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CO_2 and Water Vapor Flux Measurement by Eddy Covariance Method in a Paddy Field in Korea

Jeongtaek Lee, Yangsoo Lee, Gunyeob Kim and Kyomoon Shim
National Institute of Agricultural Science and Technology, Suwon, Korea
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한반도 논에서의 에디공분산 방법에 의한 CO_2와 수증기 플럭스 관측

이정택 · 이양수 · 김건엽 · 심교문
농업과학기술원
(2005년 1월 24일 접수; 2005년 3월 29일 수락)

ABSTRACT

This study was conducted to measure and understand the exchange of CO_2 and water in a rice canopy. Eddy covariance system was installed on a 10m tower along with other meteorological instruments. CO_2 flux and surface energy balance were measured throughout the whole growing season in 2003 over a typical paddy field in Icheon, Korea. During the early growth stage in May and June, most of net radiation was partitioned to latent heat flux with daytime Bowen ratio of 0.3 to 0.7. Evapotranspiration (i.e., daily integrated latent heat flux) typically ranged from 3 to 4 mm d^{-1}, with even higher rates on sunny days. Daily integrated net ecosystem exchange (NEE) of CO_2 increased with increasing solar radiation and leaf area index (LAI). The NEE was especially high during the stages of young panicle formation and heading. On 1 June 2003, when the rice field was flooded, it was a weak sink of atmospheric CO_2 with an uptake rate of 9.1 g m^{-2} d^{-1}. Despite frequent rainy and cloudy conditions in summer, maximum NEE of 36.2 g $m^{-2}d^{-1}$ occurred on 31 July prior to heading stage. As rice crop senesced after early September, the NEE decreased.

***Key words* : CO_2, Eddy covariance, Energy flux, Evapotranspiration, LAI**

I. INTRODUCTION

Increasing carbon dioxide concentration in the atmosphere could alter radiation balance and a rise in global temperature. Source and sink strength of CO_2 associated with land use change can significantly influence the rate and magnitude of atmospheric CO_2 concentration. Combustion of fossil fuels and deforestation significantly contribute CO_2 to the atmosphere.

Terrestrial ecosystems are an essential part in global carbon and water cycles which may alter with the current unprecedented environmental changes. The carbon and water cycles have inherently high spatial and temporal variability, due to combined influences from numerous physical, biological, ecological and anthropogenic factors and processes in various scales (Kim, 2005). Rice paddies absorb CO_2 from the atmosphere but emit carbon in forms of CH_4, thereby playing a potential role in the global carbon budget because of its relative contribution of carbon absorption and emission associated with changing hydrological conditions and cover change (Hong *et al.*, 2002).

Change in weather and climate are closely linked with land surface processes. Many scientists have been contributing to establishing global network for monitoring surface exchanges of energy and matter (Kim and Rho, 2003). In 1960s and 1970s, energy and

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Corresponding Author: Jeongtaek Lee (jtlee279@rda.go.kr)

CO_2 exchange in rice paddies has been studied intensively using conventional micrometeorological techniques such as the aerodynamic and the Bowen ratio methods (e.g., Cho, 1972; Uchijima, 1976). In 1980s, the development of fast response CO_2/H_2O analyzers enabled us to measure CO_2 flux in a rice paddy using eddy covariance method (Ohtaki and Matsui, 1982; Ohtaki, 1984). Harazono *et al.* (1998) and Miyata *et al.* (2000) investigated the role of water layer in energy, CO_2 and CH_4 exchange over rice paddies in Japan. In Korea, based on short-term flux measurements, Hong *et al.* (2001) and Kim *et al.* (2002) reported that rice paddies changed from a sink to a weak source of CO_2 (with a net release of 1-3 $g\,m^{-2}\,d^{-1}$) before harvesting. Based on a season-long tower flux measurements, Moon *et al.* (2003) reported maximum net ecosystem CO_2 exchange of 44 $g\,m^{-2}\,d^{-1}$ over the rice paddy in Hari, Kanghwa Province during late July-early August in 2002.

The purpose of this study is to better understand the exchange of energy, water vapor and CO_2 in a typical agricultural ecosystem in the central part of Korean Peninsular. Here we report our first long-term flux measurements from Icheon rice paddy, one of the KoFlux network site (www.koflux.org; Kim *et al.*, 2002).

II. MATERIALS AND METHODS

2.1. Flux measurement site

Flux measurements have been made in Icheon site (37°18'20.34"N, 127°30'40.46"E) of National Institute of Agricultural Science and Technology. The site is flat and homogeneous, surrounded by similar paddy fields and its micrometeorological fetch is more than 1km depending on the prevailing wind direction. The soil type is slit loam in surface (0-60 cm) soil, and the sand in deep soils.

Mlost of farmers transplanted 30 days old rice seedling by machine. Rice planting density was 30 × 15 cm in row and hill space. The transplanting period in the field was between 20 and 25 May 2003. Irrigation started on 10 May for preparation of the rice field and the paddy was continuously flooded until 20 June. There was 10 days intermittent irrigation during the maximum tillering stage, and then flooded irrigation up to 20 September. Fertilizer was applied three times (22 May during transplanting stage, 8 June during tillering stage, 22 July during panicle initiation stage). The total application rate was 110-70-80 (N-P-K) $kg\,ha^{-1}$.

2.2. Micrometeorological measurements

Fluxes of sensible heat, water vapor and CO_2 over the rice canopy were measured by eddy covariance method, to measure the fluctuation in wind speed, air temperature and the density of CO_2 and water vapor. We set up a three-dimensional sonic anemometer (CSAT3, Campbell Scientific Inc., USA) and open-path infrared gas analyzer (LI-7500, LICOR Inc., USA) at 3 m height on a 10 m tower. To measure the radiation components, net radiometer (CNR1, Kipp & Zonen, Holland), pyranometer (CN21 : ISO secondary standard) were installed, Also we set up rain gauge (HSRI, RM Young) temperature-humidity probe (HMP45C, Campbell Inc) soil heat flux plate (HFT3, Campbell Inc), soil thermocouple (TCAV, Campbell Inc) to measure meteorological elements in the rice paddy field. The raw flux data and micrometeorological data were collected at 10 Hz and 60-second interval, respectively, and averaged for 10 minutes and 30 minutes using two digital data loggers (CR5000 and CR23X, Campbell Inc).

2.3. Rice growth

Rice growth was checked by measuring leaf area index (LAI) and dry matter production. First of all, 20 plants were measured for the plant height and tillering number, and 3 plants were selected which were similar to the average of 20 plants at each stages. LAI was measured using leaf area meter (LI-3000, LI-COR). The selected samples were oven-dried for more than 2 days at 80oC and then the dry weight was measured.

III. RESULTS AND DISCUSSION

Change in dry matter production and LAI during rice growing season at Icheon in 2003 are shown in Fig. 1. Aboveground dry matter production was about 3 $g\,m^{-2}$ in 3 June, two weeks after transplanting. The total aboveground dry matter was 1300 $g\,m^{-2}$ at the harvest season. LAI was below 1 in mid June but increased rapidly from 21 June to 10 July. At the heading stage it showed 4.5 and then decreased later in the maturing stage.

Fig. 2 shows the diurnal variation of radiation components above the rice canopy on 1 May and 2 June 2003. On 1 May (just before the rice transplanting) and 2 June (2 weeks after transplanting),

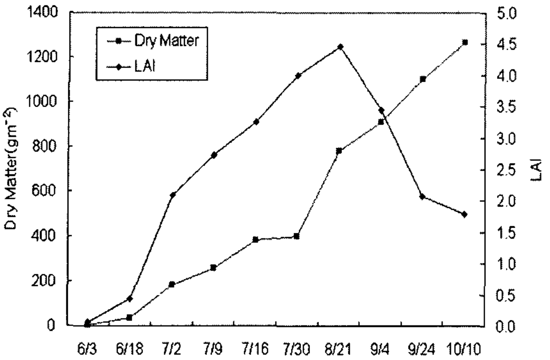
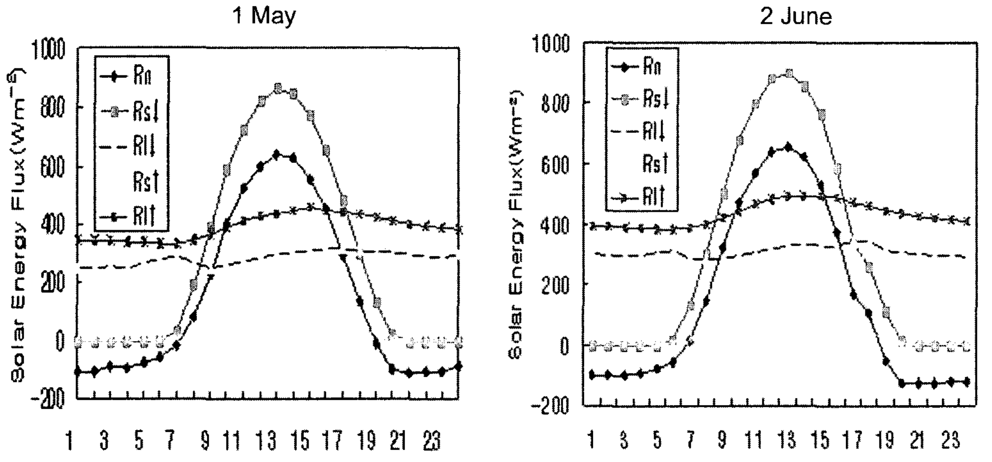


Fig. 1. Change in dry matter production and leaf area index during the 2003 growing season at Icheon in Korea.

it was clear with solar radiation of about 800 W m^{-2} around 1 p.m. Midday net radiation (Rn) was around 650 W m^{-2}, approximately 70% of solar radiation. Upward longwave radiation was greater than downward long wave radiation, and the resulting net longwave radiation tended to increase under flooded conditions. Albedo was around 8-10% and decreased after transplanting.

Fig. 3 shows diurnal variation of energy fluxes on 1 May and 2 June 2003 (The net radiation is positive when it is toward the ground). During daytime, most of Rn was partitioned into latent heat flux (LE) and thus sensible heat flux (H) was relatively small. After rice transplanting, the latent heat flux further increased by about 10%. Consequently, smaller portions of net radiation (about 3%) were partitioned to sensible heat and soil heat fluxes.

Fig. 4 shows the changes in the Bowen ratio ($\beta = H/LE$) over the rice canopy. The Bowen ratio changed


1 May

2 June

Fig. 2. Diurnal variations of radiation components over the rice canopy on 1 May and 2 June 2003.

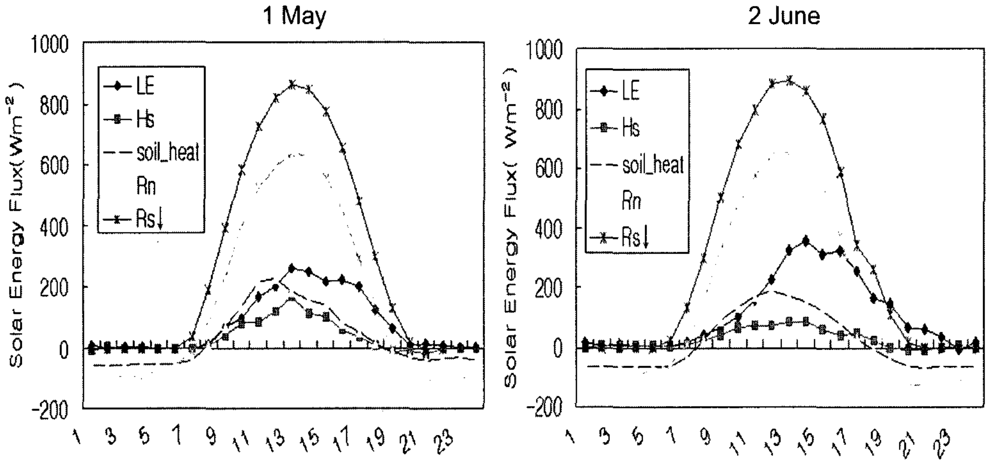

1 May

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Fig. 3. Diurnal variation of energy fluxes on 1 May and 2 June 2003.

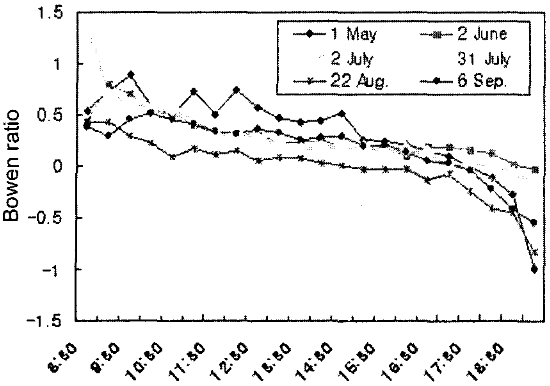

Fig. 4. Changes in the Bowen ratio over the rice canopy at Icheon.

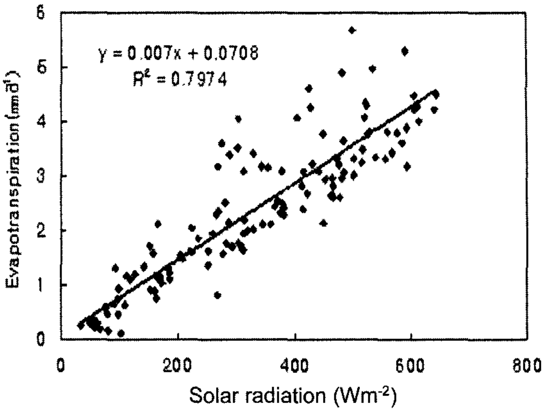

Fig. 6. Relationship between solar radiation and evapotranspiration during the growing season in 2003.

between 0.2 and 0.8. The Bowen ratio on 1 May was higher than those during other growth stages, indicating that relatively more energy was distributed to sensible heat to heat the air. On 22 August, under high leaf density and flooded conditions, latent heat flux was greater, resulting in smaller Bowen ratio.

Fig. 5 shows diurnal variation of evapotranspiration (ET) during rice cultivation season. The ET was computed from hourly-integrated latent heat fluxes. ET varies with weather conditions and growth stages. The maximum daytime ET was 0.4-0.6 mm hr^{-1}. Over the bare soil conditions, ET was lower than crop season. Fig. 6 shows the relationship between solar radiation and evapotranspiration during rice crop season. As expected, ET shows a close relationship with solar radiation. It increases linearly with increasing solar radiation.

Fig. 7 shows changes in daily ET during the growing season. The ET ranged from 0 to 6 mm d^{-1}, with a mean value of 3-4 mm d^{-1}. It depended on the sky clearness. On clear days, it showed about 6 mm d^{-1} but on rainy or cloudy days it was near zero. Most active evapotranspiration period was from 20 July to 15 August (i.e., maturing stage).

Diurnal variations of CO_2 concentration above rice canopy are presented on 1 May and 2 June (Fig. 8). On these two days, concentration was high during nighttime but low during daytime. Nocturnal maximum was 770 g m^{-3} but in daytime minimum reached 660 g m^{-3} on 1 May. After transplanting, on 2 June, the respective values were 810 g m^{-3} and 650 g m^{-3}. Hence, CO_2 concentration change was more prominent during vegetative period than under bare soil conditions.

Fig. 9 shows diurnal variations of CO_2 flux (on 1

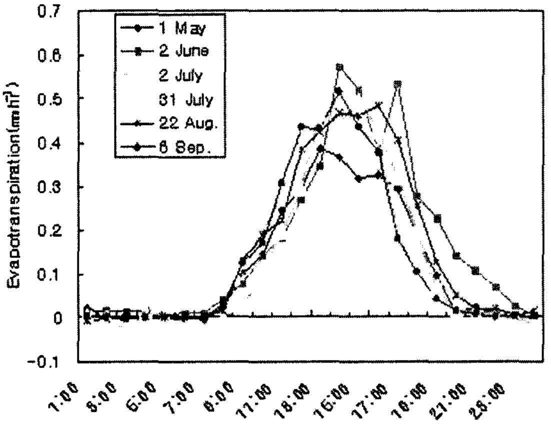

Fig. 5. Diurnal variation of evapotranspiration during the growing season in 2003.

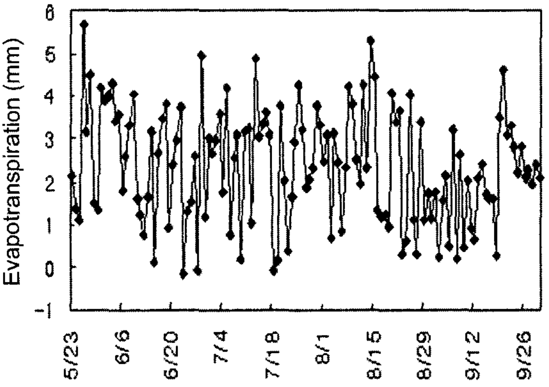

Fig. 7. Changes in daily evapotranspiration during the growing season in 2003.

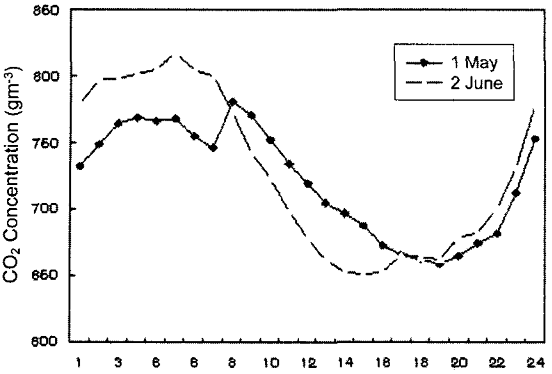

Fig. 8. Diurnal variation of CO_2 concentration above rice canopy on 1 May and 2 June 2003.

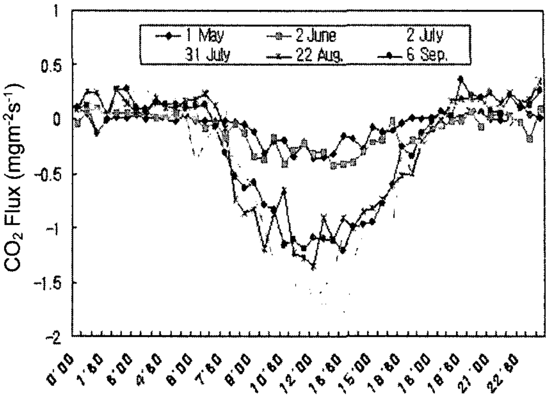

Fig. 9. Diurnal variation of CO_2 flux during the growing season in 2003.

May, 2 June, 2 and 31 July, 22 August and 6 September 2003). The fluctuation of CO_2 flux was not significant but also small amount of CO_2 movement was there to the ground surface during daytime, conversely from ground to the air on the night of 1 May. We may speculate possible CO_2 absorption by the weeds here. Daytime CO_2 absorption by the plant canopy increased as the rice plant growth continued until 31 July with 2 mg $m^{-2} s^{-1}$. During the maturing stage (6 September), CO_2 absorption was lower than those of heading stage. With greater photosynthesis during daytime, the plants respired more CO_2 at night.

Fig. 10 shows the relationship between solar radiation and CO_2 absorption rate by rice canopy. Such

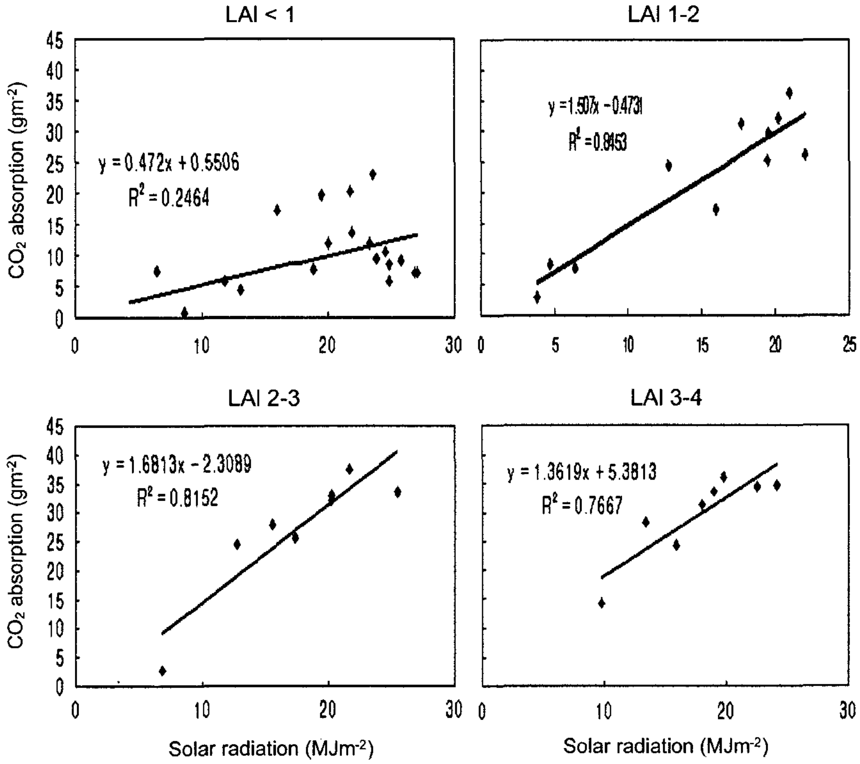

Fig. 10. Relationship between solar radiation and CO_2 absorption rate by rice canopy.

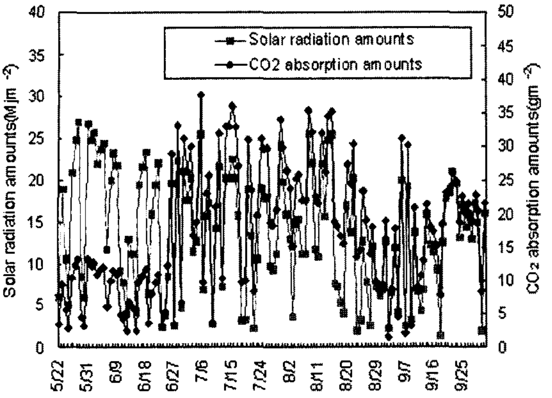

Fig. 11. Seasonal variation of solar radiation and daily-integrated CO_2 absorption.

relationship was affected by leaf area index at each growth stage. The relationship was more significant with increasing LAI. In case of LAI less than 1, the plants absorbed 0.47 g CO_2 m^{-2} per unit solar radiation (in MJ m^{-2}). For LAI of 1-2, 2-3, and 3-4, rice plants absorbed 1.51, 1.68, and 1.36 g CO_2 m^{-2}, respectively.

Fig. 11 shows seasonal variation of solar radiation and daily-integrated CO_2 absorption by rice canopy. Just after transplanting stage (from 22 May to 20 June), the rice paddy was a relatively weak sink of CO_2 with 5-10 g m^{-2} d^{-1}. During this period, even though the solar radiation was about 20 MJ m^{-2}, CO_2 absorption was relatively low.

Solar radiation was about 15 MJ m^{-2} in maximum tillering stage at the end of June, and CO_2 absorption increased up to 20 g $m^{-2}d^{-1}$. From panicle initiation stage to heading stage, solar radiation varied much and CO_2 absorption rate varied in proportion to changes in solar radiation. During the maturing stage, solar radiation was relatively small (15-20 MJ m^{-2}) and CO_2 absorption rate ranged from 10 to 20 g m^{-2} d^{-1}.

적 요

우리나라의 주요 농업 생태계인 논에서 벼 생육기간 중의 CO_2와 에너지 교환을 정량화하고 분석(평가하기 위하여 미기상학적인 방법인 에디 공분산법으로 물질/에너지 플럭스를 측정하였다. 측정장소는 한반도 중부 지방의 대표적인 벼농사 지대인 경기도 이천시 부발읍 신원리 농업과학기술원 이천 시험지 플럭스 측정 지점 (37°18'20.34"N, 127°30'40.46"E)에서 수행되었다. 벼군락 장파복사의 방출은 대기로부터의 장파복사량보다 100 W m^{-2} 정도 많았다. 벼논에서 이앙 후 에너지 배분은 잠열 플럭스로 더 많이 배분되었고, 보웬 비는 0.3-0.7 정도였다. 이앙 후 대기중의 수증기 농도는 이앙 전에 비하여 2 g m^{-3} 정도 높아졌다. 벼 논에서 CO_2 농도는 야간이 780~820 g m^{-3}, 주간에는 약 650 g m^{-3}정도 였다. 일사량 증가에 따른 이산화탄소 흡수량은 엽면적 지수가 높을수록 높았으며 특히 유수형성기-출수기에서 가장 높았다.

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