HOKKAIDO UNIVERSITY

Title	Soil Respiration in Different Forest Ecosystems Established after Volcanic Eruptions on Mt. Showa-Shinzan
Author(s)	MOON, Hyun-Shik; 文, 炫植; HARUKI, Masahiro et al.
Citation	北海道大学農学部 演習林研究報告, 55(1), 87-96
Issue Date	1998-02
Doc URL	https://hdl.handle.net/2115/21432
Type	departmental bulletin paper
File Information	55(1)_P87-96.pdf

Hokkaido University Collection of Scholarly and Academic Papers : HUSCAP

Soil Respiration in Different Forest Ecosystems Established after Volcanic Eruptions on Mt. Showa-Shinzan

by

Hyun-Shik MOON*, Masahiro HARUKI** and Kunihide TAKAHASHI*

昭和新山の噴火後成立した森林生態系における土壌呼吸

文　炫植*　春木　雅寛**　高橋　邦秀*

Abstract

To understand the patterns of soil respiration in various ecosystems established after volcanic eruptions, soil respiration by the alkali absorption method was analyzed from August 1994 to July 1996 in bareland, grassland, alder, and poplar ecosystems on volcano Mt. Showa-Shinzan. The rate of soil respiration increased exponentially with the increase in soil temperature ($r=0.95$ to 0.97, $p<0.001$) and showed perspicuous seasonal changes with a summer peak. However, soil moisture levels had little effect on soil respiration. Estimated annual rates were 0.93kg CO_2 m^{-2} yr^{-1} for bareland, 3.27kg CO_2 m^{-2} yr^{-1} for grassland, 2.53kg CO_2 m^{-2} yr^{-1} for the alder, and 3.74kg CO_2 m^{-2} yr^{-1} for the poplar ecosystem, respectively. Differences of the rates of soil respiration in each ecosystem suggest that the rate of soil respiration depended on vegetation structure on volcano.

Key words: Mt. Showa-Shinzan, Vegetation recovery, Soil respiration, Volcano

Received August 29, 1997. 1997年8月29日受理.

*Laboratory of Silviculture, Department of Forest Science, Faculty of Agriculture, Hokkaido University, Sapporo

北海道大学農学部森林科学科造林学講座

**Graduate School of Environmental Earth Science, Hokkaido University, Sapporo

北海道大学大学院地球環境科学研究科資源化科学講座

I. Introduction

The evolution of CO_2 from soil to atmosphere is an important process of C cycle in forest ecosystems. The term 'soil respiration' normally refers to the in situ assessment of CO_2 evolution at the soil surface. Measurements of the soil respiration in decomposing substrate has been recognized as an useful index of decomposition and mineralization rate of organic matter, and carbon cycling in an ecosystem (Mathes and Schriefer 1985, Schlentner and Van Cleve 1985, Ewel *et al.* 1987, Gordon *et al.* 1987), and as an index of relative soil biological activity (Weber 1985).

It follows from what has been said that the purposes of many such measurements have been to obtain a clearer understanding of mineralization processes and thereby to gain in sight into how the nutrient minerals and organic matter of the soil can be more efficiently utilized and conserved. That is, it appears likely that measurements of soil respiration are essential as a means of providing a general estimate of nutrient mineralization by soil microbial activity. Thus, measurement of soil respiration is expected to furnish important information for estimating the process of vegetation recovery.

The present study was carried out with a purpose to obtain rates and patterns of soil respiration from the soil and the effect of abiotic factors on rates of soil respiration in different forest ecosystems established on volcano Mt. Showa-Shinzan.

II. Materials and Methods

1. Study area

The study site was located in Mt. Showa-Shinzan (407m in alt, 42°33′ N, 140°52′ E) in south-western region of Hokkaido. Mt. Showa-Shinzan was created by volcanic eruptions in the period of 1944-45. The mean air temperature and annual precipitation in this area were 8.1°C and 987 mm (Fig. 1), respectively. This study is covered by snow for

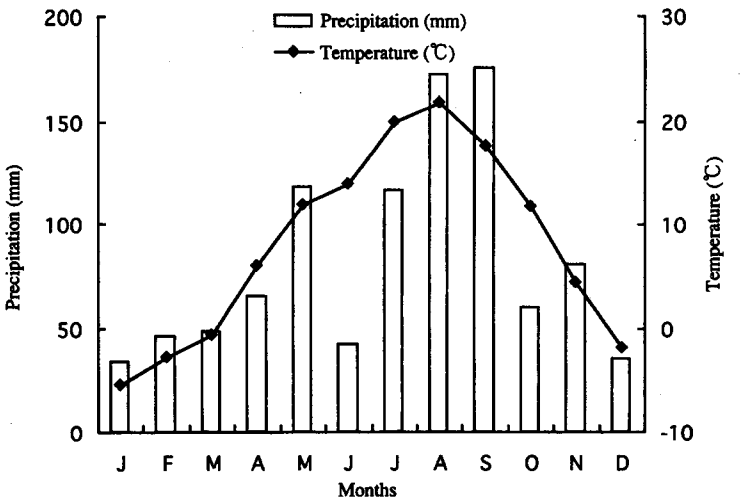

Fig. 1. Mean air temperature and precipitation measured at Mt. Showa-Shinzan in 1994-96.

4 months, from late December to early April.

Mt. Showa-Shinzan has been recovered by typical pioneer forests, grassland and bareland. The present study was carried out in four different ecosystems i.e., bareland, grassland, alder, and poplar ecosystem. The elevation of the study site ranged from 190 m to 310 m. Only toadflax (*Linaria japonica* Miq.) in bareland was found. In grassland no woody species were found, orchard grass (*Dactylis glomerata* L.) and white clover (*Trifolium repens* L.) were the most abundant herbaceous species. In the alder and poplar ecosystem *Alnus maximowiczii* and *Populus maximowiczii* was the most abundant species, respectively. The herbaceous species in the alder and poplar ecosystems was mainly represented by lagwort (*Petasites japonicus* var. *giganteus* Kitam.) and shinleaf (*Pyrola incarnata* Fisch.). Some vegetation characteristics of four ecosystems are given in Table 1. Also, some physical and chemical properties of the soil in the study site are given in Table 2.

Table 1. Site characteristics of four ecosystems

Parameter	Bareland	Grassland	Alder	Poplar
Altitude (m)	307	295	285	185
Plot size (m^2)	225	225	225	400
Aspect	NE	NE	NE	W
Slope (°)	0—6	0—3	8—12	5—7
Tree age (Year)	—	—	25—32	45—47
Basal area (m^2/ha)	—	—	19.28	25.28
Max. H (m)	—	—	9	18
Dominant species				
Upper	—	—	*Alnus maximowiczii*	*Populus maximowiczii*
Lower	*Linaria japonica*	*Trifolium repens* *Dactylis glomerata*	*Petasites japonicus* *V. giganteus*	*Pyrola incarnata*

Table 2. Physical and chemical properties of soil in four different ecosystems

Properties	Bareland	Grassland	Alder	Poplar
Bulk density ($g \cdot cm^{-3}$)	1.27	1.33	1.11	0.93
pH[a] (H_2O)	6.37	6.72	6.18	6.88
Org. matter (%)	1.71	2.9	3.39	4.15
Mineral N[b] (mg/kg)	3.11	5.06	11.29	6.87
Exch. cation[c] (me/100g)				
Ca^{2+}	11.1	13.6	10.2	12.9
Mg^{2+}	1.62	2.36	2.02	2.18
K^+	0.93	1.55	1.61	1.65
Na^+	0.26	0.21	0.20	0.21

a: 1:2.5 mixture of soil: deionized water

b: Mineral N is the sum of $NH_4^+ + NO_3^-$. 2 N KCl extraction

c: 1N CH_3COONH_4 (pH 7.0) extraction

2. Soil temperature and moisture content

Soil temperature was measured hourly with a thermo recorder (TR-71, T AND D) for each ecosystem at depth of 5cm from August 1994 to July 1996. Also, soil moisture content was determined from seven mineral soil samples for each ecosystem. Soil sample taken concurrently with measurements of soil respiration rate were dried at 105°C for 24 hr.

3. Measurements of soil respiration

Soil respiration was measured once a month from August 1994 to July 1996 by the KOH absorption method modified by Kirita (1971). In this study, cylinder of 15cm in diameter and 22cm in height was used as CO_2 isolation chamber. In the field, seven cylinders within each ecosystem were pushed into the soil to a depth of 5cm while taking precautions to minimize soil disturbance. Organic materials such as leaves beneath the chamber edges were removed. A wire holder was laid in the cylinder in order to prevent the sponge from falling to the soil surface. A sponge containing 25ml of 1N KOH solution was placed on the wire holder. The cylinder was shielded from direct sunlight by covering it with aluminum foil. Soil respiration rates were measured for 24 hr. After 24 hr, all sponges were retrieved and refrigerated at 0-3°C for transport to the laboratory. In the laboratory, 5ml of solution collected from the sponge was titrated with 0.1N HCl using phenolphthalein and methylorange as indicators.

III. Results

1. Soil temperature and moisture content

Seasonal changes in soil temperature showed very similar tendency in all the study sites (Table 3), but the midsummer of 1994 was hotter than other years. Although soil temperature in the bareland was high, soil temperature in both the alder and poplar ecosystem was relatively low probably because of the dense foliage. Soil temperature was the highest in barland located in the neighbor of center of volcano, and showed no particular differences among other ecosystems. Soil moisture content was fairly stable throughout the study period except for bareland (Table 3). Low soil moisture content in bareland might be due to the high temperature and consequent evaporation of water from the soil surface.

2. Soil respiration rates

The rates of soil respiration also exihibited seasonal changes, being high in summer and low in late fall (Fig. 2). In all the study sites, the highest rates of soil respiration were measured in August and the lowest in November. The observed maximum (max) and minimum (min) rates of soil respiration were 0.40 (max) g CO_2 m^{-2} hr^{-1} and 0.10 (min) for bareland, 0.75 and 0.26 for grassland, 0.60 and 0.16 for the alder, and 0.91 and 0.29 for the poplar, respectively. There were slight differences in the rate of soil respiration between the ecosystems, with the rate of soil respiration for the poplar ecosystem being generally high throughout the study period, and the rate for bareland being the lowest. Also, the rate of soil respiration in the alder ecosystem was relatively low. At all the

study sites, higher rates of soil respiration in 1994 reflected the warmer soil temperatures of that year.

Table 3. Soil temperature and moisture content (%) for mineral soil of four different ecosystems

Sampling date	Bareland		Grassland		Alder		Poplar	
	Temp.	Mois.	Temp.	Mois.	Temp.	Mois.	Temp.	Mois.
'94 Aug.	24.9	14.4	21.8	16.1	20.9	19.4	21.2	22.8
Sep.	22.4	16.8	19.3	18.9	18.6	22.3	18.7	25.1
Oct.	16.3	18.4	13.2	18.7	12.2	29	12.6	28.5
Nov.	7.5	13.9	4.4	14.9	3.5	27.7	3.8	24.5
'95 May	12.6	14.5	9.5	20.8	8.6	22.7	8.9	27.1
Jun.	14.4	20.3	11.3	22.4	10.3	30.9	10.7	32.7
Jul.	18.1	14.3	15	19.5	14.1	27.6	14.4	30.2
Aug.	20.8	16	17.7	15.4	16.7	21.1	17.1	27.9
Sep.	20	18.1	16.9	17	16	22.8	16.3	28
Oct.	13.7	15.2	10.6	20.7	9.7	23.5	10	29.1
Nov.	11.8	18.4	8.7	17.3	7.8	23.4	8.1	28.9
'96 May	8.7	17.4	5.6	18.4	4.6	26	5	28.7
Jun.	15.7	17.6	12.6	17.9	11.8	26.7	12	29.1
Jul.	20.9	21.6	17.8	22.9	16.9	27.4	17.2	31.4

Soil temperature (°C) are mean values at depth of 5cm.

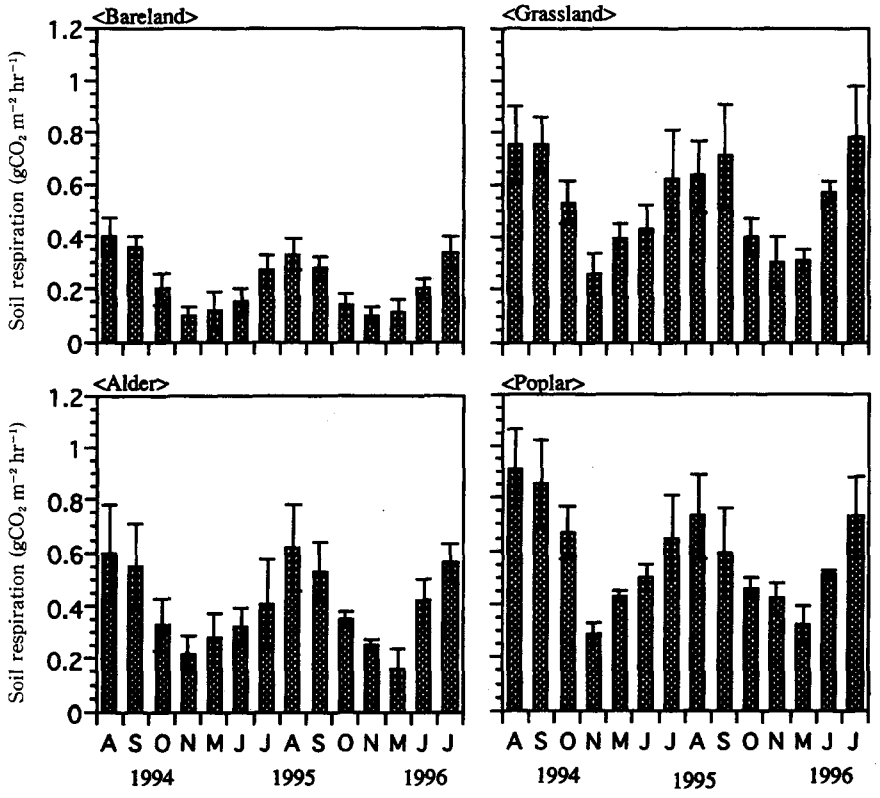

Fig. 2. Seasonal patterns of soil respiration rates for four different ecosystems. The data are mean values with standard deviations.

3. Effects of abiotic factors on soil respiration

Fig. 3 shows the relationships between the mean daily soil temperature and soil respiration. As already pointed out, the rate of soil respiration increased exponentially with the increase in soil temperature. The regression coefficient of the following equation for each plot is shown in Fig. 3.

$$\mathrm{LogSR} = a + bT \quad \cdots\cdots\cdots\cdots\cdots (1)$$

where SR is the daily soil respiration rate (g CO_2 m^{-2} d^{-1}), T is the mean daily soil temperature, and a and b are the regression coefficients.

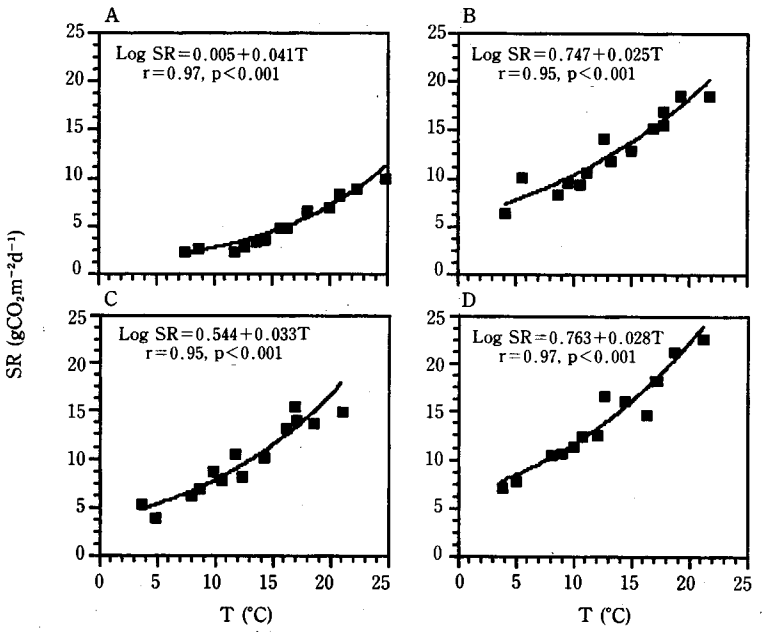

Fig. 3. Relationship between soil temperature and soil respiration rates in bareland (A), grassland (B), alder (C), and poplar ecosystem (D). (SR : Soil respiration, T : Soil temperature)

As shown in Fig. 3, there was significant correlation between soil respiration rates and soil temperatures ($r=0.95$ and 0.97, $p<0.001$), but soil respiration has no significant correlation with soil moisture content. Although there have been some reports on the effects of moisture content on soil respiration rate (Froment 1972, Orchard and Cook 1983, Weber 1985, Orchard *et al.* 1992), soil moisture contents clearly have no effect on the soil respiration rates observed in this study.

The Q_{10} values varied among all the ecosystems (Table 4). The Q_{10} value, which gives the rate of increase of soil respiration with a 10°C increase in soil temperature, was 2.95 for bareland, 1.29 for grassland, 1.47 for the alder, and 1.31 for the poplar ecosystem. Most of the already published reports stated that soil moisture content is not a limiting factor for soil respiration.

Table 4. Q_{10} values, estimated annual respiration rate and carbon loss for mineral soils of four different ecosystems

Vegetation type	Q_{10} value	Annual respiration (kg CO_2 m^{-2} yr^{-1})	Loss of carbon (kg C m^{-2} yr^{-1})
Bareland	2.95	0.93	0.25
Grassland	1.29	3.27	0.89
Alder	1.47	2.53	0.69
Poplar	1.31	3.74	1.02

Q_{10}: rate of increase in soil respiration with a 10 °C increment in soil temperature. Annual respiration was calculated from results based on regression analysis between soil temperature and soil respiration.

The annual rates of soil respiration were calculated from daily mean soil temperatures using soil temperature-soil respiration regression analysis. The results are shown in Table 4. The annual rate of soil respiration amounted to 0.93kg CO_2 m^{-2} yr^{-1} for bareland, 3.27 for grassland, 2.53 for the alder, and 3.74 for the poplar ecosystem. Also, the authors calculated the total amounts of carbon consumed through soil respiration as 0.25kg C m^{-2} yr^{-1} for bareland, 0.89 for grassland, 0.69 for the alder, and 1.02 for the poplar ecosystem (Table 4).

IV. Discussion

Although four methods have been reported for the measurement of soil respiration (Van Cleve *et al.* 1979), the alkali absorption method used in the present study furnishes an efficient way to measure the relative rate of soil respiration because of its simplicity and the possibility of realizing multi-measurements (Anderson 1982, Buyanovsky *et al* 1986).

The relationships between soil respiration and soil temperature were expressed numerically by using Vant Hoff's equation, $Q_{10}=K_{t+10}/K_t$, where Kt is the respiration rate at a particular temperature. Q_{10} values (Table 4) varied in each site, ranging from 2.95 for bareland to 1.29 for grassland. It has long been known that the Q_{10} value provides an estimation of the general response of microbial activity in soil to temperature change, and have been expressing numerically for a long time. The higher Q_{10} value in bareland might due to low rate of soil respiration during the study period. The effects of temperature and moisture levels on soil respiration have been studied and discussed (Orchard and Cook 1983, Linn and Doran 1984, Skoop *et al.* 1990, Orchard *et al.* 1992). Gupta and Singh (1981) and Rajvanshi and Gupta (1986) stated that soil respiration in grassland and forest ecosystems at India showed better correlations of CO_2 evolution rates with soil water than with temperature. Schlentner and Van Cleve (1985) reported that temperature increase had little effect on CO_2 evolution, when moisture levels was lower. However, the results of this study indicated that high soil temperature during summer months had effect on soil respiration rate from the soil, while moisture levels had little effect on soil respiration rate. That is, soil respiration rates in this study were influenced by soil temperature than moisture levels during the study period.

The differences in the rates of soil respiration among all the sites may be related to the development of root biomass, as the proportion of soil respiration contributed by the roots

is variable in different plant communities and depends on the degree of development of the root system. Some studies have reported on the relationship between root respiration and total soil respiration. Kucera and Kirkham (1971) concluded that a difference between C input and output indicated the respiration of live roots and in their work with tall-grass prairie dominated by herbaceous species of big bluestem (*Andropogon gerardi*) and little bluestem (*A. scoparious*), which root respiration was estimated to be 40% of total respiration. Katagiri (1988) estimated the rate at 20-40% in deciduous broad-leaved stand. From this, it seems that live root respiration would make a greater contribution to soil respiration in grassland than in woodyland.

In this study, low rates of soil respiration in the alder ecosystem were remarkable. The comparative high rate in grassland would be probably due to the influence of dominant herbaceous species such as orchard grass (*Dactylis glomerata* L.) and white clover (*Trifolium repens* L.), which root system and distribution are known to be crowded and entangled in the vicinity of the soil surface. However, as Coleman (1973) already pointed out, precise estimations of the contribution of plant root respiration is problematic due to difficulties in the separation of the roots and microbes from the soil and rhizosphere, respectively.

On the other hand, soil microorganism is decomposer of organic material. That is, organic materials returned to forest floor through litter are decomposed by soil microbial activity. Plant roots absorb and utilize the nutrients which were mineralized by soil microbes. Most of the nitrogen stored in forest soils exists in the organic form and it cannot be utilized by the plant roots. Nitrogen mineralization processes are predominantly brought about by soil microbial activity. Therefore, it may be expected that estimating of nitrogen mineralization in soil is possible by examining soil respiration. As concerns the relationship between nitrogen dynamics and soil respiration, it is known to some extent that soil respiration has been correlated with soil nitrogen processes of mineralization (Gilmour *et al.* 1985), nitrification (Keeney *et al.* 1985), and denitrification (Reddy *et al.* 1982). Concrete information on the relationship between soil respiration and nitrogen dynamics is not yet fully available because of the difficulty in interpreting the dynamics of soil nitrogen in the field. Actually, mineral N in the alder ecosystem was higher irrespective of compavatively low rates of soil respiration than other ecosystems, as shown in Table 2. And, the alder ecosystem showed active nitrification rate (Moon 1998). The present results suggest that the rate of soil respiration considerably depended on vegetation structure at early stages of vegetation ecovery on volcano Mt. Showa-Shinzan.

Acknowledgments

We would like to express our thanks to Mr. Saburou Mimatsu and Mrs. Yasuko Mimatsu, Mimatsu Memorial Hall, for providing us with the research sites for the present study and to the staff of Usu Volcano Obserbatory, Hokkaido University, for their helpful cooperations during the study period.

References

ANDERSON, J. P. E. (1982) : Soil respiration. p. 831-871. In A. L. Page *et al.* (ed.) Methods of soil analysis, Part 2. Chemical and Microbiological Properties (2nd eds). Am. Soc. Agronomy. Madison, Wisconsin USA.

BUYANOVSKY. G. A., G. H. WAGNER and C. J. GANTZER (1986) : Soil respiration in a winter wheat ecosystem. Soil Sci. Soc. Am. J., **50**, 338-344

COLEMAN. D. C. (1973) : Compartmental analysis of total soil respiration : an exploratory study. Oikos **24**, 361-366.

EWEL. K. C., Jr. W. P. CROPPER and H. L. GHOLZ (1987) : Soil CO_2 evolution in Florida slash pine plantations. I. Changes through time. Can. J. For. Res., **17**, 325-329.

FROMENT. A. (1972) : Soil respiration in a mixed oak forest. Oikos **23**, 273-277.

GILMOUR. J. T., M. D. CLARK and G. C. SIGUA (1985) : Estimating net nitrogen mineralization from carbon dioxide evolution. Soil Sci. Soc. Am. J., **49**, 1398-1402.

GORDON. A. M., R. E. SCHLENTNER and K. VAN CLEVE (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.

GUPTA. S. R. and J. S. SINGH (1981) : Soil respiration in a tropical grassland. Soil Biol. Biochem., **13**, 261-268

KATAGIRI. S. (1988) : Estimation of proportion of root respiration in total soil respiration in deciduous broadleaved stands. Jap. J. For. Soc., **70**, 151-158.

KEENEY. D. R., K. L. SAHRAWAT and S. S. ADAMS (1985) : Carbon dioxide concentration in soil : effects on nitrification. denitrification and associated nitrous oxide production. Soil Biol. Biochem., **4**, 571-573.

KIRITA. H. (1971) : Re-examination of the absorption method of measuring soil respiration under field conditions. II. Effect of the size of the apparatus on CO_2 absorption rates. III. Combined effect of the covered ground area and the surface area of KOH solution on CO_2 absorption rates. Jap. J. Ecol., **27**, 37-47.

KUCERA. C. L. and D. R. KIRKHAM (1971) : Soil respiration studies in tallgrass prairie in Missouri. Ecology **52**, 912-915.

LINN. D. M. and J. W. DORAN (1984) : Effect of water-filled pore space on carbon dioxide and nitrous oxide production in tilled and nontilled soils. Soil Sci. Soc. Am. J., **48**, 1267-1272.

MATHES. K. and TH. SCHRIEFER (1985) : Soil respiration during secondary succession : Influence of temperature and moisture. Soil Biol. Biochem., **17**, 205-211.

MOON, H. S (1998) : Processes of nutrient availability in different soil-plant ecosystems established on volcano Mt. Showa-Shinzan. PhD Diss., Hokkaido Univ.

ORCHARD. V. A. and F. J. COOK (1983) : Relationship between soil respiration and soil temperature. Soil Biol. Biochem., **15**, 447-453.

ORCHARD. V. A., F. J. COOK and D. M. CORDEROY (1992) : Field and laboratory studies on the relationships between respiration and moisture for two soils of contrasting fertility status. Pedobiologia **36**, 21-33.

RAJVANSHI. R. and S. P. GUPTA (1986) : Soil respiration and carbon balance in a tropical Dalbergia sissoo forest ecosystem. Flora **178**, 251-260.

REDDY. K. R., P. S. C. RAO and R. E. JESSUP (1982) : The effect of carbon mineralization on denitrification kinetics in mineral and organic soils. Soil Sci. Soc. Am. J., **46**, 62-68.

SCHLENTNER. R. C. and K. VAN CLEVE (1985) : Relationships between CO_2 evolution from soil. substrate temperature. and substrate moisture in four mature forest types in interior Alaska. Can. J. For.

Res., **15**, 97-106.

SKOOP. J., M. D. JAWSON and J. W. DORAN (1990) : Steady-state aerobic microbial activity as a function of soil water content. Soil Sci. Soc. Am. J., **54**, 1619-1625.

VAN CLEVE. K., I. C. PATRICK. E. GOODWIN. C. JOHNSON and M. KELLEY (1979) : A comparison of four methods for measuring respiration in organic material. Soil Biol. Biochem., **11**, 237-246.

WEBER. M. G. (1985) : Forest soil respiration in eastern Ontario jack pine ecosystems. Can. J. For. Res., **15**, 1069-1073.

要　　約

火山噴火後の植生回復に伴う土壌呼吸量のパターンを把握するため，昭和新山の裸地，草本群落，ミヤマハンノキ林，ドロノキ林の四つの森林生態系で，アルカリ吸収法により土壌呼吸量を1994年8月から1996年7月まで測定した。土壌呼吸量は地温の増加とともに指数関数的($r=0.95$ to 0.97, $p<0.001$)に増加し，また夏季に高く，明瞭な季節変化を示した。しかし土壌水分の影響はほとんど見られなかった。土壌呼吸量と地温との関係に基づき，各生態系における年間土壌呼吸量を推定した。推定年間呼吸量は裸地で0.93 kg CO_2 m^{-2} yr^{-1}，草本群落で3.27 kg CO_2 m^{-2} yr^{-1}，ミヤマハンノキ林で2.53 kg CO_2 m^{-2} yr^{-1}，ドロノキ林で3.74 kg CO_2 m^{-2} yr^{-1}であった。これらの結果から，土壌呼吸量は火山噴火後の植生の定着により増加し，植生構造により異なることが示唆された。

キーワード：昭和新山，植生回復，土壌呼吸，火山