Soil respiration change immediately after logging operations in an upper tropical hill forest, peninsular Malaysia

MOMO TAKADA, TOSHIHIRO YAMADA, NAISHEN LIANG, SHAMSUDIM IBRAHIM AND TOSHINORI OKUDA*

TAKADA, M., YAMADA, T., LIANG, N., IBRAHIM, S. & OKUDA, T. 2015. Soil respiration change immediately after logging operations in an upper tropical hill forest, peninsular Malaysia. Hikobia 17: 3–9.

Soil respiration rate changes immediately after logging operations as a result of two main factors; (1) change in root respiration by logged trees and (2) soil disturbance and change in litter amount by logging operations. To examine the extent of these two factors, we measured soil respiration rate in a hill dipterocarp forest in Peninsular Malaysia, approximately 1 year before and after logging operations. The soil respiration rate at the foot of logged trees did not change after logging operations, suggesting that root respiration of logged trees did not decrease because of root death within a half year after logging. This suggests that increased CO_2 emission due to decomposition of the dead roots was offset by the decrease in root respiration. In contrast, average soil respiration rate in the logged forest decreased by 25% after logging operations. Logging operations reduced soil respiration rate possibly because of environment changes within the forest, such as soil compaction and removal of litter layer by heavy machinery and extracted timbers during the logging operations.

*Momo Takada, Toshihiro Yamada & Toshinori Okuda, Graduate School of Integrated Arts and Sciences, Hiroshima University, 1–7–1 Kagamiyama, Higashi-Hiroshima 739–8521, Japan, *okudat-empat@hiroshima-u.ac.jp (author for corresponding).*
Naishen Liang, Center for Global Environmental Research, National Institute for Environmental Studies, 16–2 Onogawa, Tsukuba 305–8506, Japan.
Shamsudin Ibrahim, Forest Research Institute Malaysia, Kepong, Kuala Lumpur 52109, Malaysia.

Introduction

Soil respiration, defined as the CO_2 efflux from the soil surface and consisting of root respiration and heterotrophic respiration, is one of the most important components of the forest carbon cycle, accounting for approximately 40%–70% of the carbon emission from forest ecosystems (Goulden *et al.* 1996; Chambers *et al.* 2004; Ohkubo *et al.* 2007). Logging operations caused changes not only to the forest carbon stocks but also to soil respiration because of soil degradation, increase in air temperature and other negative environmental conditions in logged-over forests (Malhi & Grace 2000; Lytle & Cronan 1998).

Previous studies on the impact of logging on soil respiration have mainly been conducted in temperate and boreal forests. The research commenced in the early 1980s showed that logging operations increased soil respiration rate in most cases by changing root respiration rate of roots of logged trees and as a result of the soil disturbances during logging operations (*e.g.* Lytle & Cronan 1998; Strigle & Wickland 2001). However, previous studies did not detect significant changes in soil respiration rate in the tropics (Keller *et al.* 2005; Adachi *et al.* 2006; Yashiro *et al.* 2008). This non-significant change in soil respiration rate may be because of the large spatial variations in soil respiration rate and the logging methods in tropical regions. Soil respiration rates can vary by about 100% among locations only 0.5 m apart (Kosugi *et al.* 2007), with the spatial variation of soil respiration rate being much larger than its seasonal change (Ohashi *et al.* 2007). Additionally, logged-over areas after selective logging techniques become more heterogeneous than areas subject to clear felling in temperate and boreal forests (Sist *et al.* 2003). Therefore, the approaches of previous studies that compare soil respiration rates between logged and unlogged forests are thought to be ineffective because this large spatial heterogeneity may hinder the detection of logging impacts on soil respiration rates in tropical forests.

In the present study, we measured soil respiration rates during pre- and post-logging operations to reveal the effects of logging on soil respiration immediately after the operation and within a year after logging in an upper tropical hill forest in Peninsular Malaysia. We addressed the following two questions: (1) how does root respiration rate of logged trees change and (2) how does soil respiration rate in a forest change after environmental changes due to the logging operation.

Materials and methods

Study site

The study plots for the two types of soil respiration survey were placed within compartment 44, Block 5 (200 ha) in the 9765 ha Perak Integrated Timber Complex (PITC) Concession Forest (5°31′ N, 101°36′ E; 600–850 m asl) in the Temengor Forest Reserve. The overall vegetation type is considered a hill dipterocarp forest (Symington 1943), dominated in the canopy layer by *Shorea platyclados, Dipterocarpus costulatus, Dipterocarpus crinitus* and *Intsia palembanica* (PITC 2010). Tree harvesting in our study plot was conducted using the conventional Selective Management System logging regime. The concession area is located over either Silurian and Cambrian sedimentary rocks or acid, undifferentiated granitic rocks (WWF Malaysia 2002). The climate of the region is similar to that of the East Coast region of Peninsular Malaysia, which experiences heavy rainfall associated with the North East Monsoons (WWF Malaysia 2002). Annual mean temperature was approximately 23.3°C, mean diurnal range of temperature was 8.8°C, and the annual temperature range was 1.1°C. Annual precipitation was approximately 2570 mm. Precipitation of the wettest quarter (from October to December) and driest quarter (from January to March) were 985 and 393 mm, respectively, (1950–2000) (WorldClim database from http://www.worldclim.org) (Hijmans *et al.* 2005).

Soil respiration rates were measured at three or four points at the base of five logged trees before and after logging operations to estimate the temporal change in root respiration of logged trees. The sampling points were located within 1 m of the target trees. The sampling points were determined at four points every 90 degrees centered on each target tree. As heavy soil disturbance occurred for some target trees during logging operations, we avoided measuring the soil respiration rate at the points after the logging operations. Accordingly, for three trees of the five target trees, sampling points reduced to three after the logging. Selected trees for measurements were at least 5 m apart from their nearest neighbors to eliminate the effects of the root respiration of neighboring trees. The five selected trees belonged to families of Fabaceae, Olacaceae and Dipterocarpaceae; *Koompassia malaccensis* (one individual), *Strombosia ceylanica* (two individuals) and *Shorea platyclados* (two individuals). Diameters at breast height of these trees were more than 50 cm. The logging of these trees was conducted on 5 February 2011. Soil respiration rate was measured four times immediately before and after logging operations, in May 2011 and in August 2011. Subsequent measurements were conducted at exactly the same points for each target tree.

Besides the surveys above, we also measured soil respiration rates at 34 locations at the larger scale in the selected logging region by placing a 100 × 20 m plot inside the forest to examine temporal changes of soil respiration rate due to logging at the community level. The plot was located about 15 m from the nearest logging road; however, the logging road placement showed little effect on soil respiration values in the plot (Takada *et al.* 2015). The logging operations in this plot were conducted in December 2010, and the logging intensity in the plot was 25 trees/ha. The five logged trees within the plot were all *Shorea platyclados*. Soil respiration rates and environmental factors were measured for 1 yr, with the first measurement taken 3 mo before the logging operation (September 2010) and subsequent measurement were taken 5 and 8 mo after the logging operations (May and August 2011). Exactly the same measurement points were used on each measurement date.

Measurements of soil respiration rates

The soil respiration rate was measured using a portable automated chamber system (LAC-02G, National Institute for Environmental Studies, Tsukuba, Japan) (Liang *et al.* 2013). At the same points as for the soil respiration measurements, soil temperature and water content were also measured at 5 cm depth using a soil temperature probe (Type E, MHP, Omega Engineering, Stamford, CT, USA) and an ECH_2O probe (CDC-EC-5, Decagon Devices, Ins., Pullman, Wash., USA), respectively. All measurements were undertaken between 10:00 and 14:00 to avoid heavy rain in the afternoon.

Statistical Analyses

All the data of soil respiration rates showed a non-normal distribution when employing the Shapiro-Wilk normality test ($P < 0.05$). Therefore, we used a Friedman test (with Scheffe multiple comparisons), a nonparametric test, for statistical analysis to examine the significance of difference of the soil respiration rate between the study periods. We analyzed the effects of soil temperature and soil water contents on soil respiration rates at the community level using multiple regression analysis. All statistical analyses were conducted using R version 2.15.2 software (R Core Team 2012). Significant differences were determined at a probability level of $P < 0.05$.

Results

Soil respiration rates at the base of logged trees did not show temporal changes after logging. Average soil respiration rates were 10.68 ± 1.65 (SE) μmol $CO_2/m^2/s$ with a CV (coefficient of variance) of 0.69, 11.45 ± 2.00 (CV = 0.78), 12.42 ± 2.56 (CV = 0.90) and 10.02 ± 1.95 (CV = 0.83), for the measurements of 3 and 6 mo after the logging, respectively. No significant differences were observed among soil respiration rates for each time period (Friedman's test, df = 3, $P = 0.25$, Fig. 1A). Average soil temperature and soil water content were 22.5°C and 12.8%, respectively, and they showed significant temporal change (Fig. 1B, C).

Soil respiration rate at the community level decreased after logging operations, in contrast to the results for the individual level. Soil respiration rate 3 mo before logging was 10.69 ± 1.82 μmol $CO_2/m^2/s$ (CV = 0.99). Soil respiration rate 5 mo after logging was 8.25 ± 1.27 μmol $CO_2/m^2/s$ (CV = 0.90), and 8 mo after the logging was 7.71 ± 1.56 μmol $CO_2/m^2/s$ (CV = 1.18). Soil respiration rates 5 and 8 mo after logging were significantly lower than the rate 3 mo before logging (Friedman's test, df = 2, $P < 0.001$, Fig. 2A). Average soil temperature and soil water content were 22.2°C and 20.0%, respectively, and they

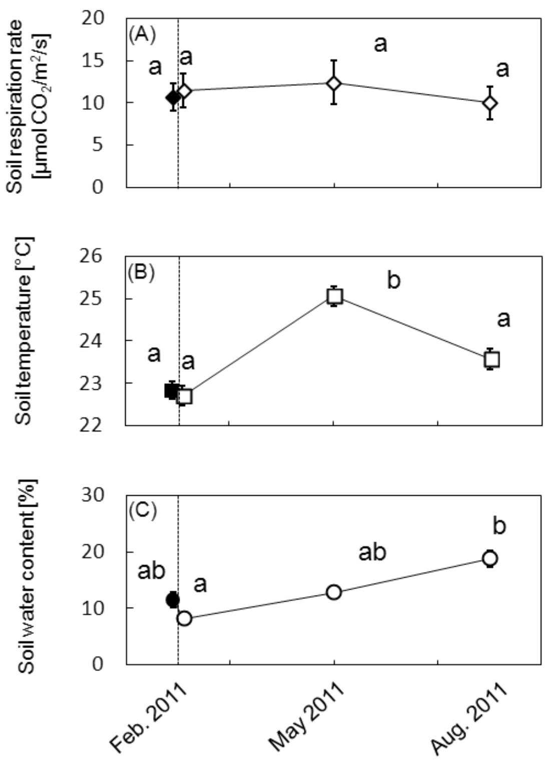

Fig. 1. Change in soil respiration rate at the base of logged trees (A), soil temperature (B), and soil water content (C). Dashed vertical lines indicate the time of the logging operations. Values before and after the logging operations are shown with solid and clear markers, respectively. Vertical bars indicate ± standard error. Different letters indicate statistically significant differences among sampling points at α = 0.05 (Friedman's test with multiple comparisons).

showed significant temporal change (Fig. 2B, C). The results of multiple regression analyses at the community level were not significant (before logging, $F_{2,31} = 0.47$, $P = 0.63$; 5 mo after logging, $F_{2,31} = 1.19$, $P = 0.32$; 8 mo after logging, $F_{2,31} = 0.31$, $P = 0.73$).

Discussion

At the present study site during our study period, soil temperature and soil water content did not affect soil respiration rates, as determined by multiple regression analysis. On a global scale, the most significant environmental factor affecting soil respiration rate is soil temperature, and soil water content is the second most important factor (*e.g.* Davidson *et al.* 2002). However, in tropical regions, soil temperature has less impact and consequently soil respiration rate is often slightly correlated with soil water content only (Raich & Schlesinger 1992, Davidson *et al.* 2000). The soil respiration rate during the present study period was affected neither by soil water content nor soil temperature, and the observations confirmed that there is no strong environmental factor controlling the characteristics of soil respiration in tropical regions. Therefore, temporal changes of soil respiration rate at the community level (Fig. 2A) were probably not the result of seasonal variations in environmental factors, but more likely to be the result of logging operations. However, we could not establish control plots because the study site was a concession forest and all areas were logged.

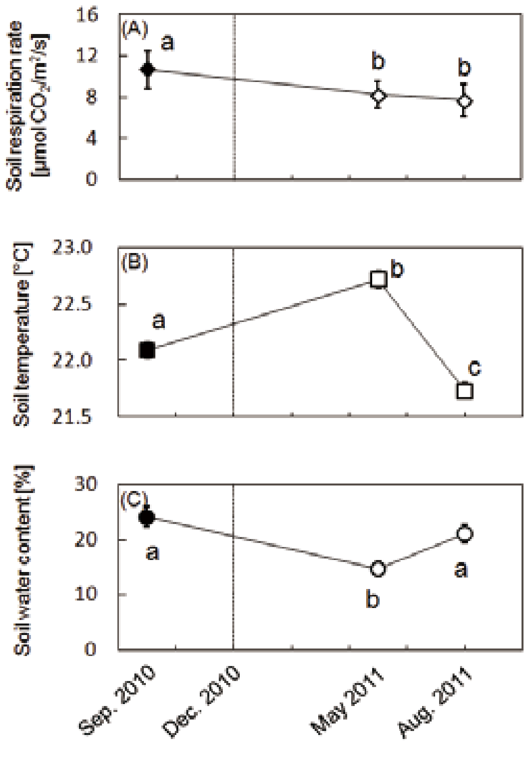

Fig. 2. Change in soil respiration rates before and after the logging operations at the community level (A), soil temperature (B), and soil water content (C). Dashed vertical lines indicate the time of logging operations. Values before and after the logging operations are shown with solid and clear markers, respectively. Vertical bars indicate ± standard error. Different letters indicate statistically significant differences among sampling points at $\alpha = 0.05$ (Friedman's test with multiple comparisons).

When a tree was logged, the root respiration of the logged tree stopped, and then decomposition of the root began to take place, as shown by studies in temperate forests (Strigle & Wickland 2001). Therefore, the soil respiration rate decreased shortly after logging and eventually increased. However, few studies have been conducted to validate this result in the tropics. At a mature jack pine (*Pinus banksiana*) forest in Canada, soil respiration rate decreased to less than half that before logging within 1 yr, and increased by 1.2 to 1.4 times in the 8 yr after logging (Strigle & Wickland 1998). The previous studies showed that the soil respiration rate varied with time after logging operations, whereas at the current study site, an upper tropical hill forest, no significant temporal changes in CO_2 emissions were observed. This might be because decomposition rates in tropical regions are higher than in temperate and boreal regions (Coûteaux *et al.* 1995), so decomposition of the roots of logged trees is assumed to start immediately after logging, and consequently the reduction in respiration might be offset by the increase in CO_2 emissions by root decomposition.

In contrast to the soil respiration rates changes at the base of logged trees, the soil respiration rate at the community level was significantly affected by logging. Soil respiration rate decreased by approximately 25% after logging, whereas in temperate and boreal forests soil respiration rate increased after logging (*e.g.*, Ewel *et al.* 1987; Gordon *et al.* 1987; Ohashi *et al.* 1999). Because logged trees did not show a change in soil respiration rate after logging, the decrease in soil respiration rate at the community level must have been because of a decrease in heterotrophic respiration in the logged forest. Environmental conditions (*i.e.*, soil compaction and reduced canopy cover) in logged forests changed as a result of logging disturbances (Pritchett & Fisher 1987). In the present study site, soil disturbance (*e.g.*, removal of litter layer and soil compaction by heavy machinery and extracted timbers) was observed after the logging operations. Soil compaction and decrease in the litter amount are known to cause reductions in the rate of heterotrophic respiration (Torbert & Wood 1992; Ruser *et al.* 2006; Zimmermann *et al.* 2009).

The spatial variation of soil respiration rates was very large at the present study site (average CV at the community level was 1.02). The changes in soil respiration rates after logging were within the ranges of the 95% bootstrap CI of the rates before logging. Therefore, the results suggest that comparison of soil respiration rates for the same sampling points before and after logging operations was more suitable for detecting logging effects on soil respiration rate than between logged and unlogged forests.

Conclusion

In the current study, we considered the soil respiration response to logging in the tropics and found that the changes to the ambient environment in the logged forest had a greater impact on soil respiration rate than that to soil respiration rate at the base of the logged trees (root respiration). This result may be regarded as a phenomenon unique to tropical regions where decomposition rate is high and soil temperature does not have a large effect on soil respiration.

Acknowledgments

This study was financially supported by the Environment Research and Technology Development Program (D-1005) funded by the Ministry of the Environment, Japan. We sincerely thank Mr. E. S. Quah, and other staff at FRIM and PITC at the Temengor Forest Reserve for their assistance and support during the field survey.

Literature cited

Adachi, M., Bekku, Y. S., Rasidah, K. W., Okuda, T. & Koizumi, H. 2006. Differences in soil respiration between different tropical ecosystems. Appl. Soil. Ecol. 35: 258–265.

Chambers, J. Q., Tribuzy, E. S., Toledo, L. C., Crispim, B. F., Higuchi, N., Santos, J. D., Araujo, A. C., Kruijt, B., Nobre, A. D. & Trumbore, S. E. 2004. Respiration from a tropical forest ecosystem: partitioning of sources and low carbon use efficiency. Ecol. Appl. 14: 72–88.

Coûteaux, M. M., Bottner, P. & Berg, B. 1995. Litter decomposition, climate and liter quality. Trends. Ecol. Evol. 10: 63–66.

Davidson, E. A., Belk, E. & Boone, R. D. 2002. Soil water content and temperature as independent or confounded factors controlling soil respiration in a temperate mixed hardwood forest. Glob. Chang. Biol. 4: 217–227.

Davidson, E. A., Verchot, L. V., Cattânio, J. H., Ackerman, I. L. & Carvalho, J. E. M. 2000. Effects of soil water content on soil respiration in forests and cattle pastures of eastern Amazonia. Biochemistry 48: 53–69.

Ewel, K. C., Cropper, Jr. W. P. & Gholz, H. L. 1987. Soil CO_2 evolution in Florida slash pine plantation: I, Changes through time. Can. J. For. Res. 17: 330–333.

Gordon, A. M., Schlenter, R. E. & Cleave, K. V. 1987. Seasonal patterns of soil respiration and CO_2 evolution following harvesting in the white spruce forests of interior Alaska. Can. J. For. Res. 17: 304–310.

Goulden, M. L., Munger, J. W., Fan, S. M., Daube, B. C. & Wofsy, S. C. 1996. Measurements of carbon sequestration by long-term eddy covariance: methods and a critical evaluation of accuracy. Glob. Chang. Biol. 2: 169–182.

Hijmans, R. J., Cameron, S. E., Parra, J. L., Jones, P. G. & Jarvis, A. 2005. Very high resolution interpolated climate surfaces for global land areas. International Journal of Climatology 25: 1965–1978.

Keller, M., Varner, R., Dias, J. D., Silva, H., Crill, P., de Olivwria, Jr. R.C. & Anser, G. P. 2005. Soil-Atmosphere Exchange of Nitrous Oxide, Nitric Oxide, Methane, and Carbon Dioxide in Logged and Undisturbed Forest in the Tapajos National Forest,

Brazil. Earth Interactions 9: 1–28.
Kosugi, Y., Mitani, T., Itoh, M., Noguchi, S., Tani, M., Matsuo, M., Takanashi, S., Ohkubo, S. & Rahim, A. N. 2007. Spatial and temporal variation in soil respiration in a Southeast Asian tropical rainforest. Agric. For. Meteorol. 147: 35–47.
Liang, N., Wang, Y., Zhang, Y., He, J., Li, S., Piao, S., Fang, J., Hirano, T., Takagi, K., Fletcher, C.D., Teramoto, M. & Tan, Z. 2013. An automated-chamber network for evaluation of carbon budget of Asian terrestrial ecosystems. AsiaFlux Newsletter 35: 3–12.
Lytle, D. E. & Cronan, C. S. 1998. Comparative soil CO_2 evolution, litter decay, and root dynamics in clearcut and uncut spruce-fir forest. For. Ecol. Manage. 103: 121–128.
Malhi,Y. & Grace, J. 2000. Tropical forests and atmospheric carbon dioxide. Trends. Ecol. Evol. 15: 332–337.
Ohashi, M., Gyokusen, K. & Saito, A. 1999. Measurement of carbon dioxide evolution from a Japanese cedar (*Cryptomeria japonica* D. Don) forest floor using on open-flow chamber method. For. Ecol. Manage. 123: 105–144
———, Kume, T., Yamane, S. & Suzuki, M. 2007. Hot spot of soil respiration in an Asian tropical rainforest. Geophys. Res. Lett. 34: L08705
Ohkubo, S., Kosugi, Y., Takanashi, S., Mitani, T. & Tani, M. 2007. Comparison of eddy covariance and automated closed chamber methods for evaluating nocturnal CO_2 exchange in a Japanese cypress forest. Agric. For. Meteorol. 142: 50–65
PITC. 2010. Second Forest Management Plan Perak ITC Concession Area Temengor Forest Reserve 2010-2020. PITC, Perak, Malaysia.
Pritchett, W. L. & Fisher, R. F. 1987. Properties and management of forest soil. 2nd edition, John Wiley & Sons, New York, U.S.A.
R Core Team. 2012. *R:* A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org/.
Raich, J.W. & Schlesinger, W. H. 1992. The global carbon dioxide flux in soil respiration and its relationship to vegetation and climate. Tellus 44: 81–99.
Ruser, R., Flessa, H., Russow, R., Schmidt, G., Buegger, F. & Munch, J. C. 2006. Emission of N_2O, N_2 and CO_2 from soil fertilized with nitrate: effect of compaction, soil moisture and rewetting. Soil. Biol. Biochem. 38: 263–274.
Sist, P., Fimbel, R., Sheil, D., Nasi, R. & Chevallier, M. H. 2003.Towards sustainable management of mixed dipterocarp forests of South-east Asia: moving beyond minimum diameter cutting limits. Environmental Conservation 30: 364–374.
Strigle, R. G. & Wickland, K. P. 1998. Effects of a clear-cut harvest on soil respiration in a jack pine – lichen woodland. Can. J. For. Res. 28: 534–539.
———. & ———. 2001. Soil respiration and photosynthetic uptake of carbon dioxide by ground-cover plants in four ages of jack pine forest. Can. J. For. Res. 31: 1540–1550.
Symington, C. F. 1943. Forester's manual of dipterocarps. Malay Forest Records No. 16. Caxton Press, Kuala Lumpur, Malaysia.
Takada, M., Yamada, T., Shamsudin, I. & Okuda, T. 2015. Spatial variation of soil respiration in relation to logging road in an upper tropical hill forest in Peninsular Malaysia. Tropics 24: 1–10.
Torbert, H. A. & Wood, C. W. 1992. Effects of soil compaction and water-filled pore space on soil microbial activity and N losses. Commun. Soil. Sci. Plant. Anal. 23: 1321–1331.
WWF Malaysia. 2002. Biodiversity Assessments and Conservation Planning for Sustainable production Forestry in High-Conservation Value Forests.
Yashiro, Y., Rasidah, K. W., Okuda, T. & Koizumi, H. 2008. The effects of logging on soil greenhouse gas (CO_2, CH_4, N_2O) flux in a tropical rain forest, Peninsular Malaysia. Agric. For. Meteorol. 148: 799–806.
Zimmermann, M., Meir, P., Bird, M., Malhi, Y. & Ccahuana, A. 2009. Litter contribution to diurnal and annual soil respiration in tropical montane cloud forest. Soil. Biol. Biochem. 41: 1338–1340.

Accepted 26. XI. 2015

高田モモ・山田俊弘・Naishen Liang・Shamsudin Ibrahim・奥田敏統：半島マレーシア熱帯丘陵林における伐採施業直後の土壌呼吸の変化

伐採施業直後の土壌呼吸は主に二つの要因で変化する．(1) 伐採木の根呼吸の変化，そして (2) 伐採施業による土壌攪乱と落葉量の変化である．これら二つの要因の程度を調べるため，半島マレーシアの丘陵地フタバガキ林において，伐採施業を挟み約 1 年間にわたって土壌呼吸を測定した．伐採木の根元の土壌呼吸は，伐採後に変化を示さなかった．このことは，伐採後半年間では，伐採木の根が枯死することによる根呼吸の減少が起こらない

ことを示している．あるいは，枯死根の分解による二酸化炭素放出量の増加が，伐採木の根の枯死による根呼吸量の減少を相殺しているのかもしれない．その一方で，伐採施業後の森林では，平均土壌呼吸が 25% 減少した．したがって，伐採施業によって土壌呼吸は減少するが，これは林内環境の変化によるものであると考えられる．例えば伐採用重機や伐採木の搬出による土壌圧縮，落葉層の剥離等が考えられる．