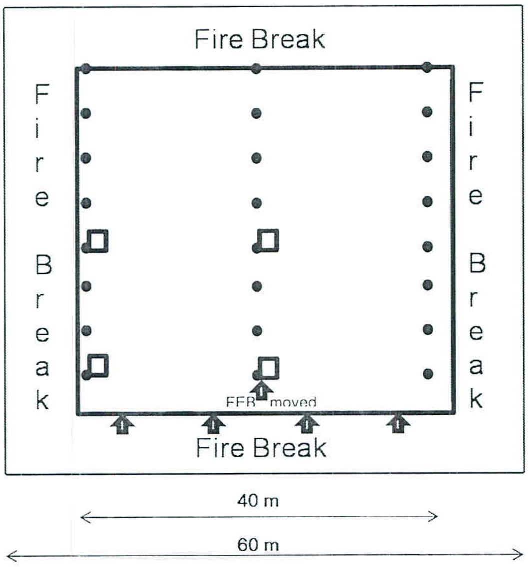
CHAPTER 4
PRESCRIBED FIRE EXPERIMENTS

4.1 Materials and Methods

4.1.1 Prescribed Burning Plot

The field experimental set up in this study was conducted during the dry season (February-March) in years 2011 and 2012. Three replicate main plots as 40m ×40m area was set for prescribe burning. Each main plot was built the fire breaks in radius about 5 m wide (Figure 4.1).



Legends: □ 1 × 1-m plot for pre-burnt fuel loads, ● wooden stick for determine rate of fire spread and flame height, 🡅 burning direction and FEB (Field Equipment Box) movement on the central line

Figure 4.1 Field experiment set up for prescribed burning of DDF and MDF at the study site

Prior to the start of the fire, three experimental plots of 40m × 40m plots were set in each DDF and MDF. Fire breaks were set up at the outside of the main plots 40m × 40m areas. Biomass fuels were sampled from four subplots of 1m × 1m then their areas were replaced by the same load of biomass fuel. The 1.5 m tall of wooden stick with heights marked at 1.0 m intervals were placed with heights marked at 5.0 m distance in right, central and left side of the main plots (Figure 4.1). The wooden stick position was used to estimate the rate of fire spread and flame height. The rate of fire spread was calculated by the distance of fire moved per time. The flame height was recorded every 5.0 m by human and measured directly by aluminum measure tape. The prescribed burning will start during February to March and the ignition time also starts during noon to 2 pm.

4.1.2 Fire Behaviors

The behavior of a forest fire can be characterized by measuring the rate of fire spread, flame height flame length, and fireline intensity. The experimental set up to collect the rate of fire spread and biomass fuel consumed during fires. The latter can be estimated using Byram's Equation (Byram, 1959) as follows.

$$I_B = H \times w \times r \qquad \text{Equation 4.1}$$

where: I_B is fire line intensity (kW/m), H is net calorific calculation (NCV) values from percentage of elemental analysis of organic elemental analysis based on model of Friedl (2005) at 16,970 and 14,171 kJ/kg in DDF and MDF, respectively, w is the biomass fuel consumed (kg/m^2), and r is the rate of fire spread, (m/s).

The flame length of fire flame is measured the head of fire at the position marked of 5, 10, 15, 20, 25, 30 and 35 m of the main plot 40 m × 40 m areas. The Byram's equation (Byram, 1959) was used to calculate the flame length as follows,

$$L = 0.08\, I_B^{0.46} \qquad \text{Equation 4.2}$$

where: L is flame length (m), and I_B is fireline intensity (kW/m).

4.1.3 Set Up of Measurement Equipment

Equipment for the measurement of gases and particulate matter were composed of real-time equipment and air samplers for taking the samples to the laboratory for chemical analysis. List of equipment with their associate measurements is presented in Appendix B. An equipment was placed in the "field equipment box" fixed at the top of a bamboo stem of 3 m height. The whole including the field equipment box and the bamboo stem constitutes the "measurement tower". Before the start of the fire, the measurement tower was prescribed at the center of the plot to conduct the measurement of background concentration of pollutants of interest.

Meteorological

The weather station (Lacrosse Technology, model ws1600, USA) composed of an anemometer, thermometer, barometer and RH sensor was placed at the top of a bamboo stem of height 3 m on the fire break zone to assure the measurement wind speed and direction, relative humidity, temperature and pressure.

Carbon Dioxide (CO_2) and Carbon Monoxide (CO) Measurement Condition

Both carbon dioxide and carbon monoxide were sampled using non-dipersive infared (NDIR) sensor. This probe has temperature and humidity sensor. CO was set up in the channel of toxic gas at the full scale 1,000 ppm, repeatability 3% ±2 LSD (Least significant digits), display resolution 1 ppm. CO_2 also has a wide range 0-20,000 ppm with the accuracy in range ±3% of reading ±300 ppm and the resolution 1 ppm (10 ppm above 10,000 ppm). The flow rate connecting tubing was connected with the micro-aethalometer at 50 mL/min for 1 min interval time set up. The Micro-aethalometer (Magee Scientific, USA) is the optical technique to measure the black carbon at 880 nm. The equipment was set up for real-time measurement the concentration of black carbon and also set up at the flow rate 50 mL/min for 1 min interval.

Particulate Matter Measurement

DustTrak aerosol monitor (TSI incorporated, USA) is a real-time optical scattering measurement that used to obtain the concentration of $PM_{2.5}$. The air flow through the chamber and scattered by the infra-red diode laser beam. The calibration of the respirable fraction of standard ISO 12103-1, A1 test dust (formerly Arizona Test Dust) was operated by factory (Mercy *et al.*, 2011). The aerosols flow through the inlet size selection by pump. The light scattering laser in photo detector determines the mass concentration of aerosol drawn to the unit in a constant stream. This study use the range of $PM_{2.5}$ data was logged at 10 second intervals.

Total particulate matter (TPM) sampling

The quartz filters (Pall Corporation, USA) size of 47 mm diameter were preheated at 800 °C for 5 h (Cao *et al.*, 2002) and then placed in a desiccator for 24 hrs before weighing and using to sample PM emitted from prescribed burning of DDF and MDF at the study site. Each filter was placed in stainless-steel filter holder that it has open-faced (Appendix B). PM sampling was performed using air pump directly in the smoking plume. The smoking plume was flow through the filters by air pump to give a total flow of 5 L/min. Each sample was taken over the whole burning process. PM sampling was started just before ignition and concluded after complete burn down indicated by area burned of main plot 40m × 40m area and no future visible smoke emissions.

The ignition position was started from one side (Figure 4.1). The field equipment box (FEB) was along the smoking plume from ignition side to the opposite side (Appendix C). The flame height was measured directly by aluminum tape based on the spread of fire every 5.0 m. The burning time period was recorded from the line the ignition had started until completely burned down indicated by no further visible smoke emission.

4.2 Results and Discussion

4.2.1 The Weather Condition

The period ignition time of all prescribed fire both DDF and MDF was started at noon to 5pm. The weather condition of Humidity, temperature, wind speed during the fire are illustrated in Table 4.1.

Table 4.1 The average of weather conditions during the prescribed fires in both DDF and MDF plots

Burning date	Burning time	Plot	Weather conditions			
			Wind speed (km/hr)	Wind direction	Temp.(°C)	Relative humidity (%)
3-Feb-11	13.00-14.18	MDF3	0.95	NNE, E	37.55	43.52
3-Feb-11	16.03-17.30	DDF4	1.40	ENE, E	37.92	43.18
3-Mar-11	13.04-14.29	DDF1	0.98	WNW, NE	35.58	49.12
3-Mar-11	15.50-16.56	MDF1	1.19	WNW,NW	35.73	47.67
25-Feb-12	12.26-13.33	DDF3	1.81	E, ESE	37.81	43.13
18-Feb-12	14.20-15.36	MDF2	0.47	ENE, E	33.80	51.36

The wind speed in DDF plots is ranged 0.98-1.81 km/hr. DDF3 is the highest of wind speed followed by DDF4 and DDF1, respectively. DDF3 and DDF4 are composed of vegetation density lower than DDF1. It should be noted that the vegetation density seemed to play a significant role on the measured wind direction. Actually, we observed that the denser was the vegetation. The tower was the change in wind direction.

The wind speed in MDF plots is ranged 0.47-1.19 km/hr. MDF2 is the lowest of the wind speed in MDF plots. The temperature in MDF2 plot is also the lowest when the relative humidity is the highest. Nevertheless, the wind speed in this study was lower than the other research studies of the western part of Thailand.

(a) (b)

Figure 4.2 Flame height directly measurement for (a) DDF fire and (b) MDF fire plots.

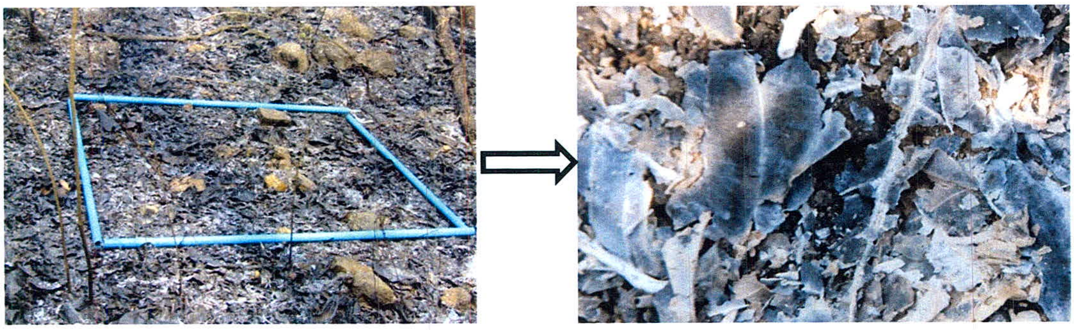


Figure 4.3 Ash and charred leaves after prescribed burning in DDF plots

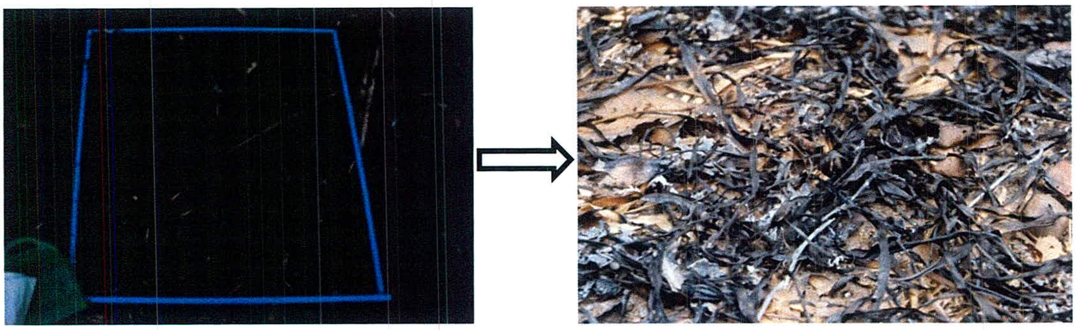


Figure 4.4 Ash and charred leaves after prescribed burning in MDF plots

4.2.2 Fire Characteristics

The flame height was measured directly from prescribed fires and the flame length was calculated based on Byram's formula (Byram, 1959).

The biomass fuels load in both DDF and MDF plots, especially leaf litter was combustion factor was estimated. The other fuels such as seedling, understory, and twig, were not used in the estimation because what is really burnt is all the leaf litter and only some small twigs. The average annual of leaf litter in DDF1 is the same order of magnitude with that found by Weerapole (Weerapole, 2003) and Himmapan (Himmapan, 2004) (Table 4.3). The rate of fire spread in DDF3 and DDF4 are the same values. In addition, the flame length and fireline intensity of DDF3 and DDF4 were very similar. The flame length and fireline intensity of DDF1 were higher than those of DDF2 and DDF3 because its slope ranged between 20-40% while it was lower than 20% for DDF3 and DDF4. However, the averages of fire front and fire back in DDF plots is the same order of magnitude with the research of Himmapan (2004) and Sompoh (1998), at the dry dipterocarp forest at Huay Kha Khaeng Wildlife Sanctuary, Uthai Thani Province. The fireline intensity found in DDF1 was quite close to that found by Sompoh, (Sompoh, 1998) while those of DDF3 and DDF4 is also ranged of the research of Himmapan (Himmapan, 2004) that is illustrated in Table 4.3.

Table 4.2 Parameters collected and calculated from prescribed fire experiments set up in DDF plots

Parameter	DDF1	DDF3	DDF4	Average	SE
Leaf litter, %$MC_{dry\ basis}$	3.39	5.10	6.52	5.00	0.90
Biomass fuel load, kg/m^2	0.56	0.21	0.25	0.34	0.11
Biomass fuel unburned, kg/m^2	0.13	0.02	0.06	0.07	0.03
Rate of fire spread, m/min	0.78	0.68	0.67	0.71	0.04
Flame length, m					
Flame height	0.44	0.38	0.21	0.34	0.07
Flame length	0.65	0.42	0.42	0.50	0.08
Fire line intensity, kW/m	95.48	36.90	36.06	56.15	19.67
Combustion completeness, %	76.72	89.99	75.93	80.88	4.56

Table 4.3 Fuel load and fire behavior in DDF from the other research studies

Forest	Location study	Fuel load (kg/m^2)	Rate of fire spread (m/min)	Fireline intensity (kW/m)	Flame length (m)	Reference
DDF	Kanchanaburi	0.44	0.45	-	0.2-0.4	Weerapole, 2003
DDF	HKK	0.50	0.47	66.17	0.45	Himmapan, 2006
DDF	HKK	0.81	0.44	44.33	1.51	Himmapan, 2006
DDF	HKK	1.10	0.67	110.71	0.7	Sompoh, 1998
DDF	Phu Kradueng	0.47	0.3-1	57.77	0.2-0.7	Sudthichart , 1996

HKK means Huay Kha Khaeng Wildlife Sanctuary, Uthai Thani Province.

Table 4.4 Fuel load and fire behavior in MDF from the other research studies

Forest	Location study	Fuel load (kg/m^2)	Rate of fire spread (m/min)	Fireline intensity (kW/m)	Flame length (m)	Reference
MDF	HKK	0.54	0.595	91.37	0.64	Sompoh, 1998
MDF	Phu Kradueng	0.49	0.6-1	102.09	0.3-1	Sudthichart , 1996

HKK means Huay Kha Khaeng Wildlife Sanctuary, Uthai Thani Province.

The fuel load in MDF plots is the highest in MDF3 followed by MDF1 and MDF3, respectively. However, the average of fuel loads in all plots of MDF is the good agreement with other research studies of Sompoh (1998) and Sudthichart (1996). The rate of fire spread in MDF2 and MDF3 is similar value and also higher than the other research of Sompoh (1998) and Sudthicart (1996) (Table 4.4). However, the rate of fire spread in MDF1 is the lowest value of MDF experiment. The fireline intensity of MDF plots is the in range of the other research that illustrated in Table 4.3.

Table 4.5 Parameter collected and calculated from prescribed fire experiment set up in MDF plots

Parameter	MDF1	MDF2	MDF3	Average	SE
Leaf litter, $\%MC_{dry\ basis}$	5.74	3.23	8.18	5.72	1.43
Biomass fuel load, kg/m^2	0.53	0.68	0.38	0.53	0.09
Biomass fuel unburned, kg/m^2	0.27	0.15	0.21	0.21	0.34
Rate of fire spread, m/min	0.73	0.89	0.80	0.81	0.05
Flame, m					
Flame height	0.35	0.39	0.28	0.34	0.03
Flame length	0.46	0.70	0.40	0.52	0.09
Fire line intensity, kW/m	45.57	111.92	32.49	63.33	24.59
Combustion completeness, %	49.87	78.25	45.37	57.83	10.29

The rate of fire spread in DDF and MDF showed that the surface fire was flaming combustion dominant and creeping ground fire as active spreading. In addition, flame length and fireline intensity are in ranged 0.5-1.5m and 5.8-630 kW/m, respectively (Ryan, 2002). The information of fireline intensity in this site was show that the fire danger class is the low level and can direct attack on the head or flanks of the fire with hand tools (Palheiro *et al.*, 2006). However, the fireline intensity in this site was lower than the other research of Akaara et al. (Akaara *et al.*, 2003) and Wanthongchai et al. (Wanthongchai *et* *al*., 2011). Due to the fuel loads and weather condition especially, wind speed in this study is quite constant that different the other research. However, not only the fuel load but also the different weather conditions and ignition burning techniques were the important parameters influencing the fire behavior as well.

4.2.3 Elemental Composition of Leaf Litter and Residues After Burning (ash and charred leaves)

Leaf litters in both DFF and MDF were of different shapes and compositions and played important roles in the forest fire propagation and fire behavior. Fuel height in this study was different from other studies in the same region of Thailand, Huay Kha Khaeng Wildlife Sanctuary, Uthai-thani province, which the average of litter height in DDF was 7-10cm (Akaakara *et al*., 2003). However, the litter height was the lowest and the fuel arrangement was discontinuous which can be attributed to the low density of vegetation plant. The amount of biomass fuel consumed in DDF plot is the good agreement with MDF plot. However, the biomass fuel in MDF was burnt only the top layer and lower combustion efficiency than DDF. It was found that the bamboo leave is an important rule the biomass fuel compactness in MDF plots and the maximum temperatures not exceed 175 °C at the 0.5m of fire flame (Baker and Bunyavejchewin, 2009). The cause of low fuel load and fuel discontinuity are may affect rate of fire spread, and hence fire intensity of this plot. The age/structure is also the one of parameter that significant influence on the floor fuel (William *et al*., 2008).

Table 4.6 Analytical parameters of biomass fuel consumed and residues after burning (ash and charred leaves)

Analytical parameter	DDF		MDF	
	Leaves	Ash and charred leaves	Leaves	Ash and charred leaves
Elemental, %				
Nitrogen	0.81±0.00	0.69±0.00	1.09±0.00	0.95±0.00
Carbon	46.00±0.02	35.07±0.04	37.31±0.04	20.23±0.11
Hydrogen	6.06±0.08	2.48±0.02	5.58±0.04	2.14±0.02
Mass, g/m^2	271.36±79.53	39.22±7.53	323.44±108.24	58.36±2.17
Carbon content, g C/m^2	124.83±36.58	18.94±2.64	120.68±40.38	11.81±0.44

Carbon mass balance method was used to estimate the total carbon content in biomass and released from prescribed fire. In DDF, carbon contents in leaf litters, twigs, understories and seedlings are 458.10, 434.90, 433.20, and 443.50 g C/kg $_{\text{dry biomass}}$, respectively. However, leaf litter dominant was present biomass fuel burnt. Therefore, carbon component in leaf litter will be used to estimate mass carbon balance of both DDF and MDF burning experiment. The combustion process in DDF and MDF is produce each gram of carbon from biomass consumed, leaf litter burned is 2.69 tons/ha in DDF1 and 1.20 tons/ha in both plot DDF3 and DDF4. In MDF, the amount of leaf litter consumed in MDF1, MDF2 and MDF3 are 1.66, 3.33 and 1.07 tons/ha, respectively. The average amount of leaf litter consumed in DDF and MDF are higher than Nelson (Nelson, 1982) was conducted in laboratory scale. Nelson (Nelson, 1982) found that 2 g of pine needles consumed was released one gram of carbon to the atmosphere. On the other hand, the average biomass consumption in the field experiment for each gram carbon in DDF and MDF plots are 2.46±0.03 and 3.05±0.11g.

In MDF plots, carbon content in leaf litter, twig, understory, and seedling prior burning are 373.10, 411.90, 428.50 and 442.30 g C/kg $_{\text{dry biomass}}$, respectively. After burnt, ash and charred leaves were oxidized by combustion process, the composition of a mixture of ash and charred leaves in DDF and MDF are 35.07 and 20.23% (Table 4.4).

Table 4.7 Amount of carbon content in residues after burned (ash and charred leaves) and carbon released to the atmosphere

Experiment plot set up	Carbon on ground soil (g C/m^2)		Carbon released to the atmosphere (g C/m^2)
	Carbon in biomass	Carbon in ash and charred leaf	
DDF	26.47±11.92	13.75±2.64	111.07±33.99
MDF	77.35±12.76	11.81±0.44	108.87±39.95

We found that the total carbon released from leaf litter burning in DDF and MDF sites are 10.14 and 17.08%. It was showed that the percentage of carbon to soil in ash and charred leaf forms was still high when compared with leaf litter. However, the average of carbon content in biomass fuel unburned in DDF and MDF burning from Table 4.7 are 26.47±11.92 and 77.35±12.76 g C/m^2. The average of carbon released that was obtained from carbon mass balance is 111.07±33.99 and 108.87±39.95 g C/m^2 in DDF and MDF, respectively. The experimental of prescribed fire was showed that the amount of carbon released to the atmosphere of tropical deciduous forest fires is higher than carbon on ground soil (Table 4.7).

Carbon content in biomass fuel of both DDF and MDF types are 460 and 373 g C/kg$_{dry\ biomass}$ that is significantly different due to the bamboo leaves being the dominant was present in MDF. Plant structure in DDF was composed of trees while MDF composed of a mixture of trees and bamboo. However, the carbon storage in stem, branch and root of trees and bamboo are never loss during surface fire occurrences in this study. Carbon in a mixture of ash and charred leaves will be returned to ground soil. The percentage of carbon in residues after burned to soil surface in DDF and MDF plots are 11.25±2.11 and 17.27±5.65 of carbon in biomass fuel consumed. It was showed that the amount of carbon return to ecosystem in form of a mixture of ash and charred leaves in DDF and MDF are 53.45 ±12.08 and 44.20±5.36 g C/kg$_{dry\ biomass}$. The data of forest fire statistic occurrence in DDF and MDF in this site were used to estimate the amount of carbon in residues after burned on ground soil during years 2007 to 2010 as illustrated in Table 4.8. The amount of carbon in residues after burned returned to soil surface in the form of ash and charred leaves after forest fires both in DDF and MDF are 0.75 and 3.83 tons C/year, respectively.

After burning the average of total carbon on ground soil in form of biomass unburned and a mixture of ash and charred leaves in DDF and MDF are 2.19±1.41 and 24.86±12.38 tons C/year or 26.65 and 42.02%, respectively.

All of the prescribed fires were shown that the carbon loss through gas and aerosols by the main of leaf litter burning. The amount of carbon released from DDF and MDF burning are 406.55±5.36 and 328.90±12.08 g C/kg$_{dry\ biomass}$. The percentage of carbon released to the atmosphere both DDF and MDF are 88.15±3.24 and 88.38±1.17% of carbon in biomass fuel consumed. It was showed that the forest fires in this study site occurrence during 2007 to 2010 will be released the average of carbon to the atmosphere from DDF and MDF burning are 0.20 and 0.77 tons C/ha/yr. The amount of carbon released from MDF and DDF are the same order magnitude, it was showed that both forest types have been invaded and important role to release the carbon emissions to the atmosphere.

Table 4.8 Carbon released from tropical deciduous forest fire occurrences in Mae Nam Phachi Wildlife Sanctuary, Ratchaburi, Thailand during 2007-2010

Year	Area burned (ha)		Carbon on ground soil (ton C/area burnt)				Carbon released (ton C/area burnt)	
			Biomass unburned		Residues after burned			
	DDF	MDF	DDF	MDF	DDF	MDF	DDF	MDF
2007	0.80	19.37	0.21	14.98	0.11	2.23	0.89	21.09
2008	-	3.04	-	2.35	-	0.36	-	3.31
2009	15.20	21.44	4.02	16.58	2.09	2.53	16.88	23.34
2010	5.76	67.68	1.52	52.35	0.79	7.99	6.40	73.68

However, more than 95% of the carbon released into the atmosphere by combustion processes is carbon dioxide, which is also a greenhouse gas and plays an important role in global climate change. In a further study, carbon released by forest fire to the atmosphere will be characterized and estimated the emission factor especially carbon dioxide, carbon monoxide, $PM_{2.5}$ and black carbon.

4.3 Summary of Findings

- The results of the prescribed fire showed that leaf litter is the major component of fuel consumed in both DDF and MDF
- The seedlings and twigs are licked by flames, and most do not burn.
- Characteristics resulting from the burning leave litter will change color to black and the original fixed structure is only partially complete burning into ashes form. So the residues after burned is composed a mixture of ash and charred leaf that is the major component in residues.
- The behavior of the fires in both DDF and MDF were similar and the fireline intensity did not exceeding 300 kW/m that is lower than the other research studies. However, the fireline intensity is related to the combustion completeness in all plots of MDF and DDF1 while in DDF3 and DDF4 plots.
- In MDF, the leaf litter was present burning on the top layer only that is the dominant feature of this forest.

- The combustion completeness in DDF and MDF are in the range 60-80% and also the major composition of residues is charred leaf. The pollutants released from incomplete combustion, especially carbonaceous aerosols emission, have high concentrations as well.
- Carbon content estimation found that the carbon released into the atmosphere is higher than the amount remaining on the soil surface.
- The average biomass consumed in the field experiment for each gram carbon in DDF and MDF plots are 2.46±0.03 and 3.05±0.11g.