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Long Term Litter Production and Nutrient Input in *Pinus densiflora* Forest[1a]

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소나무 군락의 장기적 낙엽생산을 통한 영양염류 이입량[1a]

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ABSTRACT

The litter production, the nutrient concentration of each component of litterfall, and the amounts of nutrient into the forest floor via litterfall were assessed for 5 years from January 2009 through December 2013 in a *Pinus densiflora* forest in Mt. Worak National Park. The average amounts of leaf litter, branch and bark, reproductive organs(flowers and cones), and miscellaneous categories for 5 years were 1.940 ± 0.21, 0.505 ± 0.15, 0.259 ± 0.09, and 0.737 ± 0.14 t ha^{-1} yr^{-1}, respectively. The average percentage of leaf litter, branch and bark, reproductive organs and miscellaneous categories for 5 years were 56.4, 14.7, 7.5, and 21.4%, respectively. The amounts of total litterfall in 2009, 2010, 2011, 2012, and 2013 were 2.810, 3.796, 3.268, 3.284, and 4.045 ton ha^{-1} yr^{-1}, respectively. The average amounts of litterfall for 5 years were 3.441 ± 0.49 ton ha^{-1} yr^{-1}. The average amounts of N, P, K, Ca, and Mg returned to the forest floor via litterfall for 5 years in this Pinus densiflora forest were 22.73 ± 4.92, 1.05 ± 0.42, 4.26 ± 1.69, 8.48 ± 4.62, and 2.42 ± 1.01 kg ha^{-1} yr^{-1}, respectively.

KEY WORDS : LITTER COMPONENT, LITTERTRAP, FOREST ECOSYSTEM, PINE FOREST

요 약

월악산 국립공원에서 2009년 1월부터 2013년 12월까지 5년간 낙엽생산량과 낙엽을 통해 임상으로 이입되는 영양염류량을 조사하였다. 잎, 가지, 생식기관, 기타로 분류된 낙엽의 5년간 평균 생산량은 각각 1.940 ± 0.21, 0.505 ± 0.15, 0.259 ± 0.09, and 0.737 ± 0.14 t ha^{-1} yr^{-1} 이었으며 낙엽구성원의 비율은 각각 56.4, 14.7, 7.5, 21.4%, 로 잎의 비율이 가장 높았다. 조사기간 동안 생산된 낙엽의 총량은 2009년부터 2013년까지 각각 2.810, 3.796, 3.268, 3.284, 4.045 ton ha^{-1} yr^{-1} 으로, 5년간 평균 3.441 ± 0.49 ton ha^{-1} yr^{-1}의 낙엽이 생산되었다. 조사기간 동안 조사된 낙엽을 통해 입상에 이입되는 질소, 인, 칼륨, 칼슘, 마그네슘의 평균 이입량은 각각 22.73 ± 4.92, 1.05 ± 0.42, 4.26 ± 1.69, 8.48 ± 4.62, 2.42 ± 1.01 kg ha^{-1} yr^{-1} 이었다.

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주요어: 낙엽구성원, 낙엽수거기, 산림생태계, 소나무림

INTRODUCTION

Forest ecosystems are self-maintained *via* primary production and nutrient cycling(Barnes *et al*., 1998). Some of the primary production in forest ecosystems is returned to the forest floor *via* litterfall, and then nutrients in litter are reused by plants after mineralization by decomposition processes carried out by a hugely diverse array of organisms(Lavelle and Spain, 2001). Forest soil provides nutrients, water, and a medium for physical support for plant growth(Kimmins, 1987). Soil nutrients originate primarily from the weathering of soil minerals. However, nutrients released through the decomposition of soil organic matter are fundamental to the mainte-nance of mature forest ecosystems(Daubenmire, 1974, Barbour *et al*., 1987, Mun *et al*., 2007).

The litterfall of leaves, branches and other tree organs generally constitutes the principal pathway by which nu-trients and organic matter are transferred to soil(Bray and Gorham, 1964, Wiegert and Monk, 1972, Caritat *et al*., 2006, Blanco *et al*., 2008). Litter is the food source for decomposers and detritivores, and the means by which nutrients are returned to the cycling pool(Meentemeyer *et al*., 1982, Barbour *et al*., 1987, Baker *et al*., 2001, Blanco *et al*., 2008). Nutrient cycling describes the movement within and among various biotic or abiotic entities in which nutrients occur in the environment(Lavelle and Spain, 2001).

As a component of the Korean National Long-Term Ecological Research Program, we conducted a study of litter production and decomposition in *Quercus mongolica*, *Quercus variabilis* and *Pinus densiflora* forests in Mt. Worak National Park. These species are known as the most common species in Korea. The principal objective of this study was to quantify the total amounts of nutrients returned to the forest floor *via* litterfall in a *P. densiflora* forest located in Mt. Worak National Park. For this study, seasonal litterfall and the nutrient concentration of litterfall were analyzed for 5 years from January 2009 through December 2013, and the total amounts of nutrient input to the forest floor *via* litterfall were calculated.

MATERIALS AND METHODS

1. Study area

The Mt. Worak National Park is located between Mt. Soback and Mt. Sogni and stretches over both Gyeongsangbuk-do and Chungcheongbuk-do in Korea. The highest peak in Mt. Worak National Park, Munsubong, is 1,162 m above sea level. The P. densiflora forest studied herein was located 380 m above sea level at Jaecheon-si, Hansu-myeon, Songgye-ri in a south-west direction(N 36° 51' 17", E 128° 64' 41"). Tree density was 1,300 trees ha^{-1} and average diameter at breast height (DBH) was 17.12±0.38㎝. In the shrub layer, *Qurecus variabilis*, *Fraxinus sieboldiana* and *Indigofera kirilowii* were distributed with low density. In the herb layer, *Pteridium aquilinum* and *Miscanthus sinensis* were distributed, It was examined in plot 20m^2. According to the Jecheon meteoro-logical station, about 20 ㎞ from the study area, annual average temperature and precipitation for thirty years from 1980 through 2010 were 10.2°C and 1,387.8 mm, respectively. The annual average temperature and precipitation for four years from 2009 through 2013 were 10.1°C and 2,066.2 mm, respectively.

2. Litterfall collection and chemical analysis

Five circular litter traps, with opening areas of 0.5m^2, were randomly established in the *P. densiflora* forest in December 2008. Litter traps were leveled approximately 50㎝ above the ground to prevent the input of resuspended windblown materials from the forest floor. Litterfall collections began on January 2009 and continued for 5 years in every month. The litter collected from the litter traps was brought into the laboratory and separated into leaves, branches and bark, reproductive organs and mis-cellaneous(litterfall from shrubs). Each component weighed after drying in a drying oven at 80°C for 72 hour and ground with a mixer for chemical analysis.

Chemical analysis of each component of litterfall was carried out in 3 replicates. After the litter samples were digested on a block digestor, T-N and T-P were analyzed with a flow injection analyzer(Lachat QuickChem 8000; Zellweger Analytics, Milwaukee, WI, USA). K, Ca, and Mg in litter were determined using an atomic absorption spectrophotometer(Perkin-Elmer 3110; Perkin-Elmer, Waltham, MA, USA) after wet digestion(Allen *et al*., 1974). All calculations of the nutrient contents of sample materials were based on the means of three replicate analyses. The total amounts of each nutrient returned to the forest floor *via* litterfall for each year was calculated from each nutrient concentration and the dry weights of each component of litter. The measured values were converted into areas(hα).

RESULTS AND DISCUSSION

1. Litter production

Litterfall in *P. densiflora* forest continued throughout the year, peaking in autumn(October in 2009, 2012 and 2013, November in 2010 and 2011)(Fig.1). In late winter and spring, from February to May, the proportion of reproductive organ was relatively higher than the proportion of other litter components. The amounts of litterfall in 2009, 2010, 2011, 2012, and 2013 was 2.810, 3.796, 3.268, 3.284, and 4.045 ton hα^{-1} yr^{-1}, respectively(Table 1). The yearly variation of litter production was not great. The average amounts of litterfall for 5 years was 3.441±0.49 ton hα^{-1} yr^{-1}.

Lee(2013) reported the litter production of *P. densiflora* natural forest was 3.29±0.11 ton hα^{-1} yr^{-1}. Berg and Laslowski(2006) reported that the litter production of Asian temperate coniferous forests ranged from 910~4,990 kg hα^{-1} yr^{-1}. Litter production of *P. densiflora* forests in this study area fell within those ranges. Jeong *et al*.(2013) reported that the average amounts of litter production of *P. densiflora* forest in Mt. Nam was 7.07 ton hα^{-1} yr^{-1}. The amounts of litter production in this P. densiflora forest was lower than that of Jeong *et al*.(2013). Gholz *et al*.(1985) reported that the differences in litter production might be related to tree density, age and canopy cover among forest(Mun *et al*., 2007, Namgung and Mun, 2009).

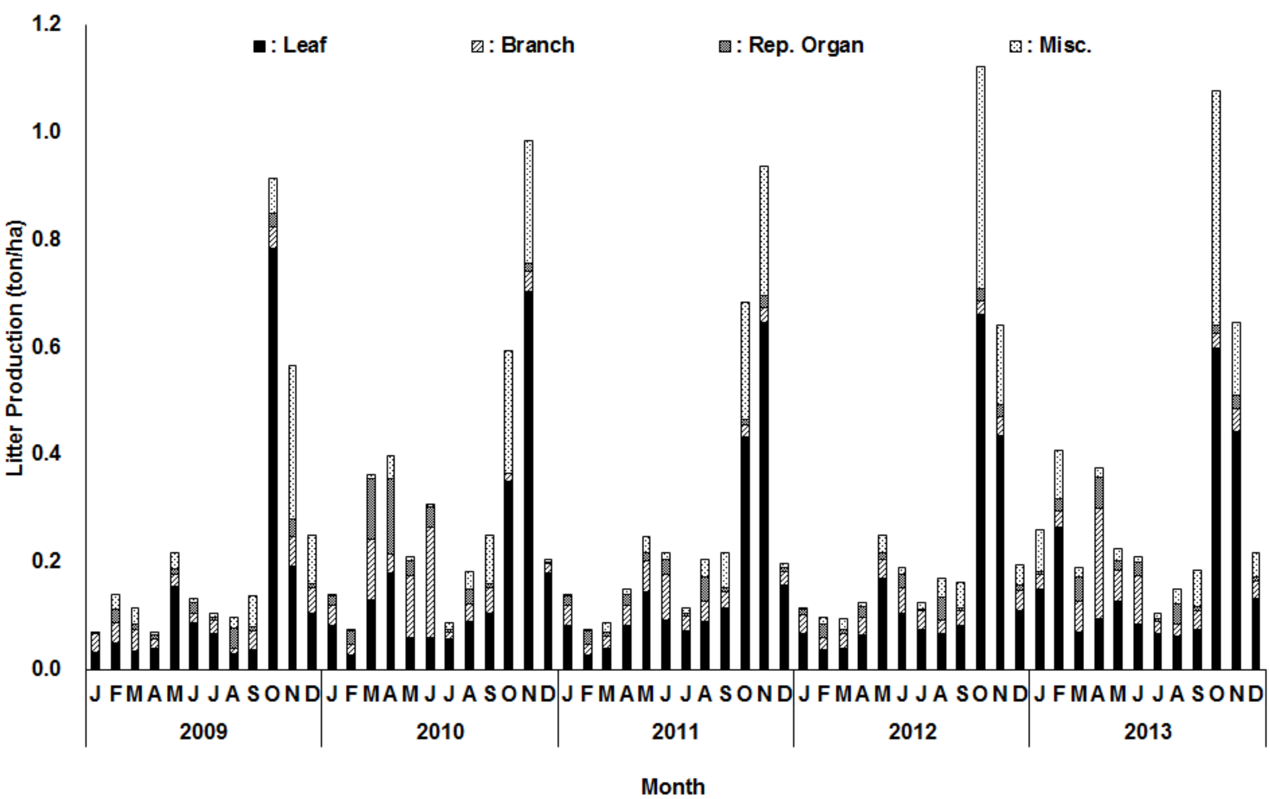


Fig 1. Seasonal changes of each component of litterfall in Pinus densiflora forest over 5 years at Mt. Worak National Park. Misc., miscellaneous; Rep. organ, reproductive organ.

Table 1. Amounts of litterfall(ton ha^{-1} yr^{-1}) for 5 years from 2009 through 2013 in the *Pinus densiflora* forest at Mt. Worak National park

Year	Component of litterfall				Total
	Leaf	Branch	Rep. Organ	Misc.	
2009	1.612	0.378	0.190	0.630	2.810
2010	2.025	0.686	0.416	0.668	3.796
2011	1.984	0.425	0.209	0.650	3.268
2012	1.914	0.377	0.215	0.779	3.284
2013	2.166	0.657	0.264	0.958	4.045
Average	1.940 ± 0.21	0.505 ± 0.15	0.259 ± 0.09	0.737 ± 0.14	3.441 ± 0.49

The average proportion of leaf, branch, reproductive organ and miscellaneous of total litterfall for 5 years were 56.4, 14.7, 7.5, and 21.4%, respectively(Fig. 2). The yearly variation in the leaf category was highest among litter components. The proportion of the leaf category in 2009, 2010, 2011, 2012 and 2013 were 57.4, 53.4, 60.7, 58.3, and 53.5%, respectively.

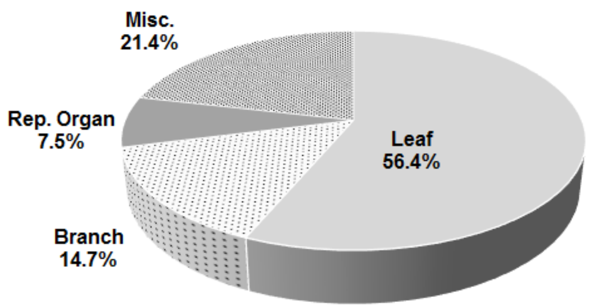
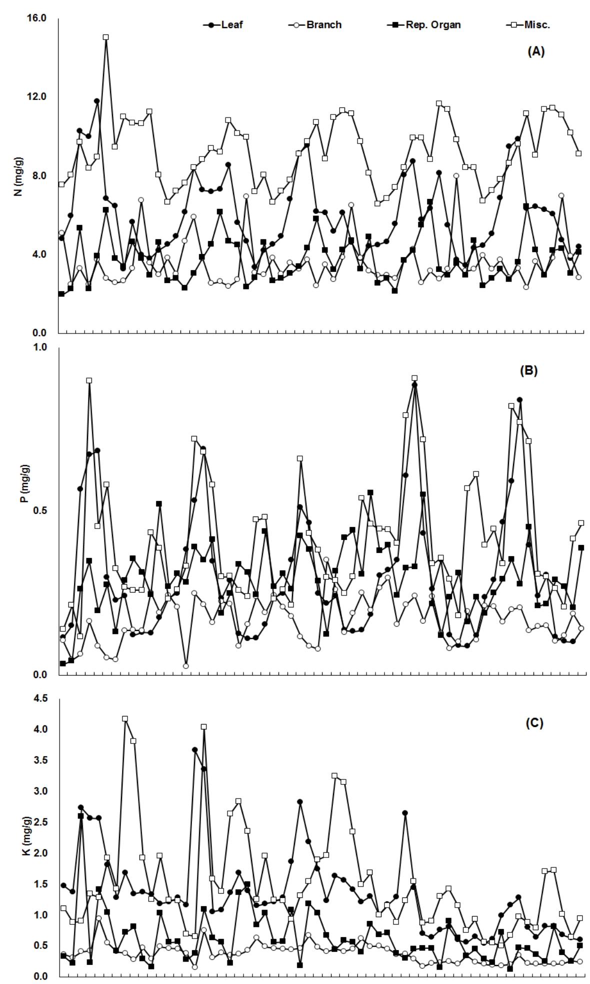


Fig 2. Pie graph showing the average percentages of each component of litterfall for 5 years in a Pinus densiflora forest in Mt. Worak National Park. Misc., miscellaneous; Rep. organ, reproductive organ.

2. Nutrient concentration of litterfall

N concentration in leaf litterfall was low in the winter, and high in the summer and autumn season(Fig. 3A). N concentration in the reproductive organ was high in May through July when the debris of flowers of *P. densiflora* falls. N concentration in the branch and bark component showed no seasonal trend over five years. Unlike the N concentration, the P concentration in leaf litterfall was high in the spring. P concentration in branch and bark litterfall was lowest among the litterfall components(Fig. 3B). Like P concentration, the K concentration in branch and bark litterfall was lowest among the litterfall components(Fig. 3C). In contrast, Ca concentration in branch and bark litterfall were the highest, and those in reproductive organ were the lowest among the litterfall components(Fig. 3D). Mg concentrations in the leaf litterfall and miscellaneous fractions were higher than those in the branch and bark and reproductive organ fractions(Fig. 3E).



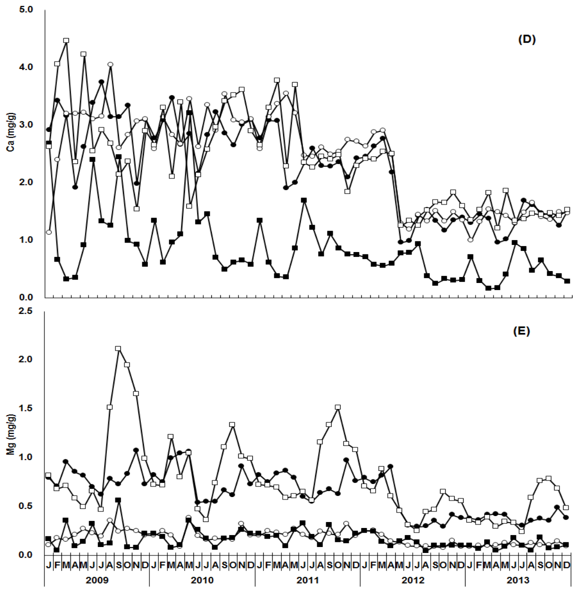


Fig 3. Seasonal changes of N(A), P(B), K(C), Ca (D)and Mg(E) concentration(mg/g) of each component of litterfall in *Pinus densiflora* forest at Mt. Worak National Park. Misc., miscell-aneous;, Rep. Organ, reproductive organ.

The average concentration of nutrients in each component of litterfall in the *P. densiflora* forest for 5 years was summarized in Table 2. With the exception of Ca, the nutrient concentration of leaf litterfall was higher than those in other litterfall components.

Lee(2013) reported that the average concentration of N, P, K, Ca and Mg in litterfall in the *P. densiflora* forest at Mt. Worak National Park over 4 years was 5.61, 0.31, 1.13, 2.27 and 0.51 mg/g, respectively. Namgung and Mun(2009) reported that the average concentrations of N, P, K, Ca, and Mg in a *P. densiflora* forest at the Mt. Worak site over 3 years were 6.34, 0.32, 1.45, 2.44, and 0.37 mg/g, respectively; this was similar that those in this study. Namgung(2010) reported that the average concentration of N, P, K, Ca, and Mg in leaf litterfall in the *Q. variabilis* forest at Mt. Worak over 4 years was 11.53, 0.67, 2.38, 3.15, and 2.14 mg/g, respectively. The average concentrations of N, P, and K in leaf litterfall in *P. densiflora* were lower than those in *Q. variabilis*. The nutrient concentrations of litterfall in oak forests were higher than those in pine litterfall(Namgung *et al*., 2008, Namgung, 2010).

3. Nutrient returned to forest floor *via* litterfall

The amounts of each nutrient returned to the forest floor *via* litterfall in the *P. densiflora* forest was summarized in Table 3. As shown in Table 3, the amounts of annual input of N, P, K, Ca and Mg to the forest floor *via* litterfall in *P. densiflora* forests in 2009, 2010, 2011, 2012, and 2013 were 20.78, 30.65, 19.21, 18.38, and 24.23 $kg\ ha^{-1}\ yr^{-1}$ for N, 0.73, 1.78, 0.80, 0.95, and 1.01 $kg\ ha^{-1}\ yr^{-1}$ for P, 4.72, 6.67, 4.61, 2.59, and 2.71 $kg\ ha^{-1}\ yr^{-1}$ for K, 8.70, 16.24, 7.39, 4.70, and 5.38 $kg\ ha^{-1}\ yr^{-1}$ for Ca, 3.11, 3.68, 2.48, 1.31, and 1.55 $kg\ ha^{-1}\ yr^{-1}$ for Mg, respectively. The average amounts of N, P, K, Ca, and Mg returned to the forest floor in this *P. densiflora* forest for 5 years was 22.73 ± 4.92, 1.05 ± 0.42, 4.26 ± 1.69, 8.48 ± 4.62, and 2.42 ± 1.01 $kg\ ha^{-1}\ yr^{-1}$, respectively(Table 3).

Generally, the amounts of nutrients returned to the forest floor *via* litterfall in pine forests was much lower than those in the oak forests(Vogt *et al*., 1983). This is because the annual input of litterfall and nutrient concentration of unit weight of litterfall in oak forests were greater than those in the pine forest(Kwak and Kim, 1992, Mun and Kim, 1992, Kim *et al*., 1997, Mun *et al*., 2007). Soil

Table 2. Average nutrient concentration(mg/g) of each component of litterfall for 5 years from January 2009 through December 2013 in Pinus densiflora forest at Mt. Worak National Park

Year	Litter component			
	Leaf	Branch & Bark	Reproductive Organ	Miscellaneous
2009	6.06±0.25	3.60±0.09	3.76±0.08	9.25±0.48
2010	0.30±0.03	0.17±0.03	0.30±0.03	0.42±0.06
2011	1.36±0.42	0.38±0.11	0.62±0.16	1.50±0.46
2012	2.27±0.72	2.40±0.73	0.84±0.33	2.34±0.64
2013	0.64±0.19	0.18±0.05	0.16±0.04	0.77±0.25

Table 3. Amounts of nutrient($kg\ ha^{-1}\ y^{-1}$) input to forest floor via litterfall for 5 years from January 2009 through December 2013 in the *Pinus densiflora* forest at Mt. Worak National Park

Nutrient	Year	Components of litterfall				Total
		Leaf	Branch & Bark	Reproductive Organ	Miscellaneous	
N	2009	8.66	1.38	0.70	10.04	20.78
	2010	14.79	5.53	1.25	9.08	30.65
	2011	10.26	1.45	0.79	6.71	19.21
	2012	9.24	1.32	0.78	7.43	18.76
	2013	11.55	2.15	0.93	9.61	24.23
	Average	10.90±2.44	2.37±1.80	0.89±0.22	8.57±1.44	22.73±4.92
P	2009	0.36	0.05	0.05	0.28	0.73
	2010	0.66	0.63	0.13	0.36	1.78
	2011	0.40	0.07	0.07	0.26	0.80
	2012	0.45	0.17	0.06	0.27	0.95
	2013	0.51	0.11	0.08	0.31	1.01
	Average	0.48±0.12	0.21±0.24	0.08±0.03	0.29±0.04	1.05±0.42
K	2009	2.51	0.16	0.12	1.93	4.72
	2010	4.28	0.37	0.18	1.84	6.67
	2011	2.94	0.21	0.13	1.32	4.61
	2012	1.53	0.11	0.10	0.85	2.59
	2013	1.57	0.15	0.10	0.89	2.71
	Average	2.57±1.13	0.20±0.10	0.13±0.03	1.37±0.51	4.26±1.69
Ca	2009	4.93	1.07	0.21	2.49	8.70
	2010	8.73	3.44	0.45	3.63	16.24
	2011	4.51	1.19	0.19	1.50	7.39
	2012	2.60	0.67	0.11	1.32	4.70
	2013	2.94	0.94	0.10	1.41	5.38
	Average	2.74±2.44	1.46±1.12	0.21±0.14	2.07±0.99	8.48±4.62
Mg	2009	1.34	0.08	0.03	1.66	3.11
	2010	2.37	0.20	0.05	1.05	3.68
	2011	1.56	0.10	0.04	0.79	2.48
	2012	0.77	0.05	0.03	0.46	1.31
	2013	0.85	0.07	0.02	0.61	1.55
	Average	1.38±0.65	0.10±0.06	0.03±0.01	0.91±0.47	2.42±1.01

nutrient concentrations in pine forests were much lower than those in the oak forest at Mt. Worak(Choi *et al*., 2006). This may be due to the greater litter production and higher nutrient concentrations of litter in the oak forest relative to those in the pine forest. Another reason for this is that the decay rates of oak litter are higher than the decay rates of pine needle litter(Mun and Joo, 1994, Mun *et al*., 2007, Namgung *et al*., 2008, Mun, 2009).

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