Estimation of the Net Production of Moss Community at Langhovde, East Antarctica

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東南極ラングホブデにおける蘚類の純生産量の推定

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要旨: 1988年1月にラングホブデの雪鳥沢で採取したコケ塊 (*Grimmia lawiana*, *Bryum pseudotriquetrum* および *B. pseudotriquetrum* と *Ceratodon purpureus* の混生塊) の光合成, 呼吸速度を現地で2台の赤外線 CO_2 分析計と温度制御付き同化箱を使用して測定した. 同時に光強度と蘚表層の温度を記録した. KAPPEN *et al.* (Polar Biol., **9**, 415, 1988) の用いた重回帰式に基づいて, 純光合成速度とコケ温度・光強度との関係式をつくった. この重回帰式と OHTANI *et al.* (JARE Data Rep., **152**, 216 p., 1990) によって測定された雪鳥沢の微気象データを使って, 雪鳥沢に生育するコケ塊の 1988 年1月から 1989 年1月までの年間の有機物生産量を計算し, 230 g～296 gdw・m^{-2} の値を得た. この値は DAVIS (Ecol. Monogr., **51**, 125, 1981) によるシグニー島の群落で報告された純生産量の下限値に近い.

Abstract: Field measurements of net photosynthesis and dark respiration (CO_2 exchange) of moss colonies were carried out at Langhovde, East Antarctica from 9 to 17 January 1988. Each colony growing at the Yukidori Valley, Langhovde was composed of *Grimmia lawiana*, *Bryum pseudotriquetrum* or the mixture of *Ceratodon purpureus* and *B. pseudotriquetrum*. Microclimatic data (photosynthetic photon flux density and moss temperature) in the assimilation chamber were recorded at the same time. A simple model to estimate the net photosynthetic rate and dark respiration rate on the basis of the microclimatic data was developed on KAPPEN's model (KAPPEN *et al.*: Polar Biol., **9**, 415 1988). Net primary production of these moss colonies was calculated with the microclimatic data recorded separately at the Yukidori Valley from January 1988 to January 1989 (OHTANI *et al.*: JARE Data Rep., **152**, 1990). The estimated net production rates of moss colonies growing in the upper reaches of the Yukidori Valley ranged from 8.8 to 11.3 mol CO_2 $m^{-2}\cdot y^{-1}$, or from 230 to 296 gdw $m^{-2}\cdot y^{-1}$.

1. Introduction

Mosses are one of the main terrestrial primary producers in the Antarctic and are growing only on sandy or gravel ground where meltwater is supplied from snow or ice. Other main producers, lichens, grow on stones, rocks, cliffs or dried moss colonies. There are some micro- and meso-faunas, such as protists, rotifers, nematodes, tardigrades, mites, springtails, etc. in moss colonies, under lichen mats or under gravels. They utilize these colonies for their habitats and energy and material resources but the faunal biomass is not large because the size of most colonies is small and the distribu-

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tion of the colonies is very sparce.

It is very important to estimate the solar energy fixation (primary production) of plants for understanding the function of the Antarctic terrestrial ecosystem. It seems that the short growing period and the irregular supply of water repress the organic matter production of these primary producers. To estimate the net primary production, the measurement of photosynthesis by a ^{14}C method or a gaseous exchange method is preferable, because the weight increase or the elongation of shoots is difficult for the short growing period and short staying period.

Davis and Harrisson (1981) measured CO_2 exchange of *Polytrichum alpestre* and *Drepanocladus uncinatus* at Signy Island and they found the correlations between the net photosynthetic rates, and radiation intensities and temperature with logarithmic regression equations. Ino (1983a) measured the net photosynthesis and dark respiration of moss colonies composed of the mixture of *Ceratodon purpureus* and *Bryum pseudotriquetrum* grown in the xeric habitat of East Ongul Island, East Antarctica by the CO_2 exchange method. He estimated the primary production of them with a multiple regression equation to radiation intensity and moss temperature (Ino, 1983b).

Recently Kappen *et al.* (1989) reported some multiple regression models about photosynthetic rates (CO_2 exchange) and environmental factors with *Schistidium antarctici*. They also reported same regression models with *Ramalina terebrata* (Kapprn *et al.*, 1988), and *Usnea sphacelata* (Bölter *et al.*, 1989). These models were used mainly to estimate the responses of photosynthetic activities to irradiance intensity, thallus temperature and water content.

From 1986 to 1990, Japanese Antarctic Research Expedition (JARE-27 to -31) planned the studies of the structure and function of the terrestrial ecosystem at the Yukidori Valley in Langhovde, East Antarctica. This paper reports part of the comprehensive research and predicts the net primary production of mosses with a simple model.

2. Materials and Methods

2.1. Site

The Yukidori Valley (lat. 69°15′S, long. 39°46′E) is situated in the middle of Langhovde ice-free area, on the east coast of Lützow-Holm Bay. This valley, described in detail in Kanda *et al.* (1990), is about 3 km in length from east to west and connects with the continental ice sheet at the upper reaches. The Yukidori Valley was designated as No. 22 SSSI (Sites of Special Scientific Interest), because the valley has prominent vegetation and numerous snow petrel (*Pogodroma nivea*) nests on its cliffs in the middle reaches.

Four moss blocks about 10 cm square (P0, P1, P2, and P3 samples) were taken along the valley on 8 January 1988. P0 sample was taken from a moist *Grimmia lawiana* colony near the head of the valley. P1 and P2 samples were collected from moist colonies near Lake Yukidori, which divides the middle from the upper reaches. P1 sample was composed of *Bryum pseudotriquetrum* and *Ceratodon purpureus*, and P2 sample was *B. pseudotriquetrum*. P3 sample was taken from a moist *B. pseudotriquetrum* colony in the lower reaches.

2.2. Field measurement

Net photosynthesis and dark respiration (CO_2 exchange) of the upper green portion from each moss block were measured from 9 to 17 January in the field near the hut for biological study at Langhovde. CO_2 concentration at the entrance and the exit of the assimilation chamber (Koito Industries, MC-A3W) was measured with two infrared CO_2 gas analyzers (Horiba, VIA 300).

The air temperature in the chamber was either controlled independently of the field condition or was kept the same as the air temperature at 3 cm above the ground surface. The wet weight of the sample was held almost constant by a supply of water several times during the experiments. The relationship between the net photosynthetic rate and the water content of each sample was measured in a separate experiment back in Japan. The water content of each sample was decided after the sample was dried at 80°C in an oven in Japan. It showed that the water content of each sample in the field measurement was kept near the optimum content for net photosynthesis.

CO_2 concentration, photosynthetic active photon flux density (PPFD) and the temperature in the surface layer of the sample were recorded with a chart recorder. The method of the field measurement was described by INO (1990a).

2.3. Regression models

A non-linear multiple regression model was the same as the KAPPEN's model with a lichen species *Ramalina terebrata* (KAPPEN *et al.*, 1988). In the present experiment, CO_2 exchange (net photosynthesis and dark respiration) data and the environmental factors (PPFD and moss temperature) were obtained every 20 or 30 min from the chart records of field measurements. Hourly mean data were calculated with those every 20 or 30 min data and were used to calculate the following models.

CO_2 flux (F; μmol CO_2 m^{-2} s^{-1})-moss temperature (T; °C) and PPFD (I; μmol m^{-2} s^{-1}) model:

$$F_{T\cdot I}=p_0+p_1\times T+p_2\times T^2+p_3\times \ln(I+1)+p_4\times(\ln(I+1))^2+p_5\times T\times \ln(I+1)\,, \quad (1)$$

where p_n is the proportion of each component.

CO_2 flux (F)-water content (W; g water g^{-1} dry sample) model:

$$F_W=q_0+q_1\times W+q_2\times W^2+q_3\times W^3\,, \quad (2)$$

where q_n is the proportion of each component.

2.4. Microclimate

Microclimate was measured at three stations in the Yukidori Valley from 1987 to 1989. The first station is situated in the upper reaches (180 m in altitude), the second station, in the middle reaches (60 m in altitude) and the third station, at the mouth of the valley (10 m in altitude). Environmental factors measured at each station were PPFD, wind direction, wind speed, relative humidity, air temperature and temperature at each surface layer of wet, moist and dry moss colonies. These data were recorded in a data logger (Koito Industries, MES-801) and were collected periodically. The records from January 1988 to January 1989 were reported in the JARE Data Reports (OHTANI *et al.*, 1990).

Hourly mean microclimatic data from 18 January to 4 February 1988 at the first station are shown in Fig. 1. PPFD changed in diel course and first 0 μmol m^{-2} s^{-1},

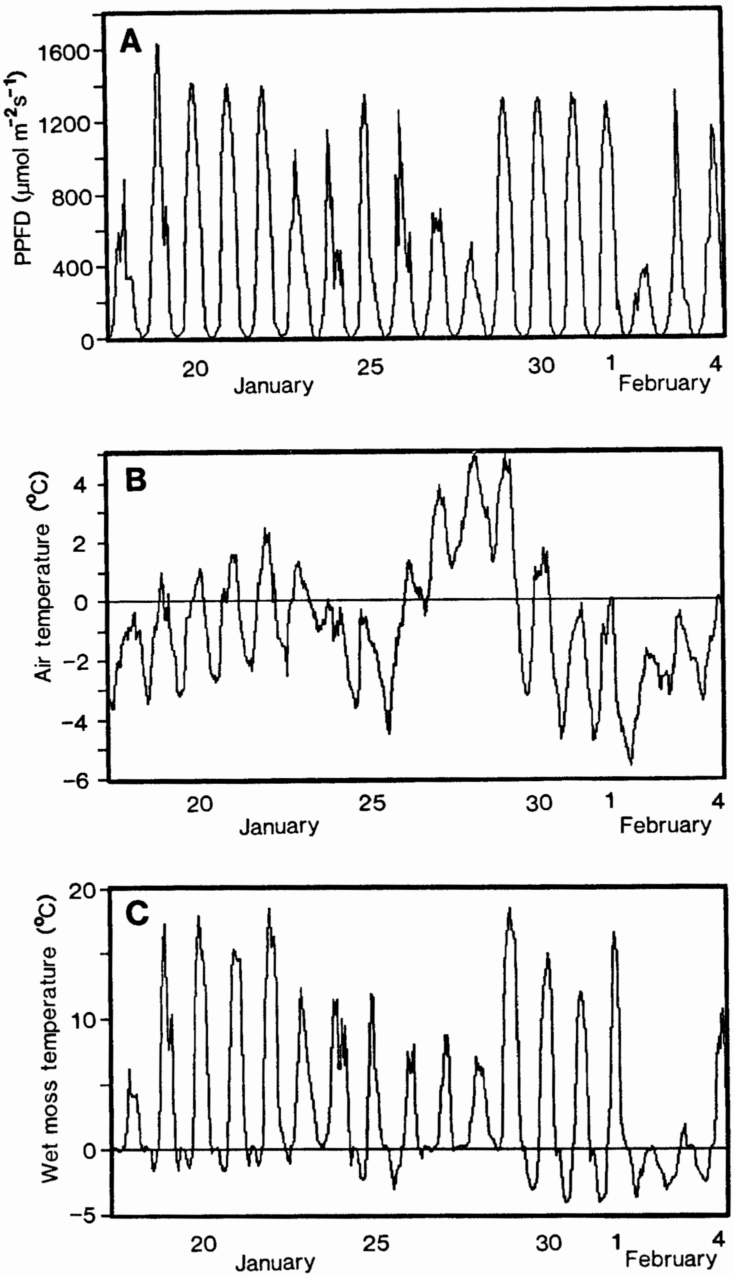


Fig. 1. Microclimate at the upper reaches in the Yukidori Valley, Langhovde, East Antarctica. First measurement by the 29th Japanese Antarctic Research Expedition (JARE-29) was take from 18 January to 4 February, 1988 (OHTANI et al., 1990). (A) Photosynthetic active photon flux density (PPFD), (B) Air temperature, (C) Wet moss temperature.

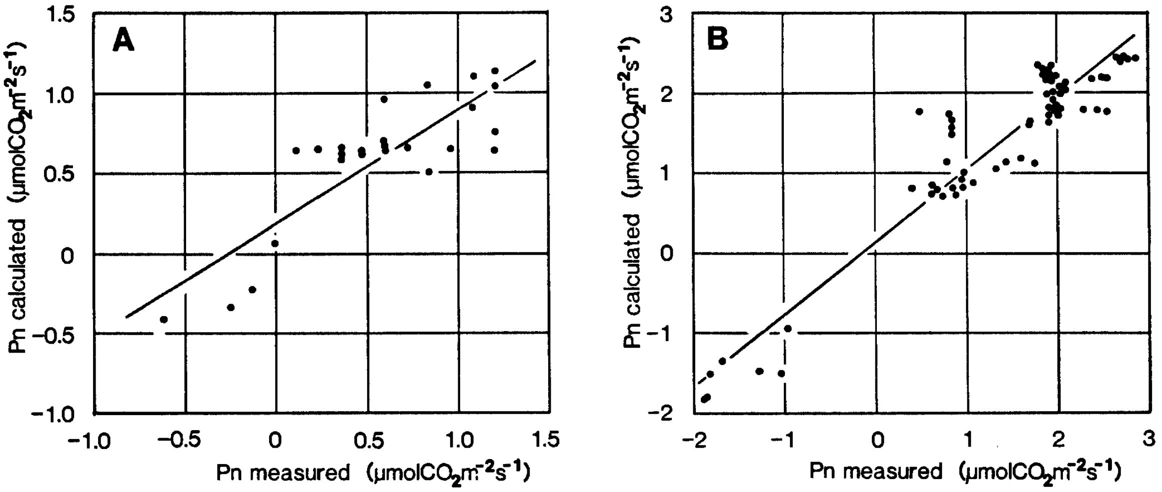
i.e., dark night, was recorded on 31 January. Air temperature on 28 January did not fall below freezing point and the maximum temperature was higher than 5°C. The diel fluctuation of moss temperature was very large and the difference between the highest and the lowest often became nearly 20°C. The minimum temperature of the wet moss colony frequently fell lower than 0°C and the maximum instantaneous temperature rose above 20°C (OHTANI *et al.*, 1990). The surface temperature of moss colonies was much higher than the air temperature. The diel change of relative humidity was not clear.

2. Results and Discussion

3.1. *Regression models*

Figure 2 shows the relationships between the measured net photosynthetic rates and the calculated rates based on the regression equations. The calculated rates with the equations corresponded to the measured rates in P1 and P2 samples (r=0.942 and 0.957, respectively), but in P0 sample the calculated rates did not correspond as well to the measured rates (r=0.841). The regression equation about P3 sample was not developed, because it was measured at a constant temperature to estimate the relationship between the net photosynthetic rate and the water content.

Net photosynthetic rates in P0, P1 and P2 samples were calculated with each regression equation (eq. 1). The relationships between the calculated rate and radiation intensity at different moss temperature are shown in Fig. 3. Net photosynthetic rates were not saturated at 1500 μmol m^{-2} s^{-1}. In P1 and P2 samples, the rates at



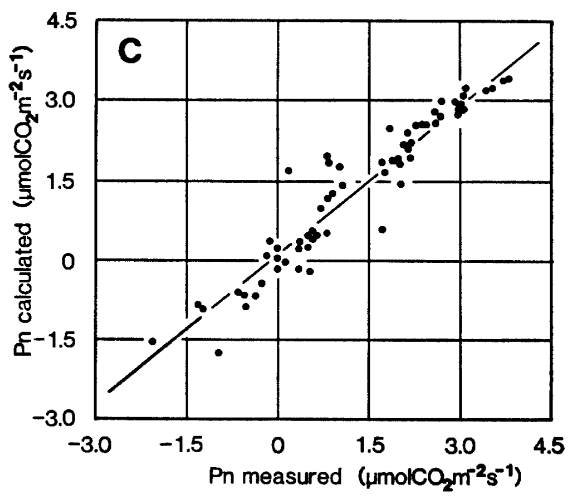


Fig. 2. Relationships between the calculated net photosynthetic rates (Pn calculated) and the measured rates (Pn measured) in P0, P1 and P2 samples. (A) P0 sample (Grimmia lawiana colony), (B) P1 sample (Bryum pseudotriquetrum and Ceratodon purpureus mixed colony), (C) P2 sample (B. pseudotriquetrum colony).

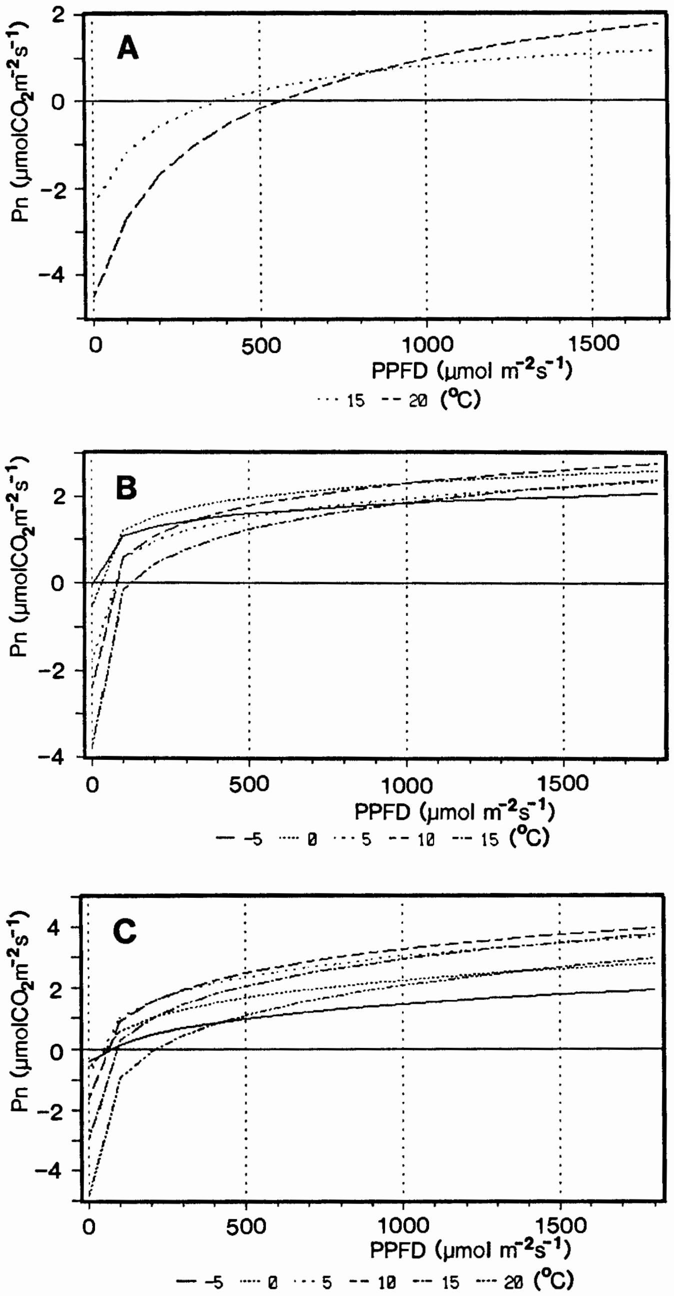


Fig. 3. Net photosynthetic rate (Pn) at different PPFD and moss temperature conditions calculated with the regression models. (A) P0 sample, (B) P1 sample, (C) P2 sample.

10°C were maximum at high radiation intensity, but in the P0 sample the rate at 20°C was higher than that at 15°C, and high radiation intensity. At low radiation intensity, net photosynthetic rate of P0 was high at low moss temperature.

3.2. Calculation of net photosynthesis of a moss colony in the upper reaches

Net photosynthetic rates of P0, P1 and P2 samples from 18 January to 4 February were calculated by the models with the microclimatic data in the upper reaches. The calculated rates changed in a diel course and they are shown in Fig. 4. In the P0

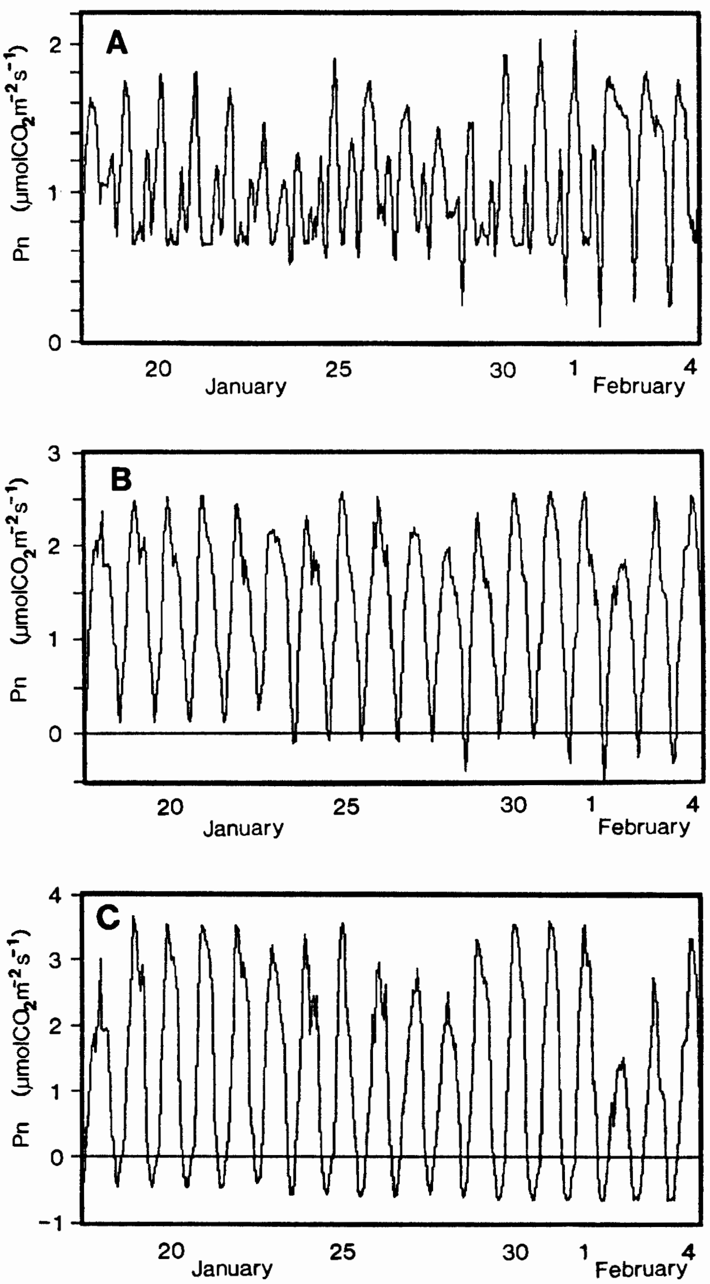


Fig. 4. Net photosynthetic rates (Pn) of P0 (A), P1 (B) and P2 (C) samples from 18 January to 4 February. These rates were calculated with the regression models.

sample, two peaks were recognized in a day, because high temperatures in the daytime suppressed net photosynthesis. The maximum of the calculated rates in P0, P1 and P2 samples was 2.1, 2.6 and 3.7 μmol CO_2 m^{-2} s^{-1}, respectively.

Diel amount of net photosynthesis was calculated by the summation of the hourly mean rates and the amounts in the period from 18 January to 3 February are shown in Table 1. P0 sample fixed CO_2 at the rate of 0.075 to 0.117 mol CO_2 m^{-2} d^{-1} (mean; 0.092 mol CO_2 m^{-2} d^{-1}), and P1 and P2 samples had the rates of 0.096 to 0.128 and

Table 1. Calculated rates (mol CO_2 m^{-2} d^{-1}) of the net photosynthesis of mosses at the upper reaches in Yukidori Valley, Langhovde.

Date		Sample		
		P0	P1	P2
January	18	0.102	0.121	0.096
	19	0.092	0.128	0.129
	20	0.086	0.120	0.127
	21	0.087	0.122	0.126
	22	0.085	0.117	0.125
	23	0.082	0.134	0.127
	24	0.076	0.113	0.115
	25	0.095	0.118	0.102
	26	0.103	0.121	0.095
	27	0.095	0.115	0.097
	28	0.085	0.101	0.084
	29	0.075	0.105	0.122
	30	0.090	0.119	0.115
	31	0.094	0.125	0.114
February	1	0.094	0.118	0.107
	2	0.117	0.096	0.036
	3	0.113	0.107	0.061
Mean		0.092	0.116	0.105

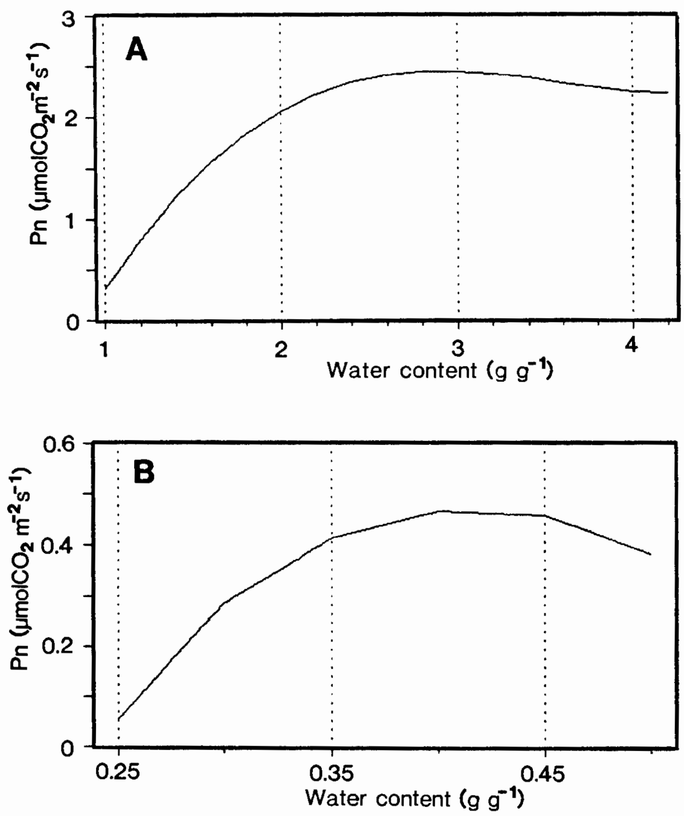


Fig. 5. Relationships between the net photosynthetic rates (Pn) and the water content of P1 (A) and P3 (B) samples calculated with the regression models.

0.036 to 0.129 mol CO_2 m^{-2} d^{-1} (mean; 0.116 in P1 and 0.105 mol CO_2 m^{-2} d^{-1} in P2), respectively.

3.3. Net photosynthesis in different water contents

The regression equations (eq. 2) between the net photosynthetic rate and the water content had a high correlation coefficient (r=0.964 in P1 sample and 0.935 in P3 sample). Figure 5 shows the relationship between the net photosynthetic rate and the water content in P1 and P3 samples. In the P1 sample, the optimum water content for the net photosynthesis was estimated at about 3 g g^{-1} and the net photosynthetic rate became 0 at about 0.9 g g^{-1} of water content. The optimum content was about 0.4 g g^{-1} in the P3 sample and the net photosynthetic rate dropped rapidly in the range higher than 0.5 g g^{-1}. The difference between the optimum water contents in two samples was caused by the difference in the amount of sand particles included in the sample block. The rate of CO_2 exchange in different water contents is decided by the diffusion resistance of CO_2 gas and the water deficit of protoplasm (DILKS and PROCTOR, 1979).

This relationship was not used in estimation of the net production, because the long-term measurement of the water content of moss colony was not carried out at Langhovde. Therefore, if there was a long xeric period in the growing season, it is guessed that the calculated amount of net production was overestimated.

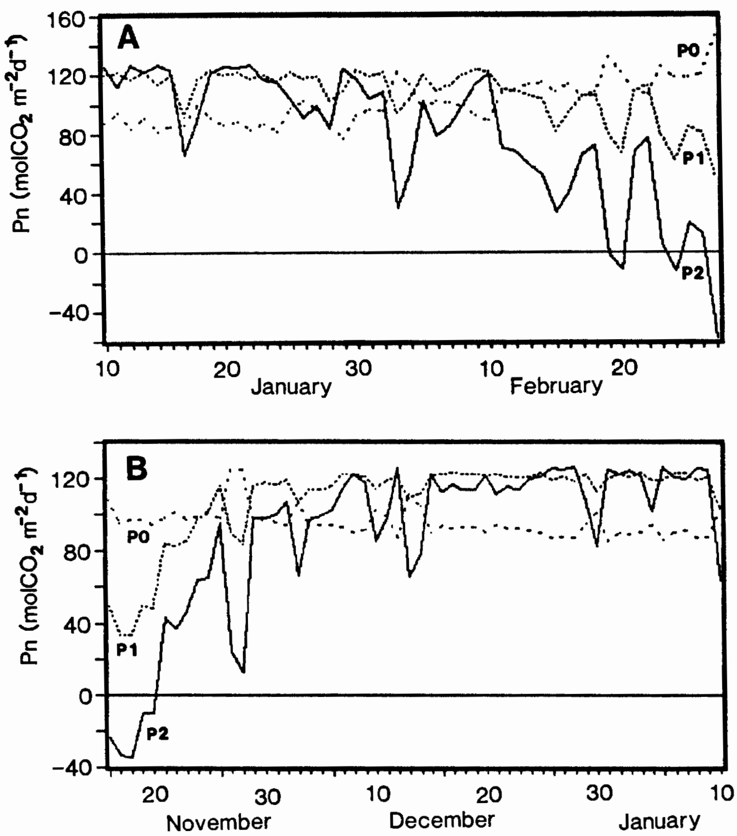


Fig. 6. Diel net photosynthetic rates (Pn) of P0, P1 and P2 samples in the periods from 10 January to 27 February 1988 (A) and from 16 November 1988 to 10 January 1989 (B).

3.4. Calculation of net primary production

The net primary production of P0, P1 and P2 colonies in the 1988 growing period was estimated with each multiple regression equation. The relationship between diel net photosynthesis and daily cumulative PPFD (the sum of hourly mean PPFD) and daily cumulative wet moss temperature (the sum of hourly mean temperature) from 18 January to 4 February was calculated. The multiple correlation coefficient of each regression equation was very high (r=0.981, 0.933 and 0.988 in P0, P1 and P2 samples, respectively).

Diel net photosynthesis of the moss colony in wet conditions in the upper reaches from 10 January 1988 to 9 January 1989 was calculated with the regression equations and microclimate data at the Yukidori Valley. The net production rate became negative from March to October. In March, PPFD was over 500 μmol m^{-2} s^{-1} sometimes, but moss temperature remained below freezing.

From April to October, the moss community was covered with snow. Therefore, it is assumed that the physiological activities of mosses stopped during that period. After the middle of November, diel net photosynthesis changed to a positive rate. At that time the moss temperature was low, but the day became longer and PPFD was often over 1000 μmol m^{-2} s^{-1}.

The result is shown in Fig. 6. The primary production rate in P0 sample did not correspond well during the seasonal change of environment. It appears that the cause was the low correlation coefficient between the measured net photosynthetic rate and the calculated rate with eq. (1). The total net production in the two periods from 10 January to 27 February and from 16 November to 9 January amounted to 8.8, 11.3 and 10.3 mol CO_2 $m^{-2}\cdot y^{-1}$ in P0, P1 and P2 samples, respectively. If the carbon content in the green part of the moss colony is 46% (NAKATSUBO and INO, 1986), each amount corresponds to 230, 296 and 269 gdw $m^{-2}\cdot y^{-1}$. These amounts are calculated under the favorable moisture condition.

Net primary productions of two moss communities in Signy Island were 409 gdw $m^{-2}\cdot y^{-1}$ (in range, from 321 gdw to 497 gdw $m^{-2}\cdot y^{-1}$) and 392 gdw $m^{-2}\cdot y^{-1}$ (in range, from 226 gdw to 548 gdw $m^{-2}\cdot y^{-1}$), respectively (DAVIS, 1981). The production rate at the Yukidori Valley corresponds to the lowest rate in Signy Island. In the continental part, the rate, 3 gdw $m^{-2}\cdot y^{-1}$, under unfavorable water conditions, was reported (INO, 1983b).

The next step to study is how the energy fixed by mosses flows into other components of the ecosystem.

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