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Catch-fire Temperature and Amount of Combustion-Heat on the Fuel of *Miscanthus* type

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참억새 (*Miscanthus*) 燃料의 着火温度 및 燃燒熱量

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ABSTRACT

This study examined the relationship among catch-fire, burning, maximum temperature (MT), amount of combustion-heat (ACH), and combustive time (CT) in heating temperature treated with the same amount of each organ of *Miscanthus*. In the survey sites, about 19% of the areas were covered by *Miscanthus* types, and the dry weight of *Miscanthus* and debris on the ground were 1,164 and 178 g/m^2, respectively. At 350℃ and 400℃, the rise of temperature by Culm type (culms and ears) and Leaf type (leaves and debris) were 90℃ and 82℃, respectively. At 350℃, burning time (BT) of culms-200, ears-200, leaves-200 and debris-200 was 0-10'30", 0-07'40", 0-04'20" and 0-02'40", and that at 400℃ was 0-01'20", 0-00'50", 0-00'35" and 0-00'30", respectively. BT was shorter at higher temperatures, and BT of Leaf type was shorter than that of Culm type. The amount of samples consumed was as follows: Culm type (culms-200 and ears-200) was 14.6g and 12.6g more than Leaf type (leaves-200 and debris-200) at 350℃ and 400℃, respectively. The total amount of combustion-heat (TACH) of samples was 5,859.7 kcal. The amount of mean combustion-heat generated from sample at 350℃ and 400℃ differed little: 727.6 kcal (24.9%) at 350℃ and 737.3 kcal (25.0%) at 400℃.

Key words: Combustion-heat, Combustive time, Heating temperature, *Miscanthus*

INTRODUCTION

The knowledge on catch-fire and combustive time (CT) of living or dead plant's body is very important in understanding forest fires, and the effect of fire on plants can be determined by the fire behavior. In Korea, forested areas consisted of coniferous, deciduous and mixed forests are 6,289,000 ha (Forestry Administration 1993), and forested areas of Chung-Nam Province was 446,273 ha (Chungcheongnam-Do 1993). Coverage of *Miscanthus* types has been nearly 70% at the present study sites. Most of *Miscanthus*, mixed with and grown over other grasses, is pushed down during the winter, or possibly early spring, and become strong flammable fuels, which is a factor of frequent fires in spring time.

It is likely that the direct cause of withering or burning of dead plants is water loss and temperature rise inside the plant dependent on combustion temperature (Iwanami 1973a, Paysen and Narog 1993). Forest fire would alter the combustion form in accordance with the specific characters of fuels, topography and weather (Baker 1992, Lloyd 1972, Lorimer 1990, Naito *et al.* 1971, Wright and Bailey 1982). Besides, the burn will greatly vary, depending on the amount, moisture content and vertical deposition of fuels (Iwanami 1971, Rundel 1981, Wright and Bailey 1982).

In Korea, grassland fire usually incur forest fire, and frequently occur before and after early spring, or late fall, especially when many people climb mountains. Therefore the fire frequency is very high at these seasons. Especially, when it will burn a dry grass on the ground by a climber's cigarette light (Kim *et al.* 1994), more combustibles produce higher temperatures over 800℃ in the middle height rather than near the soil surface (Iwanami 1972a, 1972b), and if it winds the combustion form change greatly, so the fire momentarily destroy the vast area.

It is almost impossible, in the actual sites of forest fires, to measure the changes in plant conditions at high temperatures. Thus, the purpose of this study is to examine the relationship among catch-fire, burning, CT, total amount of combustion-heat (TACH), and heating temperature with each organ of *Miscanthus*. The result of this study on combustive forms and features will be used as a basic data for preventing forest fires.

MATERIALS AND METHODS

Distribution of *Miscanthus* types and preparation for the fuel samples

To examine the coexisting plants as well as the fuel distribution and dry weight of *Miscanthus*, ten 1 m × 1 m quadrats were randomly established on each survey site, Mt. Ohsoe (791 m: E126° 39′50″~N36° 27′30″), Mt. Seonchi (758 m: E127° 22′25″~N36° 03′05″), Mt. Woonju (459.7 m: E127° 14′30″~N36° 40′55″), Mt. Museong (613.6 m: E127° 04′30″~N36° 33′20″) and Mt. Younwha (284 m: E126° 36′30″~N36° 49′05″), in October and November, 1994.

In preparation for testing fuel samples, we examined the range of moisture according to the time variation within drying oven in lab, after the live fuel moisture was measured directly in the field. Then dry fuels (moisture content: 2~6%) of *Miscanthus* were divided into ears (E-200), leaves (L-200) and culms (C-200), and these three types and debris (D-200) were used for combustion test.

Catch-fire and burning temperatures

To compensate the exact heating temperature value, after AT (Auto Tuning) parameter of Temperature Controllor (DX7; Hanyoung Electronic Co.) have operated each time before the experiment, the experiment was conducted at wind speed of 5-6 m/s at night for the detection of exact catch-fire point. Catch-fire (C-FT: taking fire for the first time), burning times (BT: burning with flame), maximum temperature (MT) and duration of high temperature through combustion procedures were measured with Ignition Point Tester (Jeil Scientific Co.; chamber dimensions, 30×20×25 cm^3), and were compared with the heating temperatures of each sample of 200 g at 250, 300, 350, 400, 450 and 500℃. The combustion processes were accurately measured by means of 12-Channel Scanning Thermocouple Thermometer (0.8 mm in diameter) (Cole-Parmer, U.S.A.) which was inserted in Tester, and each channel could be output to computer simultaneously at 5-s timelag. CT and duration of high temperature were expressed as 0-00'00", hours-minutes, seconds.

Amount consumed and total amount of combustion-heat

The amount of fuels consumed after combustion under each heating temperature and the relation between the amount of fuels and the temperature were measured with each sample. TACH generated at the time of combustion was calculated after Iwanami (1972a): TACH (kcal/m^2) ≒ ACH (kcal/g) × DWCF (g/m^2). ACH is amount of combustion-heat (4.2 kcal/g) and DWCF is dry weight of combustion fuel.

RESULTS AND DISCUSSION

Distribution of *Miscanthus* types and preparation for the fuel samples

Coverage of *Miscanthus* was 55~90%, an average grass height was 185.4 cm, dry weight on the ground was 1,164 g/m^2 (164 individuals) and amount of debris was 178 g/m^2 in October and November at the survey sites (Table 1). Besides *Miscanthus*, there occurred *Carex lanceolata*, *Setaria viridis*, *Spodiopogon cotulifer*, *Anthoxanthum odoratum*, *Erigeron annuus*, *Artemisia feddei*, *Hypericum erectum* and other grasses (Table 2). Of the total survey site of 18.872 km^2, the distributed areas of *Miscanthus* communities were about 19% (3.538 km^2) (Table 1). Wide distribution of *Miscanthus* community means that *Miscanthus* will be high-volatile fuels during the dry season of the spring time because they have affected by snowfall and strong wind. Average dry weight of *Miscanthus* was 1,492±35 g/m^2,

Table 1. The state of fuel distribution and dry weight of *Miscanthus* type

Sites	Area (km^2)	Height (cm)	Coverage (%)	Dry wt (g/m^2)	Dry wt of debris (g/m^2)
Mt. Ohsoe	5.332	108-212.0	56	453.4	65.8
Mt. Seonchi	2.726	100-198.5	68	686.2	132.8
Mt. Woonju	3.254	115-181.9	77	1617.7	274.6
Mt. Museong	4.034	106-178.3	76	1569.0	198.5
Mt. Younwha	3.526	103-220.0	92	1492.2	220.3
Mean		185.4	75	1163.6	178.4

Table 2. The coexisting plants of *Miscanthus* types in the survey sites

Species	Number of individuals				
	Mt. Ohsoe	Seonchi	Woonju	Museong	Younhwa
Achyranthes japonica	2				
Allium grayi		1			1
Anthoxanthum odoratum	11				11
Artemisia feddei			8		
Artemisia princeps var. *orientalis*		1	2	4	
Arundinella hirta		6			
Carex humilis		2			
Carex lanceolata	8	13	15	22	
Carex neurocarpa	5				7
Carex tristachya	2				
Cirsium japonicum var. *ussuriense*		1	1		
Coculus trilobus				2	1
Erigeron annuus		2	2	6	
Eularia speciosa	7		8		
Hypericum erectum				2	4
Imperata cylindrica var. *koenigii*		4	3		
Ixeris dentata	2	3		1	2
Lespedeza cyrtobotrya	2	2			
Metaplexis japonica			1	1	
Oenothera odorata	4	9	2	7	
Pennisetum alopecuroides			4		
Potentilla fragarioides var. *major*	1		2		2
Potentilla freyniana	1	2			2
Setaria viridis	5		2	6	5
Spodiopogon cotulifer		8	13		
Themeda triandra var. *japonica*				3	2
Zoysia japonca					5

and those of leaves, culms and ears of *Miscanthus* were 853±15 g, 587±16 g and 52±4 g, respectively.

Catch-fire and burning temperatures

At 250℃, C-200 did not reach catch-fire but became partial black soot after 20 min. E-200 reached catch-fire within about 12 min but did not spread out from ignition part, and no burning occurred even after 30 min. L-200 reached catch-fire over approximately 15 min but did not burn either as in E-200. D-200 reached catch-fire after 5 min, and burning occurred in 10 min (Table 3, Fig. 1A).

At heating temperature of 300℃, C-200 and E-200 reached catch-fire within about 10 and 5 min, respectively, but no burning occurred. L-200 reached catch-fire after approximately 5 min and then burned in 9 min. D-200 reached catch-fire within 3 min, burned about 4 min 30 s, and MT was 476℃ (Fig. 1B).

Table 3. Summary of the catch-fire, burning time, maximum temperature and amount of ash on the fuel of *Miscanthus* according to heating temperature

Heating Temp.	Fuel type	Catch-fire time	Burning time	Maximum temp.(℃)	Amount of ash(g)
250℃	C-200	0-00'00"	0-00'00"	9-259	52. 9
	E-200	0-12'00"	0-00'00"	18-268	37.5
	L-200	0-15'20"	0-00'00"	20-270	23.6
	D-200	0-05'10"	0-10'00"	166-416	12.5
300℃	C-200	0-10'20"	0-00'00"	63-363	38.5
	E-200	0-04'50"	0-00'00"	49-349	30. 6
	L-200	0-05'20"	0-09'10"	51-351	25.2
	D-200	0-02'50"	0-04'30"	176-476	21.5
350℃	C-200	0-08'30"	0-10'30"	72-422	31.2
	E-200	0-03'10"	0-07'40"	87-437	29.6
	L-200	0-02'50"	0-04'20"	56-406	24.8
	D-200	0-01'20"	0-02'40"	83-433	21.4
400℃	C-200	0-01'00"	0-01'20"	104-504	26.4
	E-200	0-00'30"	0-00'50"	103-503	28.8
	L-200	0-00'20"	0-00'35"	88-488	22.6
	D-200	0-00'20"	0-00'30"	101-501	20.0
450℃	C-200	0-00'15"	0-00'20"	94-544	11.8
	E-200	0-00'05"	0-00'08"	95-545	※
	L-200	0-00'05"	0-00'06"	86-536	※
	D-200	0-00'05"	0-00'06"	79-529	※
500℃	C-200	0-00'02"	0-00'03"	※	※
	E-200	0-00'01"	0-00'02"	※	※
	L-200	0-00'01"	0-00'01"	※	※
	D-200	0-00'01"	0-00'01"	※	※

Notes: C-200: 200g culms, E-200: 200g ears, L-200: 200g leaves, D-200: 200g debris, ※: Not caculated

In C-200, E-200, L-200 and D-200, C-FT were 0-08'30", 0-03'10", 0-02'50" and 0-01'20", and BT were 0-10'30", 0-07'40", 0-04'20" and 0-02'40" at 350℃, respectively (Fig. 1C). Similarly, C-FT of a sample at 400℃ were 0-01'00", 0-00'30", 0-00'20" and 0-00'20", and BT were 0-01'20", 0-00'50", 0-00'35" and 0-00'30", respectively (Fig. 1D).

Those of each sample except C-200 were before and after 6 s, for C-FT and BT were very fast at 450℃ and 500℃ (Figs. 1E, 1F). Particularly, in every sample occurred in a moment a catch-fire and burning within 3 s at 500℃. Therefore, as mentioned above, CT was shorter at higher temperatures.

When the sample tissue was rigid, CT was somewhat longer than that of the soft tissue, even with the same amount of samples (Table 3). Accordingly, the tissue of culm type was rigid than that of leaf type, and thus catch-fire and burning were slow or did not occur at 250℃ and 300℃. However when the temperature was over 400℃, CT was shorter (Table 3). This result coincided with the fact that woods begin a thermal decomposition over 100℃, ignited at 300℃ and finally burned strongly at 500℃ (Odajima 1978).

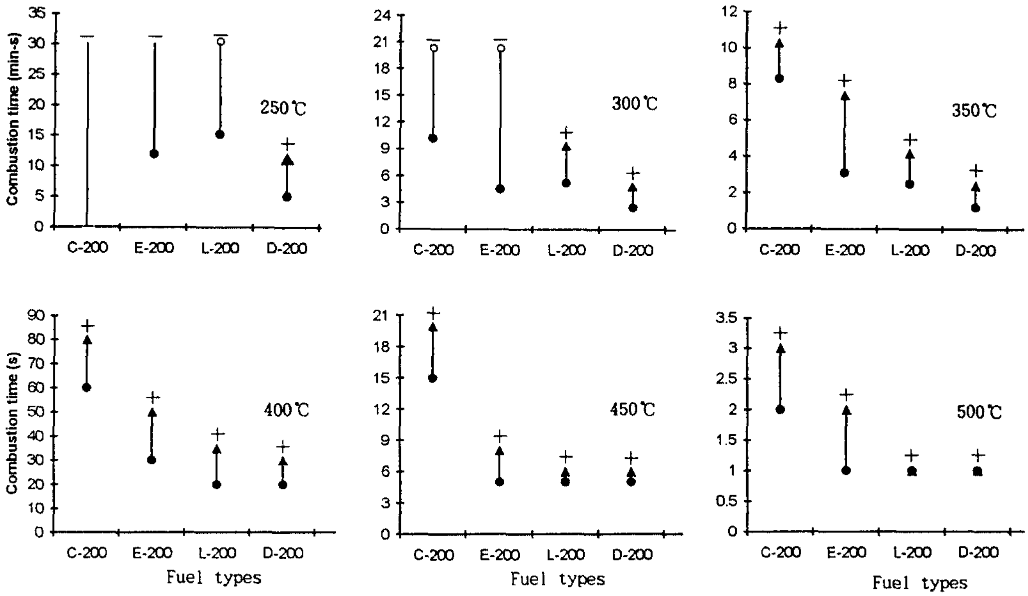

Fig. 1. Catch-fire and burning times of *Miscanthus* fuel types according to heating temperature.
+ : Burn — : No burn ○ : Dangerous
● : Catch-fire point ▲ : Burning point

Since surface fire, the most frequent forest fire, was burned with weeds, fallen leaves, dried branches and shrubs (Barbour *et al.* 1980, Spurr and Barnes 1980), it may incur a crown fire by igniting the ladders (e.g., the understory) that carry surface fires into the crowns of the larger trees. Thus many trees can be destroyed by fire within a short time when there are much combustibles such as *M. sinensis* on the soil surface. When the fire intensity is weak, the damage of trees is small, but trees younger than ten years old are almost destroyed by fire.

At 250℃ and 300℃, MT was lower than that of other heating temperatures due to incomplete combustion of fuels. As temperature rises to 350℃, 400℃ and 450℃, MT reached 56~87℃, 88~104℃ and 79~95℃, respectively, but at 500℃ it was difficult to measure C-FT, BT and MT because it burned whithin 1~2 s at high temperatures. Especially, at 350℃ and 400℃ it reached 75~99℃ in average and so the difference was about ±24℃. However, we found that the heating temperature was stable to some extent at 350℃ and 400℃, and that over 450℃ it was difficult to measure it because CT was very fast (Figs. 1, 2).

The high- or low-volatility depends upon the sort of plants and fuel types. As each organ of *Miscanthus* had different CT according to the heating temperature, CT will be still shorter when each kind of microenviornmental factor is added. Forest fire start catch-fire easily from dried *Zoysia*, pushed down *Miscanthus*, weeds, debris and fallen leaves, and if a fire is transferred to combustibles such as dry branches or trees and spread wide, it may be developed into a catastrophic fire in a moment.

Dry grasses have the highest risk of ignition (Gohay and Nakawla 1971), and become high-volatile fuels, and even can be burned by the cigarette light if dried fallen leaves are trampled and the percentage of detritus is high (Kim *et al.* 1994). In the dry season of early spring, if pushed down *Miscanthus* is dried completely and is added with a live coal to make a fire, a catch-fire and burning will be occur within several minutes, and can be truned into a large forest fire in a moment.

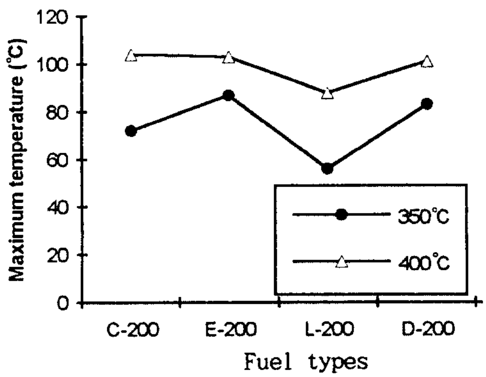

Fig. 2. Maximum temperature according to *Miscanthus* fuel types.

Amount of consumption and total combustion-heat

The amount of consumed fuel by a sample was as follows: at 350℃, a deviation of both C-200 and E-200 to Culm type was ± 1.6 g and that of L-200 and D-200 to Leaf type was ±3.4 g, but the amount of consumed fuel to C-200 and E-200 was 14.6 g more than that of L-200 and D-200. And also a deviation of C-200, E-200 and L-200, D-200 was ±2.4 g and ±2.6 g, respectively, at 400℃, but the amount of consumed fuel to C-200, E-200 was 12.6 g more than that of L-200, D-200 (Table 4).

TACH of each sample was 5,859.7 kcal and the amount of mean generated combustion-heat by a sample were 727.6 (24.9%) and 737.3 kcal (25.0%) at 350℃ and 400℃, respectivley, and the difference was not signigicant (Table 4).

Table 4. The dry weight of *Miscanthus* fuels according to heating temperature and the comparison of amount of generated combustion-heat

Amount of	Amount of ashes (g)		Percentage of ashes (%)		ACH* (kcal)	
samples (g)	350℃**	400℃**	350℃	400℃	350℃	400℃
C-200	31.2	26.4	15.6	13.2	708.9	729.1
E-200	29.6	28.8	14.8	14.4	715.7	719.0
L-200	24.8	22.6	12.4	11.3	735.8	745.1
D-200	21.4	20.0	10.7	10.0	750.1	756.0
Amount of mean generated combustion-heat (kcal)					727.6	737.3
Total amount of generated combustion-heat (kcal)					2910.5	2949.2

* Amount of generated combustion-heat (kcal)

** Heating temperature

摘 要

본 연구는 산불발생시 연소대상 초본식물의 주종의 하나인 *Miscanthus*를 대상으로 가열온도에 의한 부위별 시료의 착화, 발염, 최고온도 (MT), 연소열량 (ACH) 그리고 연소시간 (CT)과의 관계를 조사하였다. 조사지에서 약 19%가 *Miscanthus* 군락으로 조사되었고, 지상부의 건량은 1,164 g/m² 그리고 부스러기의 양은 178 g/m² 정도였다. *Miscanthus*의 부위별 연소 상승온도는 350℃, 400℃에서 줄기 (C-200), 화수 (E-200)가 가열온도보다 약 90℃ 높았고 잎 (L-200), 부스러기 (D-200)는 82℃ 여서 Culm type이 다소 높았다. 그리고 350℃에서 시료별 즉, C-200, E-200, L-200과 D-200의 발염시간 (BT)은 각각 0-10'30", 0-07'40", 0-04'20", 0-02'40"였고 400℃에서는 각각 0-10'20", 0-00'50", 0-00'35", 0-00'30"로 조사되어 고온일수록 빨랐고 또한 Culm type 보다 Leaf type이 더욱 빨랐다. 시료의 연소량은 350℃에서 C-200, E-200이 L-200, D-200보다 14.6g 더 많았고 400℃에서 C-200, E-200, D-200 보다 12.6 g 더 많았다. 시료의 전연소열량 (TACH)은 5,859.7 kcal 였고, 평균 연소열량은 350℃에서 727.6kcal (24.9%), 400℃에서 737.3 kcal (25.0%)로 차이는 거의 없었다.

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