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Effect of Deforestation on CH_4 Uptake in Khabarovsk, Far East, Russia

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K e y w o r d s : CH_4 flux, clear cut, Russia, forest soil, soil moisture.

S u m m a r y

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To clarify the effect of deforestation on CH_4 dynamics in semi-boreal forests dominated by coniferous trees, we measured CH_4 fluxes at five sites in each of the three adjacent coniferous forests, a natural forest (above ground biomass is 191-196 t ha^{-1}), a selective cut forest (99-101 t ha^{-1}) and a clear cut forest (22-23 t ha^{-1}), Korfovsky, near Khabarovsk, Russia, in 1999-2001 by using a closed chamber technique. The slope of natural forest was about 10 degrees, while selective cut and clear cut forests were flat. Mottles were observed in A or B horizon of selective cut forest and clear cut forest soils, but not observed in natural forest soils. CH_4 uptake was highest in the natural forest (-63±30 μg C m^{-2} h^{-1}), intermediate in the selective cut forest (-22±24 μg C m^{-2} h^{-1}) and lowest in the clear cut forest (-5.2±44 μg C m^{-2} h^{-1}). CH_4 emissions were observed in the selective cut forest (maximum: 72 μg C m^{-2} h^{-1}) and the clear cut forest (maximum: 34 μg C m^{-2} h^{-1}). The maximum CH_4 concentration in the soil gas was 6.0×10^3 ppmv. The CH_4 flux was positively and strongly correlated (r^2=0.49) with the soil moisture, and weakly correlated (r^2=0.07) with the soil temperature. The soil moisture content in the selective cut forest and the clear cut forest was always significantly higher than that in the natural forest ($p < 0.01$). The reason of this could possibly be a decrease in water uptake by trees due to deforestation.

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Introduction

The Russian Federation consists of a largest forest area in the world (about 8.5 $\times 10^6$ km^2), which accounts for 22% of the total forest area (FAO 2003). The forested area in Asian Russia including Khabarovsk accounts for 78% of the total forest area in Russia (SHVIDENKO & NILSSON 1996). The forest biomass in European Russia increased by 1.8 $\times 10^9$ m^3 from 1966 to 1993, but that in Asian Russia decreased by 3.0 $\times$ 10^9 m^3 (SHVIDENKO & NILSSON 1996). The overall forest area in Russia is reported to be decreased due to deforestation and developments (SHVIDENKO & NILSSON 1996).

The terrestrial soils, especially forest soils, are important sinks for atmospheric methane (CH_4), and their annual consumption amounts to about 30 Tg CH_4, which is equivalent to the annual increase of CH_4 in the atmosphere (IPCC 2001). The CH_4 uptake increases with increase in soil temperature (WHALEN & REEBURGH 1996, ROSLEV & al. 1997), while decreases with increase in soil moisture, because CH_4 diffusion from the atmosphere to the soil is limited (LESSARD & al. 1993, CASTRO & al. 1994). In addition, it was reported that the increase in soil moisture associated with deforestation decreases CH_4 uptake in the tropical (KELLER & al. 1990, VERCHOT & al. 2000) and temperate (CHAN & PARKIN 2001, KAGOTANI & al. 2001) forests, where precipitation is relatively high. On the contrary, it was reported that deforestation decreases soil moisture in temperate forests (HENDRICKSON & al. 1985, WEIER & al. 1990, LONDO & al. 1999). Precipitation is relatively lower in semi-boreal forest. The objective of this study was to elucidate the effect of deforestation on CH_4 uptake in forest soils in Khabarovsk, Far east, Russia.

Material and Methods

Site description

This study was conducted in three adjacent forests, a natural forest (NAT), a selective cut forest (SC), and a clear cut forest (CC), in Korfovsky village, located 40 km south of the city of Khabarovsk (lat 48°N, long 135°E), Russia. The annual mean temperature and precipitation are 1.4 °C and 680 mm, respectively (ROBERT 1997). The maximum snow cover is about 20 cm in February. The soil is frozen from mid- November to the end of April down to 160 cm depth. The permafrost does not occur in the research sites (KONDRASHOV, personal communication). The soils type is Typic Destrochrepts (SOIL SURVEY STAFF 1999). All measurements were carried out in September 1999, May and September 2000, and May and July 2001. The forests consist mainly of coniferous trees (*Pinus koraiensis*, *Picea jezoensis*, and *Abies nephrolepis*) (SHIBUYA & al. 2002). There was no felling in NAT site (slope of 10 degrees) since more than 60-70 years ago. The SC and CC sites are adjacent to the lower part of the NAT site with

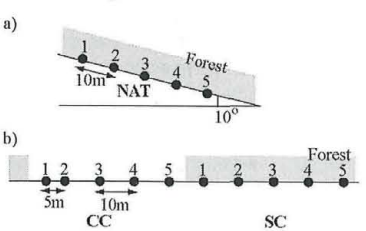

Fig. 1. The illustration of the sampling points in line transects.

flat landscape. All trees were felled down in 1998 in the CC site, and about 34% were felled down 30 years ago in the SC site. The amount of forest biomass was in the following order: NAT (191-196 t ha^{-1}) > SC (99-101 t ha^{-1}) > CC (22-23 t ha^{-1}).

Set up of line transects

Two line transects were established at the investigation sites (Fig. 1). One transect (40 m) was set up from the upper part to the lower part in the NAT site, and the other transect (85 m) was set up across the CC and SC sites. Five measuring points were set up in each forest type at every 10 m in all sites, except one point in CC site, which had only 5 m distance.

Soil environment

Disturbed soil samples were collected from all horizons of each soil profile. These samples were air-dried for more than 3 weeks in the laboratory in Hokkaido, and then sieved through a 2 mm mesh sieve for chemical analysis. Soil pH was determined with a glass electrode pH meter in a supernatant suspension of 1:2.5, soil: deionized water. The electric conductivity (EC) was determined with an EC meter in a 1:5 soil: deionized water mixture. After the soil samples were air-dried and ground, total carbon and nitrogen contents were determined by using C/N analyser (NC-1000, Sumica Chemical Analysis Service, Ltd., Osaka, Japan). The exchangeable cations (Na, K, Mg. Ca) were determined by batch method (KAMEWADA & SHIBATA 1997).

CH_4 flux and concentration in the soil gas

The CH_4 flux was measured by using a closed chamber technique. The Open-bottomed stainless steel chambers, 25 cm high and 18.5-21.0 cm in diameter, were used. The CH_4 fluxes were measured for each site in the morning (10:00 - 12:00) and the afternoon (13:00 - 15:00). Chambers were set up at least above 1 m away from the nearest tree. Measuring of CH_4 fluxes two or three times were regarded as replications. The CH_4 fluxes in May 2000 were measured only at NAT_1, NAT_2, CC_1, CC_2, CC_4, SC_1, and SC_4. The Chamber collars were installed at 3 cm depth into the soil and kept overnight to eliminate the disturbance. In the following day, a 20-mL gas sample was taken into a 10-mL glass bottle vacuum-sealed with a butyl rubber stopper and a plastic cap at 0, 10, 20, and 40 minutes after the chamber lid was set up. The soil temperature was measured with a digital thermometer at a depth of 4 cm. The soil moisture was measured by using the FDR (Frequency Domain Reflectometry) (ML2 Theta Probe, Delta-T Devices, Co.) at a depth of 0 to 7 cm. The soil temperature and soil moisture were measured at 10 cm from the edge of the chambers with five replications. In addition, stainless steel pipes of 9-mm in diameter were installed at depths of 5, 10, 20, 35, and 55 cm (3 pipes at each depth) to collect soil gas. After the pipes were set up, 50 mL of air was exhausted from each pipe. The pipes were then sealed by using a 3-way cock and kept overnight to allow gas concentrations in the pipes to equilibrate with the soil air. From each of the pipes installed at each depth, air samples (50 mL) were taken into Tedlar® bags. At the same time, air on the soil surface was taken into a Tedlar® bag as a sample of soil air at depth of 0 cm. Within the same day, 20 mL air samples from each of the Tedlar® bags were transferred into 10 mL glass bottles. Sometimes we could get only water from the pipes. In that case, dissolved CH_4 concentrations were measured, according to the method proposed by MCAULLIFE 1971 and SAWAMOTO & al. 2002. A 30-mL water sample was taken from the pipe with a 60-mL syringe, and 30 mL of air was immediately drawn into the syringe. Then the syringe was vigorously shaken for 3 min and a 20-mL air sample from the head space was taken into a 10-mL glass bottle.

Gas analysis and calculation of CH_4 flux

CH_4 concentrations were analysed by a gas chromatograph (GC, Shimadzu GC-8A, Kyoto, Japan) at the laboratory of Hokkaido University in Sapporo, Japan. The analysis was performed within 3 weeks of the sampling. The GC was equipped with a flame ionization detector and a 2-m activated carbon column. Samples (1 mL) were injected into the GC. The injection/detection and column oven temperatures were 130 and 70 °C, respectively. Ultra pure nitrogen gas was used as the carrier at a flow rate of 60 mL min^{-1}. The standard CH_4 gas (1.95 µL L^{-1}) was used for a calibration. The CH_4 flux rates were calculated according to the change in CH_4 concentrations in the

chamber against closure time:

CH_4 flux ($\mu g\ C\ m^{-2}\ h^{-1}$) = $\rho \times V/A \times \Delta c/\Delta t \times 273/T$

Where, ρ is the density of CH_4 ($0.536 \times 10^9\ \mu g\ C\ m^{-3}$) at standard conditions; V (m^3) and A (m^2) are the volume and bottom area of the chamber, respectively; $\Delta c/\Delta t$ ($10^{-6}\ m^3\ m^{-3}\ h^{-1}$) is the rate of CH_4 concentration in the chamber during a given period; and T is the absolute temperature. A positive value indicates CH_4 emission from the soil, whereas a negative value indicates CH_4 uptake from the atmosphere. The non-detectable flux (F) ranged from -8 to 8 $\mu g\ C\ m^{-2}\ h^{-1}$.

Statistical analysis

Mean temperatures, soil moistures, and CH_4 fluxes in each measurement were calculated from two or three replications. One-way analysis of variance (ANOVA) followed by the Tukey test was used to compare the means of CH_4 flux at each site by using STATISTICA (StatSoft, Japan).

Table 1. Chemical properties of soils.

Horizon	Depth	pH	EC	Exchangeable cation				C	N	C/N
				Na	K	Mg	Ca			
	cm	(H_2O)	mS m^{-1}	cmolc kg^{-1}				%		
Natural Forest (NAT)										
O	-5									
A	6	6.0	15.6	0.2	1.0	4.8	29.5	13.9	1.2	12
AB	8	5.0	3.5	0.1	0.3	0.9	3.0	4.6	0.5	10
B2	16	5.5	2.0	0.2	0.2	0.9	3.7	1.8	0.2	11
BC	44+	5.7	1.5	0.2	0.2	0.6	2.7	0.7	0.1	11
Clear-Cut (CC)										
O	-2									
A11	5	4.7	9.4	0.2	0.9	3.4	11.8	13.1	0.9	14
A12	17	5.1	3.5	0.2	0.7	2.6	6.6	4.9	0.4	13
AB	30	5.3	2.3	0.2	0.5	2.1	4.8	3.0	0.3	12
B1	40	5.5	1.4	0.2	0.2	1.0	2.3	1.2	0.1	14
B2g	60	5.8	0.9	0.2	0.2	1.2	2.4	0.1	0.0	17
B3g	75+	5.9	1.0	0.2	0.2	2.5	4.2	0.7	0.0	14
Selective-cut (SC)										
O	-3									
A1	15	5.2	4.4	0.3	0.7	4.9	10.1	14.1	1.0	14
Ag	22	5.4	2.7	0.2	0.5	4.4	8.8	8.5	0.7	13
B21	46	5.9	1.2	0.2	0.2	2.0	3.9	0.9	0.0	27
B22g	65+	6.0	1.1	0.2	0.2	3.9	5.4	0.5	0.0	20

Table 2. Soil temperatures at the study sites.

	Soil temperature °C				Soil moisture $m^3\ m^{-3}$				CH_4 Flux ug C $m^{-2}\ h^{-1}$				
	mean		SD		mean		SD		mean		SD		n
Natural Forest	12.1	±	3.6	a	0.34	±	0.14	a	-63	±	30	a	48
Clear cut	11.1	±	5.1	b	0.52	±	0.17	b	-5.2	±	44	c	51
Selective cut	10.8	±	4.3	b	0.49	±	0.16	b	-22	±	24	b	49

Values representing mean soil temperature, moisture, and CH4 flux followed by different letters are significantly different by Tukey's test ($p<0.05$).

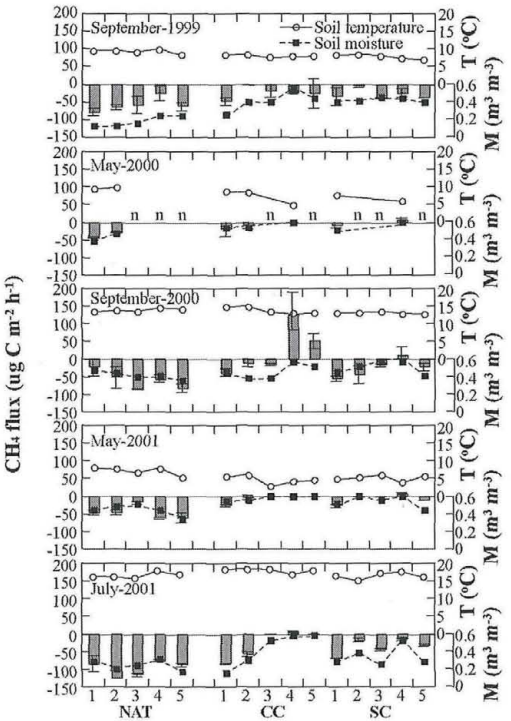

Fig. 2. CH_4 fluxes with soil temperature and moisture along the line transects. "T" and "M" means soil temperature and soil moisture, respectively. Vertical bars denote maximum and minimum values of CH_4 flux. "n" means not measured.

Results and Discussion

The soil chemical properties of each site are shown in Table 1. Mottles were observed in A or B horizon of sites SC and CC, but was not observed in site NAT. The averaged soil temperature was higher in site NAT than in other sites (Table 2). The soil moisture in site NAT was the lowest among the sites in all the measurements (Fig. 2 & Table 2). The sites CC_4 and CC_5 were almost water saturated from May 2000 onward. SILKWORTH & GRIGAL 1982 and LONDO & al. 1999 reported that a decrease in water uptake by plants led to the increase in soil moisture. On the other hand, it was also reported that deforestation would decrease soil moisture. This is because the evapo-transpiration is promoted due to the exposure of soil surfaces to the sunlight which is associated with the removal of forest canopies (HENDRICKSON & al. 1985, WEIER & al. 1990, LONDO & al. 1999). In this study, soil temperature did not increase due to deforestation (Table 2). Therefore, this result suggested that the decrease in water uptake by plants could have led to the increase in soil moisture.

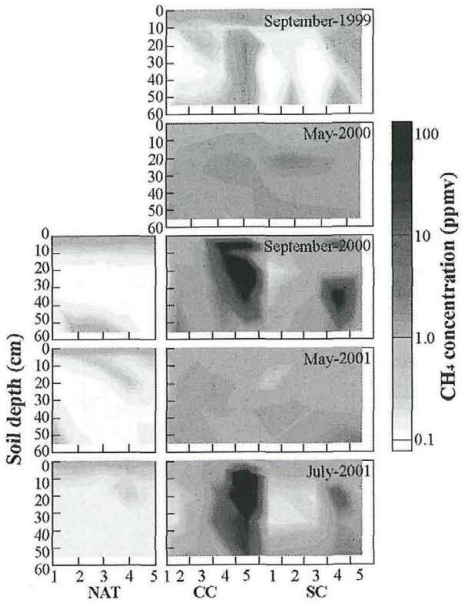

Fig. 3. CH_4 concentration (ppmv) in soil and water along the line transects. Each contour graph was drawn by Delta Graph 5.0 (JPD K.K, Japan).

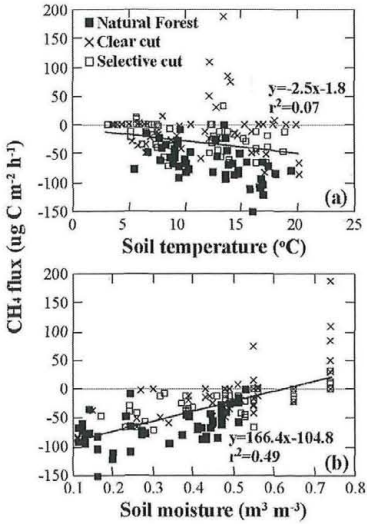

Fig. 4. Relationship between CH_4 flux and a) soil temperature and b) moisture.

The CH_4 flux at each site is shown in Figure 2 and Table 2. In site NAT, CH_4 uptake was always observed. The CH_4 uptake showed a distinct seasonal fluctuation, i.e. low in May (below the detection limit) and high in July (-148 μg C m^{-2} h^{-1}). In site CC, both CH_4 uptake and emission occurred. The maximum CH_4 uptake (-85 μg C m^{-2} h^{-1}) at CC_2 was observed in July 2001, and the maximum emission (188 μg C m^{-2} h^{-1}) at CC_4 in September 2000. In site SC, there was a tendency of CH_4 uptake, but small CH_4 emission was also observed at SC_4 (maximum: 32 μg C m^{-2} h^{-1}). Averaged CH_4 uptake was highest in site NAT and lowest in site CC (Table 2). The CH_4 concentrations in soil and water are shown in Figure 3. In site NAT, the soil CH_4 concentration decreased with increasing the soil depth (minimum: 0.13 ppmv in September 2000). In site CC, the soil CH_4 concentration decreased with increasing soil depth at CC_1 and CC_2, but the soil CH_4 concentration increased with increasing soil depth at CC_4 and CC_5. The highest soil CH_4 concentrations (6.0×10^3 ppmv) were observed at CC_5 at the depth of 20 cm in July 2001. In site SC, the soil CH_4 concentration decreased with increasing soil depth except in SC_4. There was a weak correlation (r^2=0.07) between the CH_4 flux and the soil temperature (Fig. 4). On the other hand, the CH_4 flux strongly and positively correlated (r^2=0.49) with the soil moisture (Fig. 4), indicating CH_4 uptake decreased with increasing soil moisture.

Some studies have reported that the effects of deforestation on CH_4 uptake in forests in tropical and temperate forests where the precipitation was relatively higher. KELLER & al. 1990 reported that the CH_4 uptake in grassland, which was deforested 15 years ago, was lower than that in the adjacent forest in Central Panama. They stated that the changes of soil temperature and moisture had changed the condition of the micro-organisms associated with the disappearance of those canopies due to deforestation. Similar results were also reported in Brazil (VERCHOT & al. 2000) and Central Iowa (CHAN & PARKIN 2001). KAGOTANI & al. 2001 reported that CH_4 uptake in the clear cut forest was 30 to 40% lower than that of the adjacent deciduous forest in Central Japan. They also stated that the decrease in water uptake by plants led to the increase in soil moisture. On the other hand, BOWDEN & al. 1993 reported that there was no difference in the CH_4 uptake between the natural forest and selective cut forest where 68% of all trees were felled down in Massachusetts. They stated the reason of decreasing CH_4 uptake as the similar condition of soil temperature and soil moisture among the sites. In the present study, the CH_4 uptake in the SC and CC sites were lower than that in the NAT site (Table 2). On the other hand, the soil moisture in the SC and CC sites were higher than that in the NAT site (Table 2). It is considered that water tended to be stored in CC and SC, which were located in the flat area, than in NAT, which was located in the slope. However, the CH_4 uptake was significantly higher in SC than in CC where the topography was similar, and soil moisture tended to be higher in clear cut forest than in selective cut forest. Furthermore, although the sites CC_5 and SC_1 were located in very close to each other and had a similar topography, the soil CH_4 concentration was very high in CC_5, but was even lower in SC_1 than that in the atmosphere. Therefore, it appeared that the effect of existence of plants were larger than that of topography on CH_4 uptake in this study. The CH_4 uptake decreased with increase in soil moisture (Fig. 4), and the soil moisture was higher in the deforestation site than in the natural forest (Table 2). The precipitation was relatively lower in semi-boreal forest, but the difference of soil moisture among the sites might have been caused by the decrease in water uptake by plants.

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