixed deciduous forest in the central parts 2005.** Forest Protection and Fire Control Office, Department of National Park, Wildlife and Plant Conservation, Bangkok. (In Thai)

Office of Forest Land Management. 2015. Forest cover in Thailand. **Royal Forest Department information**. Available source: http://forestinfo.forest.go.th/, 16 September 2016. (In Thai)

Panuthai, S., K. Pongboon, P. Trepattanasuwan, S. Onarsa and S. Wanwong. 2009. **Forest fire and fire behavior in watershed**. Department of National Park, Wildlife and Plant Conservation, Bangkok. (In Thai)

Saihu, P. 2009. **Thai society and agriculture extension**. 4th edition. Sukhothai Thammathirat Open University, Bangkok. (In Thai)

Sangthong, Y. 2006. **Estimation of biomass lost from forest fire in deciduous forest of Huai Kha Khaeng wildlife sanctuary by distance survey**

technique. M.Sc. Thesis, Kasetsart University. (In Thai)

Sompoh, B. 1998. **Fuel sources in dry dipterocarp and mixed deciduous forests at Huai Kha Khaeng wildlife sanctuary, Uthai Thani province.** M.Sc. Thesis, Kasetsart University. (In Thai)

Tarusadumrongdesh, W. 2013. **Fuel characteristics and fire behavior in degraded pine forest and sub-community of mixed pine forest, Nam Nao national park, Phetchabun province** M.S. Thesis, Kasetsart University. (In Thai)

The Bureau of Registration Administration, Department of Provincial Administration. 2015. Population statistic report. **Registration administration statistic system**. Available source: http://stat.bora.dopa.go.th/stat/y_stat59.htm, 16 September 2016. (In Thai)

Wanthongchai, K. 2008. **Effect of different burning frequency on fire behavior, nutrient dynamics, soil properties and regeneration structure and composition in dry dipterocarp forest, Huay Kha Khang wildlife sanctuary Thailand**. Ph.D. Thesis, Freiburg University.

_____, V. Tarusadamrongdet, K. Chinnawong and K. Sooksawat. 2013. Fuel properties and fire behavior characteristics of prescribed fire in pine-dominated forests at Nam Nao national park, Thailand. **International Journal of Wildland Fire** 22 (5): 615-624.

_____ and P. Wongsawat. 2012. Effects of rotation farm burning on carbon storage and release to the atmosphere. **Thai Journal of Forestry** 31 (3): 25-35. (In Thai)