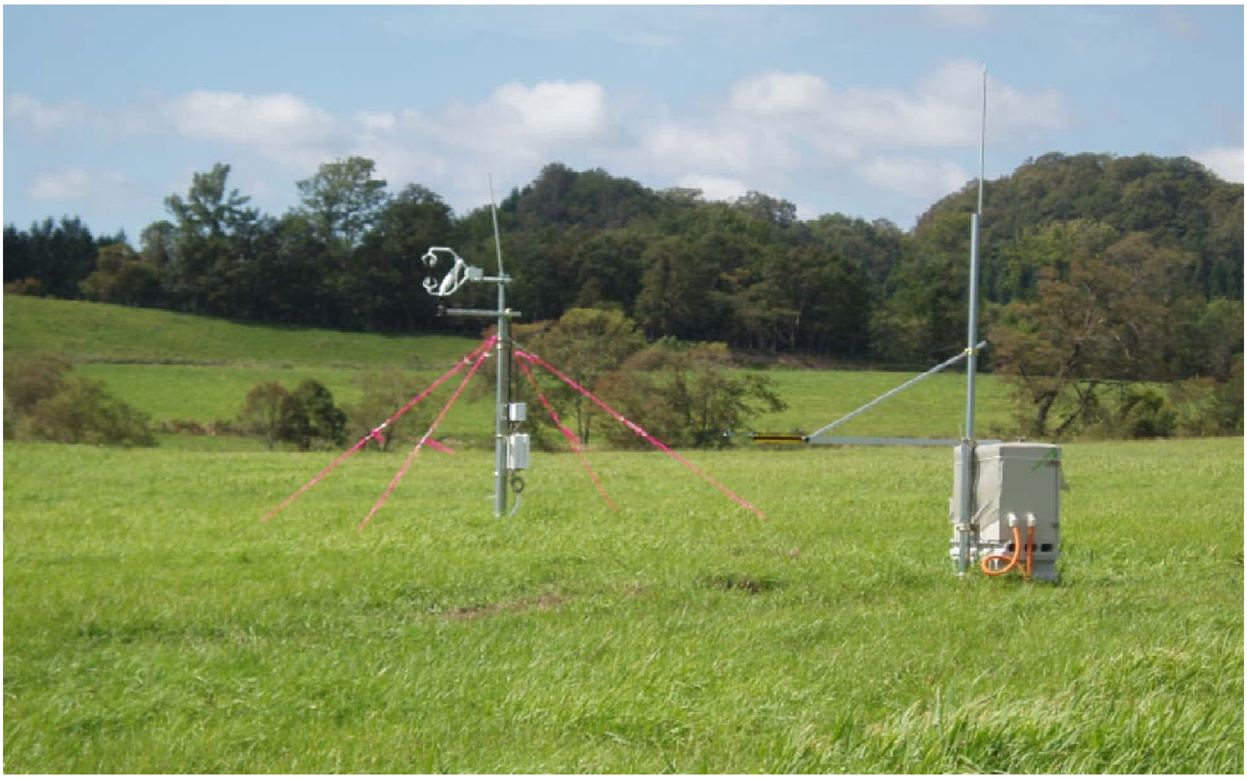
Japan Racing Association
Special Promotion Foundation
Support Project

Research Project Report "Establishment of good practices to mitigate greenhouse gas emissions from Japanese grasslands"



（Measuring CO_2 by an eddy-covariance method）

OCTOBER　2008

Japan Grassland Agriculture and Forage Seed Association

Foreword

There have been attempts to improve the productivity of large livestock production by expanding processing-type livestock husbandry, supported by comparatively low-cost imported feed in Japan. However, the processing-type livestock husbandry that depends on the imported feed is causing diverse issues such as environmental problems due to livestock waste, and it is important to make an effort in promotion of large livestock production based on self-feeding in the future.

A scheme of promoting measures for global warming aiming at achieving the goals of the Kyoto Protocol was developed in Japan in March 2002. In this scheme, promotion of the present measures for maintenance and management of grassland were added in order to control the emissions of carbon dioxide, methane and nitrous oxide in non-energy fields. Promotion of livestock manure application to grassland was submitted as a new policy. In addition, the Ministry of Agriculture, Forestry and Fisheries (MAFF) implemented the "Basic principles of environmental policy in agriculture, forestry and fisheries" in December 2003, to promote a policy aiming for a sound atmospheric environment. This included development of technology for controlling the emission of greenhouse gases, together with the thorough and proper management of livestock wastes. On the basis of such condition, through the new "Basic plan for food, agriculture and farm village" the cabinet meeting in March 2005 proclaimed a major shift in agriculture, forestry and fisheries that valued environmental conservation, aiming to maintain and improve the natural cycling function of agriculture together with demonstrating multiple functions.

A plan for concrete reduction measures to the agricultural sector was not presented at the greenhouse gas reduction target prescribed by the Kyoto Protocol, but a review was scheduled in 2007. An agricultural measure for this has already been explored in EU nations. Moreover, in the second commitment period after 2012, reporting an obligation of greenhouse gas budgets with respect to the agriculture sector is expected.

Internationally it is reported that there is no representative data on the C budget for Japanese grasslands. This is because the scientific data concerning the greenhouse gas budget according to grassland management in Japan is extremely rare, and even internationally, there is a situation of very low influence. The reason for this is that it is not only concerning the grassland, but it also includes arable lands and forests; it is comparatively recent that the measurement of greenhouse gases in a terrestrial ecosystem that includes arable lands and forests was begun, and there is little accumulation of highly reliable data with long-term observation. Also, the impact of using livestock manure on the generation of greenhouse gases from grasslands has not been measured on a real scale level.

This research project was initiated to gather scientific findings aiming to establish grassland management techniques corresponding to the mitigation technology for greenhouse gas emission. This report presents results of a research project on measuring greenhouse gases from 2004 to 2006. It was conducted on grasslands of four sites throughout Japan, by setting up chemical fertilizer and manure application plots, for which the Japan Grassland Agriculture and Forage Seed Association received a sponsorship from the Japan Racing and Livestock Promotion Foundation. It is anticipated that these achieved results could be utilized as basic information to revise the "Grassland management index".

The index was prescribed for proper management and utilization of grasslands that were developed and maintained by the grassland development and management project. It is also expected that it could be useful for enhancing measures for the prevention of global warming in the agricultural sector that is aimed at achieving the commitment for reduction of the total amount of greenhouse gas emission as directed by the Kyoto Protocol.

March 2007
Corporate Japan Grassland Agriculture and Forage Seed Association

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Outline of the results with respect to a research project on “Establishment of good practices to mitigate greenhouse gas emissions from Japanese grasslands”

Outline of the results with respect to a research project on “Establishment of good practices to mitigate greenhouse gas emissions from Japanese grasslands”

Japan Grassland Agriculture and Forage Seed Association received a sponsorship from the Japan Racing and Livestock Promotion Foundation, and conducted an investigation on uptake and emission of greenhouse gases from 2004 to 2006 on the grasslands of four sites through out the country. Following are the conclusions obtained from the investigation results:

- The use of compost manure in the grasslands of Japan has a mitigating effect on global warming. The effect is especially high in the cold region.
- Although global warming is contributed to by the conventional cultivation of paddy and upland fields, grassland has a small effect or in some situations actually mitigates global warming.

The result outline is introduced as following.

1. Investigation background

The livestock production of our country has been attempting to improve productivity by processing-type livestock husbandry supported by a huge import of feed. However, the processing-type livestock husbandry is causing various environmental problems. Since the Kyoto Protocol to the United Nations Framework Convention on Climate Change came into effect in February 2005, and the development of measures technology for controlling the global warming has been an urgent issue.

The proper management of livestock excreta is crucial because it might become a source of greenhouse gases such as carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4). Especially regarding the milk and beef cattle farming, an effective use of compost manure and expanding the self-supported feed production based on improved natural cycling function become effective measures technology in preventing the global warming. However, the impact of reducing compost manure to the grassland on the budgets of greenhouse gases was not apparent at the real scale level.

2. Investigation methods

1) Setting up experimental plots

We measured greenhouse gases from 2004 to 2006 at four sites of cool season-type grasslands in Nakashibetsu and New Hidaka Shizunai Towns in Hokkaido, Nasushiobara

City in Ibaraki Prefecture, and Kobayashi City in Miyazaki Prefecture (Figure 1). Greenhouse gasses were measured at each site by setting up two experimental plots using both compost manure and chemical fertilizer (compost manure plot) in one and only chemical fertilizer (chemical fertilizer plot) in the other. The amount of compost manure applied to compost manure plots was set to the amount that did not exceed the upper limit of the recommended amount of nitrogen, potassium, and phosphorus, and the insufficient nutrient was supplemented with chemical fertilizer.

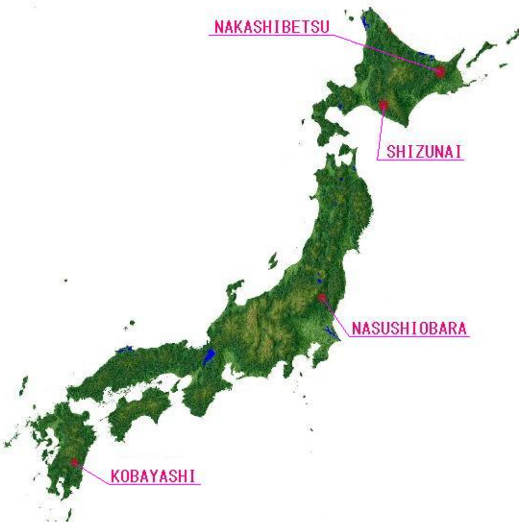

Figure 1 Location of monitoring sites.

2) Measurement of greenhouse gases

Major greenhouse gases in grasslands are CO_2, CH_4, and N_2O. The relationship between emission and uptake of these gases is illustrated in Figure 2. The uptake source of CO_2 is pasture, and the source of emission is organic matter (compost manure, soil organic matter, and dead plant body). The difference in uptake of CO_2 due to the growth of pasture and CO_2 emission due to the decomposition of organic matter is the net CO_2 absorbed from the atmosphere and the amount of carbon of this budget is called net ecosystem production (NEP) (The positive value of NEP indicates that grasslands absorb net CO_2 from the atmosphere). The uptake and emission of CO_2 was measured by an eddy-covariance method and the uptake and emission of CH_4 and the emission of N_2O were measured by chamber method (Photograph).

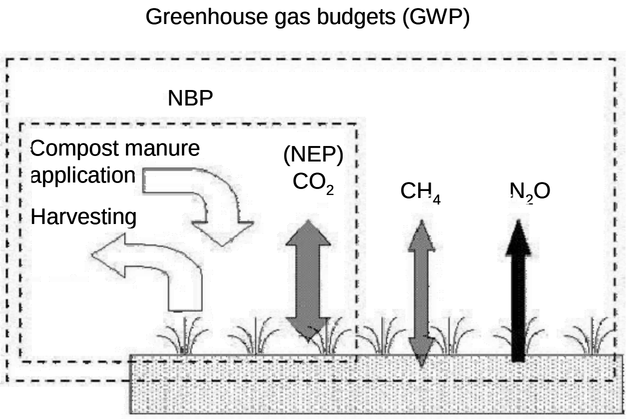

Figure 2 Components of greenhouse gas budgets for grasslands.

3) Method of calculating global warming potential

A carbon budget for grassland is expressed by the harvested carbon content subtracted from a sum of NEP and applied carbon content by compost manure because the amount of carbon on grassland is taken out by harvest and is supplied by applying compost manure.

Photograph. Measuring CO_2 by an eddy-covariance method (left) and CH_4 and N_2O by a chamber method (right)

This is called net biomass production (NBP) (The positive value of NBP indicates that grasslands can actually function as a CO_2 sink). Furthermore, N_2O is emitted by chemical fertilizers and organic matters of compost manure etc. CH_4 is taken up by soil micro-organisms and is emitted by organic matters of compost manure etc. Here, the budget of N_2O and CH_4 is added to that of CO_2, and an index that evaluates the effect of global warming is called global warming potential (GWP). When assuming the global warming effect of CO_2 equivalents to one, CH_4 and N_2O become 23 and 296 times, respectively, and GWP is calculated by considering difference in these effects. The positive value indicates the enhancement of global warming while the negative value indicates mitigation. The net emission of CH_4 and N_2O was calculated by the measurement using a chamber method (photograph).

3. Results

1) Net uptake of CO_2 from atmosphere by grassland (NEP)

(1) A detailed measurement of temporal variation in NEP was carried out by a continuous observation following an eddy-covariance method (Figure 3). The NEP of compost manure plot was smaller than that of chemical fertilizer plot in all investigation sites.

(2) The seasonal change in NEP from spring to autumn period increased with the re-growth after grass harvesting in both compost manure and chemical fertilizer plots in each investigation site (Figure 3). However, although there was a small absolute value and variation range of NEP for Shizunai and Nakashibetsu Towns during the winter and there was no obvious change in days, CO_2 was taken up during the day time and was emitted during the night time in Nasushiobara. In addition, absorption of CO_2 was observed even during the winter at Kobayashi, which corresponded with summer in other investigation sites.

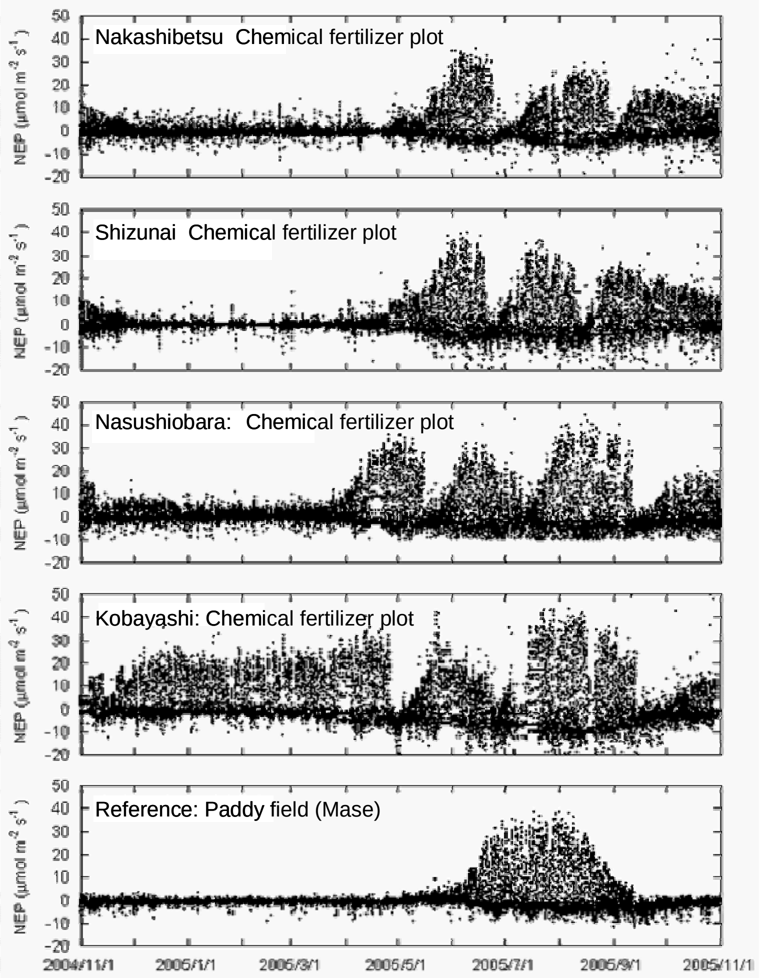

Figure 3 Seasonal variation in NEP of various study sites. (The positive value indicates CO_2 uptake by grassland while the negative value indicates CO_2 emission. For the purpose of comparison, the reference of NEP measured in the same period was taken from a paddy field of Mase, Tsukuba City in Ibaraki Prefecture.)

(3) There was a positive NEP value for seven months also in Nakashibetsu town where the growth period is short, and CO_2 was absorbed over a long period. Moreover, because the maximum value of NEP also showed the same degree of the value as the rice field in Ibaraki Prefecture, the amount of absorbed CO_2 was obviously higher in grassland than that in paddy field (Figure 3).

2) Mitigating global warming effect of grassland by applying compost manure

(1) The compost plots had the negative value of GWP for all regions and the use of compost manure was able to mitigate the global warming (Table 1).

(2) The pattern of effect on GWP was highest for NBP followed by N_2O, and that for CH_4 was the lowest (Table 1).

(3) The GWP was influenced by annual mean temperature and the duration of sunshine during the growing period. In chemical fertilizer plots, the global warming was enhanced by becoming the GWP value positive when the duration of sunshine was below 1000 hours and the annual mean temperature was below 10°C (Figure 4). Although the grassland in warm regions had the effect of mitigating global warming even not applying compost manure, global warming could be enhanced when the

productivity of grasslands decreases due to the shortage of sunshine. On the other hand, global warming cannot be mitigated without applying compost manure in the grassland of cold regions.

Table 1 Global warming potential (GWP) in regions

Region	Year	GWP (Mg CO_2eq ha^{-1} y^{-1})							
		Compost manure plot				Chemical fertilizer plot			
		GWP components			GWP	GWP components			GWP
		NBP	CH_4	N_2O		NBP	CH_4	N_2O	
Nakashibetsu	2005	-13.1	-0.01	0.3	-12.8	3.3	-0.02	0.1	3.4
	2006	-12.9	0.00	0.9	-12.0	-0.4	0.01	0.2	-0.2
Shizunai	2005	-19.0	0.01	1.8	-17.2	2.7	0.01	1.3	4.0
	2006	-20.6	0.00	2.3	-18.3	-2.6	0.00	1.3	-1.3
Nasushiobara	2005	-8.6	-0.02	3.3	-5.4	-6.7	-0.03	2.2	-4.5
	2006	-6.7	0.00	5.1	-1.6	0.8	-0.02	4.2	5.1
Kobayashi	2005	-6.5	-0.01	5.3	-1.2	-5.5	-0.01	0.9	-4.6
	2006	-17.7	-0.01	2.5	-15.3	-4.8	-0.01	1.4	-3.4

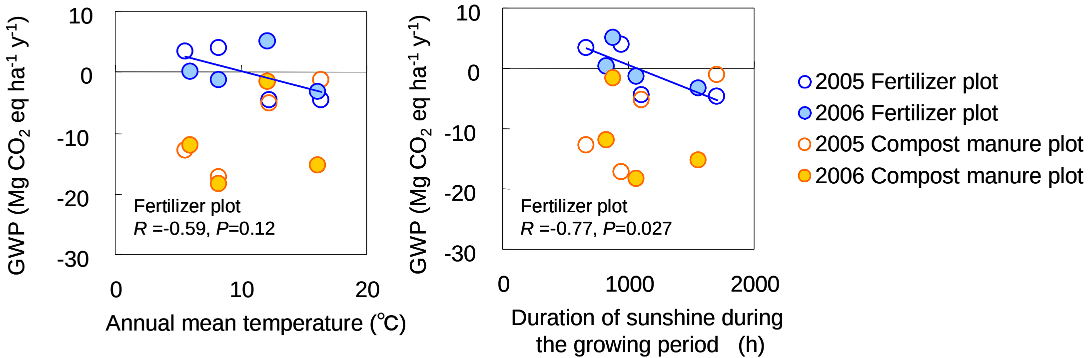

Figure 4 The relationship between global warming potential (GWP) and (left) annual mean temperature, (right) duration of sunshine during the growing period.

(4) The harvested carbon content and NEP increased because of an increase in application of nitrogen (Figure 5). This effect was higher in warm regions than in cold regions.

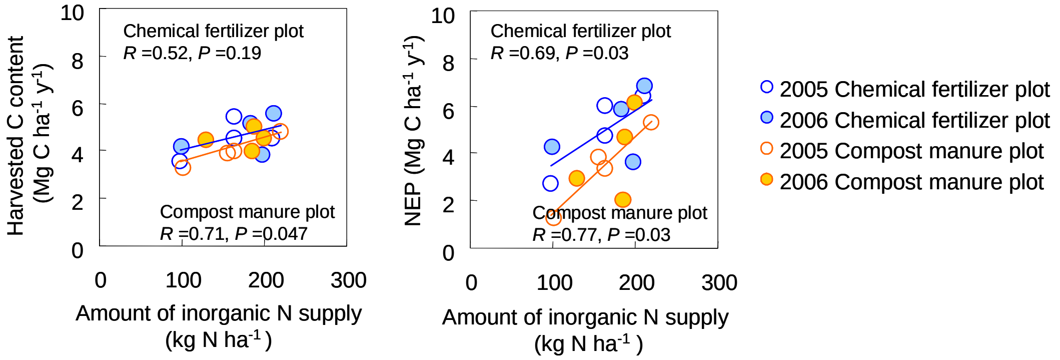

Figure 5 The relationship between the amount of inorganic N supply and (left) the harvested carbon content, (right) net ecosystem production (NEP).

(5) From the results of 3) and 4), the global warming mitigation effect can be expected to be further improved by raising the productivity after renewing the grassland of low productivity in warm regions. However, it would be necessary to carry out further research on the pattern of its effectiveness in the future.

(6) A comparison among some examples of the measured values of GWP of paddy and upland fields in Hokkaido showed that global warming was enhanced due to CO_2 and N_2O emissions from upland field in Hokkaido, although CO_2 was fixed in and CH_4 was emitted from paddy fields in Hokkaido, and only the grassland supplied with compost manure in this study showed the mitigation of global warming (Figure 6). The use of compost manure was found to be an effective technique to mitigate the global warming especially in the cold region. However, since the use of compost manure is increasing the emission of N_2O, its mitigation method should be the subject of further research in the future.

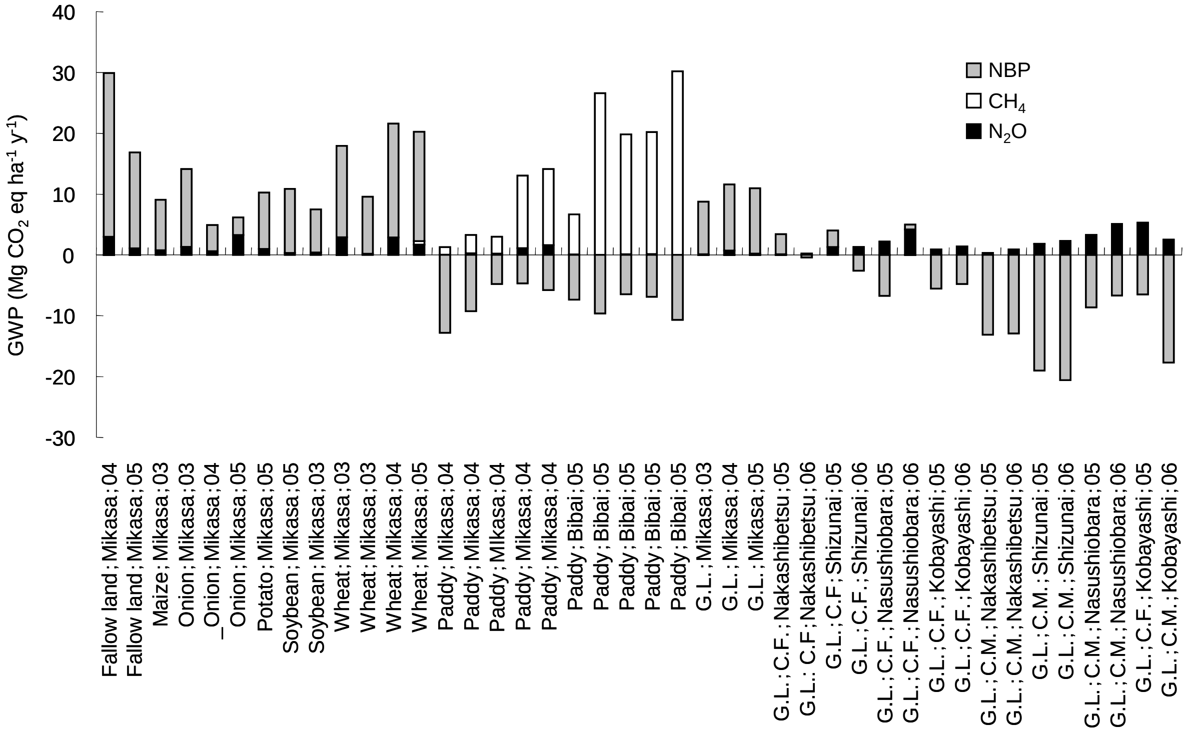

Figure 6 Comparison among the documented values of GWP for various land uses of Hokkaido and the measured values of this study. NBP of the documented value was measured by an ecological technique. Note: C.F., C.M. and G.L. stand for chemical fertilizer, compost manure and grassland, respectively.

Chapter 1. Outline of the initiation of this research project

1.1 Purpose of the research project

The "Basic principles of environmental policy in agriculture, forestry and fisheries" were decided in December 2003, and focused on the measures of aiming to shift the agriculture, forestry and fisheries industry to respect environmental conservation and exercise a natural cycling function of the agriculture, forestry and fisheries industry. Regarding the grassland, immediate establishment of a management system corresponding to problems of an increase in N and greenhouse gases, such as carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) resulting because of the application of organic resources such as livestock waste, is crucial, especially, in the case of greenhouse gases. However, it is necessary to understand the status-quo of the emission and uptake of greenhouse gases in grasslands, because there is a situation in which long term, holistic and accurate evaluations are not performed because there have been no greenhouse gas observation sites with references to grasslands in Japan. Moreover, since there is a condition of no scientific data on the influence of manure fertilization of livestock waste on greenhouse gas emissions, it is necessary to promptly carry out a study.

In order to contribute to the establishment of an environment-friendly grassland management system by considering such circumstances, a research project that aims to understand the actual situation of emission and uptake of CO_2 and other greenhouse gases in grasslands, and is considered to contribute to the promotion of livestock husbandry has been conducted.

1.2 Implemented items

From a research fund for environment-friendly grassland management, the following two items were implemented from 2004 to 2006:

(1) Establishment of committees for exploring the promotion of environmental conservation

The establishment of an Environment Conservation Promoting Committee and an Environment Conservation Working Committee that consisted of people from an academic background was begun, and some other activities such as exploration and research were conducted efficiently.

(2) Measurement of greenhouse gases

In order to clarify the effect of mitigation of greenhouse gas emission from grassland, CO_2, CH_4 and N_2O fluxes were measured with flux measurement devices. This was done by setting up fields with conditions suitable for the study, such as having a low influence on the surrounding environment and uniformity in soil characteristics.

1.3 Implementation system

Figure 1.1 shows the system of implementing this project and a flow chart of the study measurement. The observation sites were selected in 2004 by ensuring a proper representation of Japanese grasslands through a prior field survey of grasslands that met the measurement requirements. A total of four observation sites were selected among which two sites are located on Hokkaido Island, which possesses the largest grassland area in Japan, and one site each on Honshu and Kyushu Islands. Grasslands in Hokkaido Prefectural Konsen Agricultural Experiment Station and Hokkaido University Shizunai Livestock Experiment Farm on Hokkaido Island were selected. On Honshu Island, grassland in the National Institute of Livestock and Grassland Science, Nasu Research Station located at Nasushiobara City, Ibaraki Prefecture was selected as a representative site, in the central region of Japanese grassland. On Kyushu Island, grassland in the National Livestock Breeding Center, Miyazaki Station, located at Kobayashi City, Miyazaki Prefecture was selected to represent grasslands distributed in the warm temperate region. Miyazaki University (Division of Grassland Science, Faculty of Agriculture) took charge of the observation site in Miyazaki Station.

Chemical fertilizer and livestock manure plots were set up to be parallel in each site. Not only CO_2 but CH_4 and N_2O were also taken as measurement items, aiming for comparative measurement. Therefore, data with high accuracy was obtained by executing common observation items and analysis methods at the same time, and also by using eight observation system devices of the same model for all sites. The use of an eddy-covariance method was recently developed, in which high specialty is required for data processing using an equation of higher degree precision for data analysis. Therefore, attempts were made for accuracy improvement of data analysis, by organizing training workshops from 2004 to 2005. In addition, uniform management was performed by establishing a data acquisition system at each site to efficiently process the huge data that showed changes every hour.

An Environment Conservation Promoting Committee was formed to perform an objective evaluation examination of the advisory direction and achieved results. Moreover, sound observation sites and measurement methods were decided by the Environment Conservation Working Committee (Appendix-3), based on the exploration policy of the Environment Conservation Promoting Committee. The achieved results were examined by the Working Committee each year, together with the study measurements conducted from the latter half of 2004 to 2006 (based on the promotion system that had been set up in 2004). Those results were examined by the Environment Conservation Promoting Committee, followed by an evaluation, and were reflected in the study measurement in the following year.

1.4 Outcomes

1) Preparation of progress reports

(1) A compiled document concerning the measurement methods including the eddy-covariance method, and the survey and data analysis methods for greenhouse gas emissions were published in March 2005.

(2) The result of study measurements obtained from 2004 to 2005 with references to environment-friendly grassland management was published in March 2006 as a mid-term progress report.

(3) The result of study measurements obtained from 2004 to 2006 with references to environment-friendly grassland management was published in March 2007 as a final progress report.

2) Progress reports presented in international conferences such as the Asia Flux Network

The result with respect to greenhouse gas budgets obtained in this study was offered as one of the performance targets of this project and the information was provided to the Asia Flux Network. The evaluation of multiple functions of the grassland in the temperate monsoon zone is supposed to be obtained. In order to achieve this target, the following activities were carried out.

(1) Five progress reports of the study's results of this project were submitted to Asia Flux International Conference and the associated international conferences from 2005 to 2006 (Refer to the list of outcomes).

(2) The outline of the implementation of this project was introduced to the homepage of Asia Flux (newsletter) in English in March 2006 (Refer to the list of outcomes).

3) Progress reports presented in national conferences

Ten reports on the results of greenhouse gas budgets for the grasslands of this project were presented to Japanese Society of Soil Science and Plant Nutrition from 2005 to 2007 and an evaluation of multiple functions of grasslands in Japan was obtained (Refer to the list of outcomes).

4) Website development

To make the content of the activity of this project available to the general public, a GHGG-Japan website （http://www.ghgg-japan.net/） has been developed (Figures 1.2 and 1.3). The main content of the web site is an introduction of this study project, information on each observation site and connected pages to the database. Each page can correspond to both Japanese and English, and was made possible to disseminate information worldwide.

In the introduction page of this study project, the purpose of the study, the system and organization that have promoted this study and the outline of the study have been described. In the information page of each observation site, ecosystem features, measurement items and detailed information on the devices used have been described. The information page of each site is the same as the format of the observation site information page on the website of Asia Flux (Flux Network in the Asian Region). This is to contribute to the construction of a worldwide flux network and to bear in mind the registration of four observation sites of this study as the observation sites of the Asia Flux. A database and the connected pages are described later.

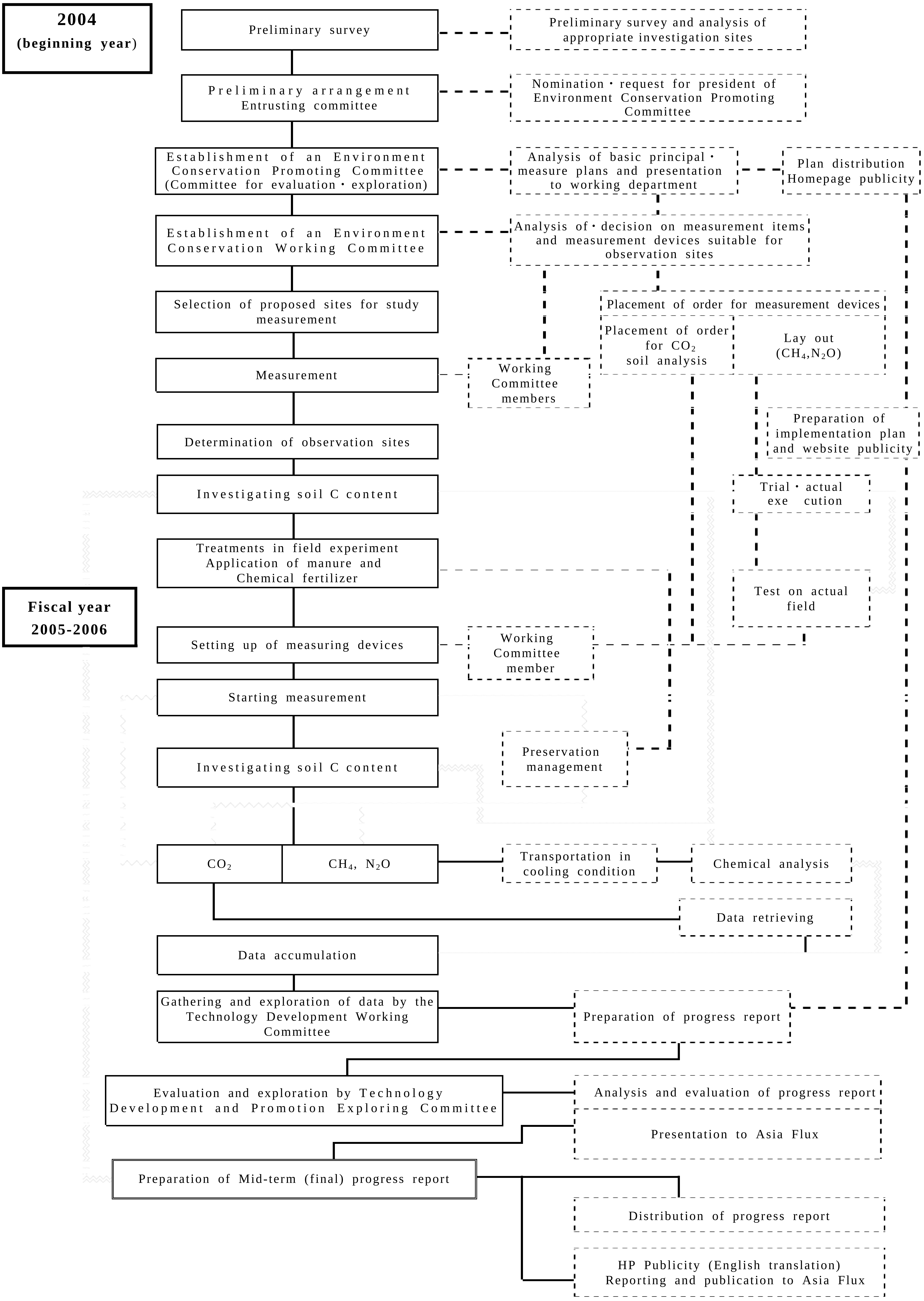

Figure 1.1 Flow of forming a Research Project Committee, its operations, field measurement, etc with respect to environment-friendly grassland management.

環境に配慮した草地管理に係わる調査事業について

- ホーム

観測サイト情報

- 1.北海道中標津町
- 2.北海道静内町
- 3.栃木県那須塩原市
- 4.宮崎県小林市

データベース

- グラフ
- ダウンロード

- 本調査の推進組織
- リンク

渦相関法によるCO₂フラックスの観測　　全国4か所の観測地

調査事業の目的

わが国の家畜生産は、膨大な輸入飼料に支えられた加工型畜産によって、生産性の向上を図ってきました。しかし、加工型畜産方式ではわが国の農地に還元できない大量の家畜ふん尿が国内に排出されるため、さまざまな環境問題を生んでいます。とくに平成17年2月には気候変動枠組み条約京都議定書が発効し、温暖化防止に向けた対策が緊急の課題となっています。

家畜ふん尿は二酸化炭素、亜酸化窒素、メタンなどの温室効果ガスの発生源になる恐れがあり、その適正管理を徹底しなければなりません。とくに乳・肉牛の飼養においては、堆肥を有効に活用し、自然循環機能を増進させた自給飼料生産を拡大させることが温暖化防止

Figure 1.2　A part of the top page of the GHGG-Japan website.

5) Preparation of database

The database was prepared where measured and collected data in this project could be registered, and which aimed at disseminating the observation results of this research project to flux researchers worldwide to contribute to the promotion of the flux research and the preparation of a flux database. The eddy-covariance data of each site and the relating meteorological data were collected and added to the database. Connection with the database can be performed by introducing the Client Tool software distributed to the Research Working Committee and the person-in-charge of the project who performs the observation and data processing, or introduces the database connection page of the GHGG-Japan website.

Access to the database by the manager for publicity makes observation and downloads of the graph data possible. It is necessary to provide a user ID and password. These are issued from the database administrator after application in order to access the database from the website. Neither the user ID nor the password has been issued to the public because the observational data still has not been published.

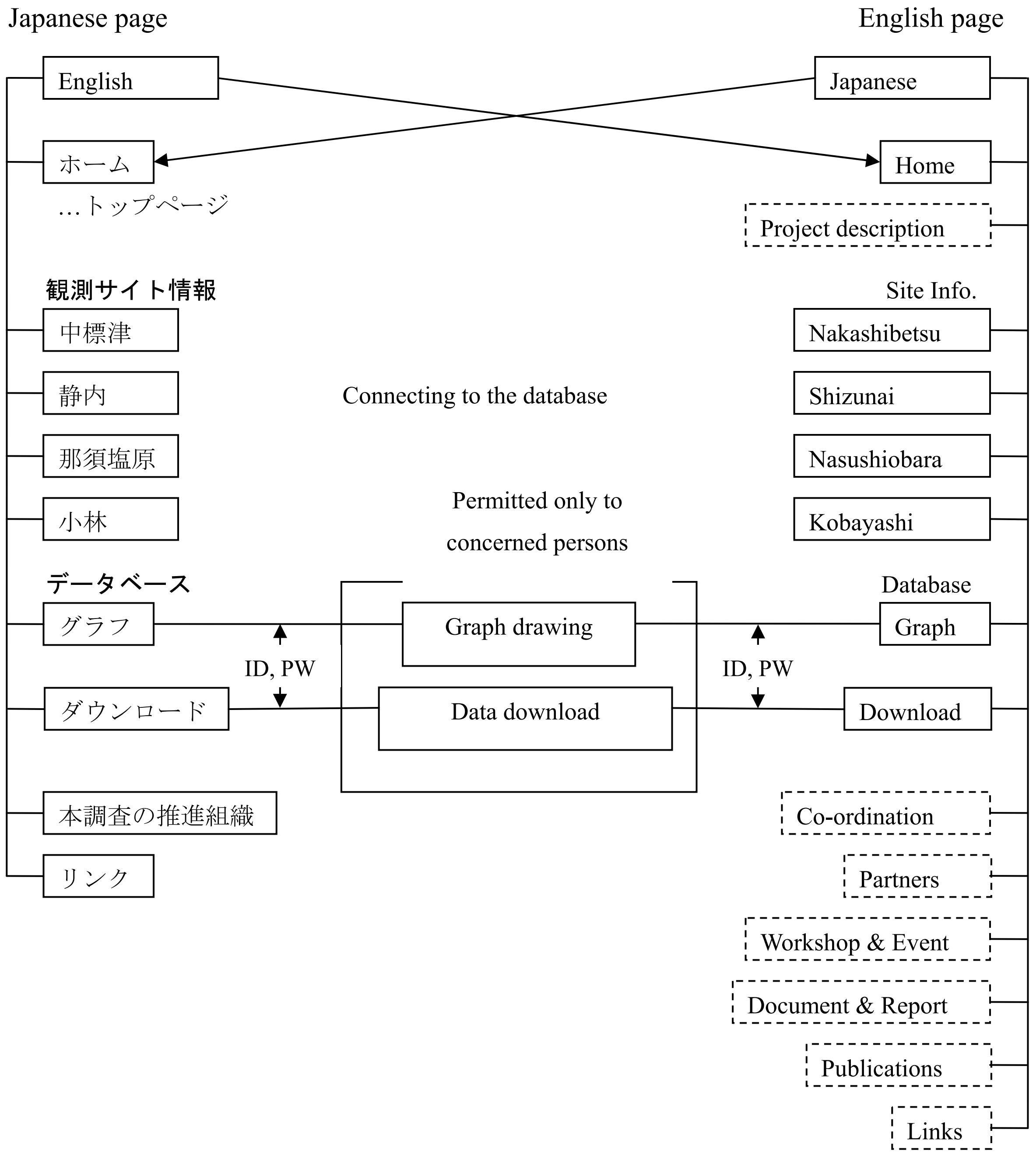

Figure 1.3 Preparation of the GHGG-Japan website.

6) Organizing training workshops for technical improvement of eddy-covariance data processing

If various corrections that use general meteorological data and other external variables are not applied, it has been found that the raw data obtained by measurement using the eddy-covariance method cannot calculate the flux value. Moreover, it is necessary to supplement the missing data according to proper procedure to calculate the annual data accumulated from the flux data obtained. However, in the current situation it is such that an individual researcher performs calculation processing by an individual method using great effort because these calculation processes are not only complex, but also contain no presence of a uniform method. In this study, the processing methods of the eddy-covariance data were made similar for all observed sites. Several training workshops on technical improvement of the eddy-covariance data processing for the person-in-charge of the project were held. This aimed at securing consistency of the flux data between sites. The contents are as follow:

(1) 21-22nd June 2004: Training workshop on the methods of installation and use of measuring devices and data collection and processing methods

Location: National Institute of Livestock and Grassland Science (Nasu)

Lecturer: Miyata Akira, Mano Masami and Ono Keisuke (National Institute for Agro-Environmental Sciences)

Contents: Lectures concerning measurement principles of the eddy-covariance method, methods of installation and use of measuring devices, the data collection method, and the procedure of data processing.

(2) 21-25th November 2005: Special training workshop for processing eddy-covariance data

Location: National Institute for Agro-Environmental Sciences

Lecturer: Miyata Akira, Ono Keisuke, Mano Masami, Yamada Tomoyasu, Nagai Hideyuki and Kobayashi Yoshikazu (National Institute for Agro-Environmental Sciences)

Contents: Lectures and practice on processing methods of general meteorological data, flux value calculation processing methods, supplementing method of flux data, and analyzing methods of flux data

(3) 6th June 2006: Training workshop on C budget calculation and soil respiration measurement

Location: Hokkaido University

Presenter: Hatano Ryusuke, Miyata Akira and Matsuura Soji

Contents: Basic knowledge of the measurement items required for a C budget calculation and the methods used for measurement and calculation, gathering measured greenhouse gas data, and measurement of soil respiration by a chamber method using a small CO_2 sensor.

7) List of outcomes

(1) Progress reports of the research project

1. Collection of references relating to environment-friendly grassland management: March 2005
2. Mid-term progress report of the research project concerning environment-friendly grassland management: March 2006
3. Final progress report of the research project concerning environment-friendly grassland management: March 2007

(2) List of papers presented at international conferences

1. Miyata, A., M. Mano, S. Matsuura, M. Oikawa, R. Hatano, A. Hayakawa, M. Hojito, N. Katayanagi, O. Kawamura, K. Kohyama, Y. Kouda, M. Niimi, T. Saigusa, and M. Shimizu (2005) Exchange of carbon dioxide and water vapor between grasslands and the atmosphere at

four hay grassland sites in Japan from autumn to spring. Proceedings of Asia Flux Workshop 2005, held in Fujiyoshida, Japan, 24-26 August, p.90

2. Miyata, A., M. Mano, S. Matsuura, M. Oikawa, R. Hatano, A. Hayakawa, M. Hojito, N. Katayanagi, O. Kawamura, K. Kohyama, Y. Kouda, M. Niimi, T. Saigusa, and M. Shimizu (2005) Carbon dioxide and water vapor exchange between managed grasslands in Japan and the atmosphere from autumn to spring. Proceedings of the International Conference on Research Highlights and Vanguard Technology on Environmental Engineering in Agricultural Systems, held in Kanazawa, Japan, 12-15 September 2005, p.149-156
3. Miyata, A., R. Hatano, M. Mano, Y. Kouda, M. Shimizu, S. Matsuura, M. Niimi, T. Saigusa, S. Kano, M. Hojito, A. Mori, O. Kawamura, A. Hayakawa, S. Marutani, H. Fukami, Y. Taniguchi, M. Oikawa and T. Mitamura (2006) Seasonal variation of carbon dioxide exchange and annual carbon budget at four managed grassland sites in Japan. Proceedings of Asia Flux Workshop 2006: International Workshop on Flux Estimation over Diverse Terrestrial Ecosystems in Asia, held in Chiang Mai, Thailand, 29-30 November 2006, p.43
4. Matsuura, S., A. Miyata, M. Mano, M. Oikawa, R. Hatano, M. Hojito, A. Mori, K. Kohyama and H. Sasaki (2005) Fluxes of carbon dioxide, water vapor and energy over a temperate grassland in central Japan from autumn to early summer. Proceedings of Asia Flux Workshop 2005: International Workshop on Advanced Flux Network and Flux Evaluation, p.89
5. Matsuura, S., A. Miyata, M. Mano, M. Hojito, A. Mori, T. Miyaji, T. Miyaji, S. Itano, R. Hatano, K. Kohyama, and H. Sasaki (2006) Effects of Manure Application on Carbon Budget over Managed Grassland in Central Japan. Proceeding of Asia Flux Workshop 2006; International Workshop on Flux Estimation over Diverse Terrestrial Ecosystems in Asia. p.52
6. Hatano, R. (2006) Introduction to a Japanese Research Project on "Establishment of Good Practices to Mitigate Greenhouse Gas Emissions from Japanese Grasslands" Asia Flux Newsletter, No.17

(3) Research papers presented at national conferences

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Chapter 2. Outline of the study and measurement methods

2.1 Characteristics of the selected four observation sites and the study processing method

The area of the world's grasslands occupies 37.1% of its total terrestrial area. The grassland is an important ecosystem that supports domestic production in several regions (World Resources Institute, 2005). The C fixation amount of the terrestrial ecosystem is the added quantity of the budget in extracted organic matter through crop harvesting, grazing and soil erosion and supply of organic matter from the outside such as manure in the net ecosystem production (NEP), subtracted from the net primary production (NPP) (Figure 2.1). This is called the net biome production (NBP) (Intergovernmental Panel on Climate Change (IPCC), 2000). The NBP becomes equal to the amount of C fixed to the soil because there is no C accumulation in the plant in farmlands where annual crops are grown. A study on C fixation in British soil showed that soil C disappeared at the annual average rate of 0.6% regardless of the cultivation method, and that the rate of speed of loss was as large as soil which had high C content rate (annually exceeding 2% in more than 100g kg^{-1}).

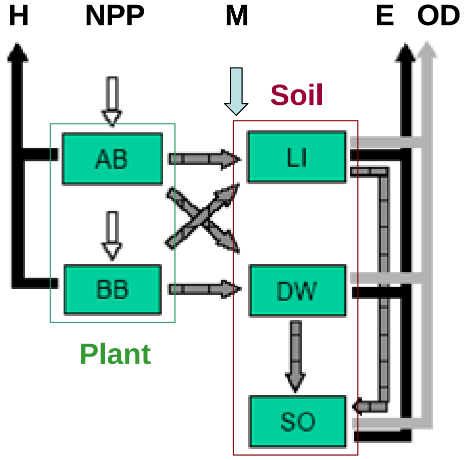

Figure 2.1 Carbon cycling in grassland
H, Yield; NPP, Net primary production; M, Manure; E, Erosion; OD, Organic matter decomposition; AB, Above-ground biomass; BB, Below-ground biomass; LI, Litter; DW, Dead plant body ; SO, Soil organic matter.

The decomposition of soil organic matter increases with an increase in temperature and this fact shows that the impact of global warming on the loss of soil C is becoming serious (Bellamy et al., 2005).

In a large livestock production system in Japan that depends on huge amounts of imported feed, livestock manure is not being sufficiently applied to farmlands, livestock waste is disposed, and is becoming a cause of water pollution. Therefore, a law concerning the promotion of use and management of the livestock waste was enforced in November 1999, ensuring the production of good quality livestock manure and its application to farmlands.

From such a background, study sites were established at Nakashibetsu (43°32'N, 144°58'E) and Shizunai (42°26′N, 142°29′E) in Hokkaido, Nasushiobara (36°55'N, 139°58'E) in Ibaraki Prefecture, and Kobayashi (31°58′N、130°56′E) in Miyazaki Prefecture, covering important grassland regions in Japan to examine whether the C fixation amount of the soil can be increased by using livestock manure (Figure 2.2). It was scheduled that the NEP could be completely measured by the eddy-covariance method from 2004 to 2006 followed by the preparation of a database.

Regarding the study method of each site, two grasslands (100m×100m) for the measurement until August 2004 were prepared. The measurement began using one plot for application with livestock manure and the other with chemical fertilizer. Using the same average amount that is used by a regular farmer, fertilizer was applied 40t ha^{-1} in two sites of Hokkaido, 15t ha^{-1} in Ibaraki Prefecture and 10t ha^{-1} in Miyazaki Prefecture. The difference in fertilizer amounts between these regions is based on the quantity that a potassium supply to grasslands does not become excessive. The C budget together with the emission of CH_4 and N_2O were measured by a chamber (diameter 40cm and height 30cm, Figure 2.5) method, and the effect of manure application was clarified. The measurement by a chamber method was conducted in six replications, once to twice after fertilization, once during the snow melting season and once in three weeks during the remaining period. It is expected that this project will mitigate global warming, and will contribute to the reduction in water pollution and the control of greenhouse gas emission since it is a program being conducted to achieve the proper use of manure.

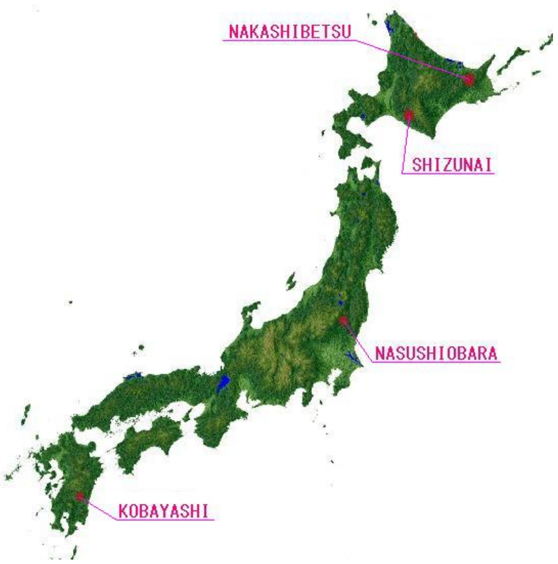

Figure 2.2 Location of the study sites.

The eddy-covariance method repeatedly measures the CO_2 exchange of plants and the atmosphere in short intervals. It is a technique for catching the reaction of photosynthesis and respiration. This method enables measuring NEP of a short duration accurately. However, the factor of an error margin is also large concerning long term measurement as the unexpected value is generated during the event of rainfall. The annual loss rate is reported to be 34.8% on average in Ameriflux and Euroflux on the global flux observation network (Falge et al., 2000). In the eddy-covariance method, the budgets of photosynthesis and respiration are measured in the day time, respiration is measured in the nighttime, and from this the amount of photosynthesis and respiration of the ecosystem can be obtained. However, it is necessary to divide the respiration between the plant and the soil, and to measure the amount of soil organic matter decomposition separately. Moreover, the NPP of the plant has to be measured separately. Therefore, to solve this problem, in this project NPP was also measured together with the measurement of NEP by the eddy-covariance method. An attempt is also made to estimate the amount of decomposition of manure and soil organic matter.

The decomposition amounts of soil organic matter and manure were measured directly by the chamber method and the result was compared with that obtained from the eddy-covariance method. Furthermore, although NPP is composed of above-ground and below-ground parts, contribution of these to NEP has rarely been investigated. It was planned to estimate the composition of NEP by measuring the NPP of above-ground and below-ground parts separately.

Chemical fertilizers generally control the amount of CH_4 uptake (Steudler et al., 1989) and increase the emission of N_2O (Bouwman, 1996). However, these depend on the obstruction of CH_4 oxidation and N_2O generation due to nitrification and N_2O emission due to denitrification. Also, in the case of manure application, although the measurement examples of what influence these receive at a local level are only a few, control of the amount of CH_4 uptake and an increase in N_2O emission are expected from the high possibility of an increase in the amount of mineralization. Moreover, N_2O emission factors per unit of applied N through livestock manure and chemical fertilizer is calculated by measuring the emission of CH_4 and N_2O from the bare field. Also, the N_2O emission coefficient from livestock manure is hardly ever measured, and is becoming an important issue.

In order to compare the differences in CO_2 budget and the emission of CH_4 and N_2O due to the application of livestock manure and chemical fertilizer, the global warming potential (GWP) was obtained by using the value of a 100 years by a technique presented by the IPCC. Please refer to the next section for the method of estimating greenhouse gas budgets. The explanation of major terms used in this report is described in Appendix-2.

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2.2 Measurement methods of greenhouse gas budgets

1) Definition of the greenhouse gas budget for grasslands

The purpose of this research project is to clarify the impact of applying livestock waste to grassland using livestock manure on the annual budget of greenhouse gases for grasslands in a scientific manner. The annual budget of greenhouse gases of the grassland is the differences of the amount of greenhouse gases that flow in from outside and the amount of the greenhouse gases that flow out from the grassland of a constant area (for instance, one hectare) in one year. It can be said that if the inflow amount is large, grasslands absorb greenhouse gases (mitigating global warming) and if the outflow is large, grasslands emit greenhouse gases (enhancing global warming). There are three major greenhouse gases associated with grasslands: CO_2, CH_4 and N_2O. The greenhouse gas budgets for grassland are expressed as the overall budget of these three types of gas (Figure 2.3). The uptake and emission of gas between grasslands and the atmosphere occupy a large part of the inflow and outflow of these greenhouse gases from grasslands. This means that, CO_2 is absorbed from the atmosphere by herbage plants in the grassland, and CO_2 is emitted to the atmosphere by decomposition of the soil organic matter. Furthermore, N_2O is emitted from the grassland soil to the atmosphere, while CH_4 is absorbed or emitted. Although the absorption of CO_2 by herbage plants accumulates inside the grassland as organic matter, a major part is taken out from grasslands during harvest. Moreover, a large part of the organic matter applied to grasslands as livestock manure is also emitted to the atmosphere as CO_2 after its decomposition inside the soil.

Therefore, it is necessary to put the inflow and outflow amounts resulting from manure application and harvesting in the calculation by converting the CO_2 amount when thinking about the annual budget of CO_2. The uptake and emission of CO_2 between grasslands and the atmosphere is called NEP. The inflow and outflow amount of CO_2 including abiotic processes such as harvest and manure application is called NBP; and both are distinguished (Figure 2.3). In addition to this, although it is considered that the inflow or leaching of greenhouse gases dissolved in water also constantly affects the annual budget of greenhouse gases for grasslands; these have been excluded in this research project.

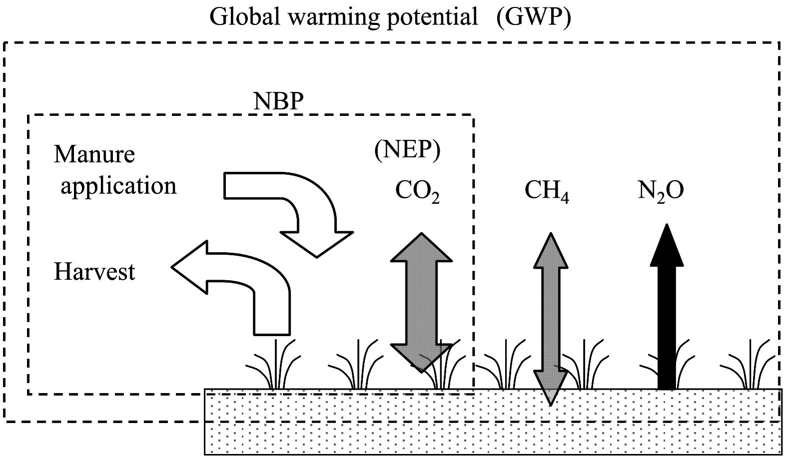

Figure 2.3 Components of greenhouse gas budgets for grasslands.

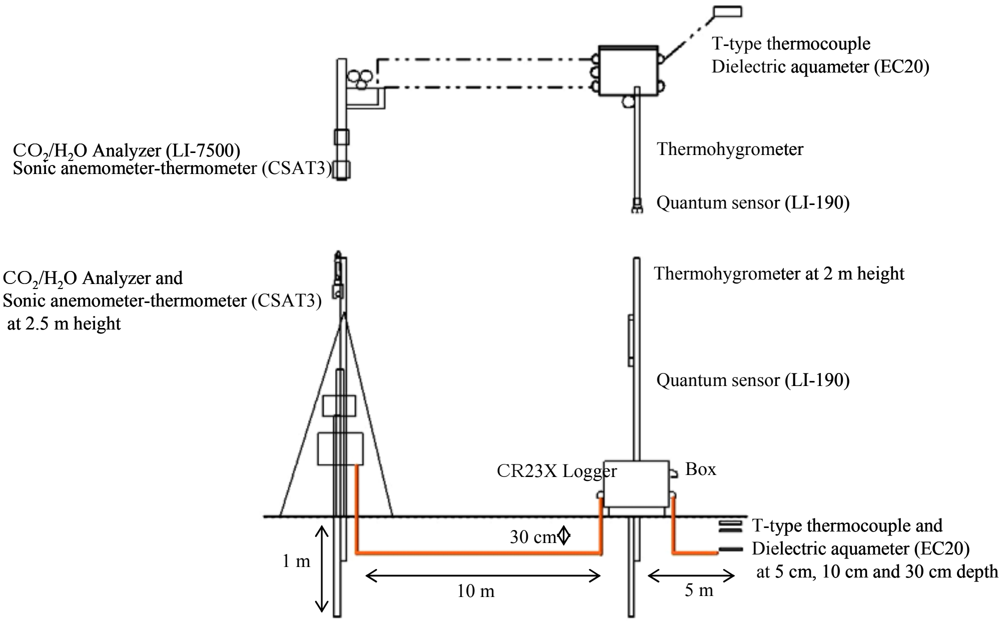

Figure 2.4 Layout of the eddy-covariance measurement system

As mentioned above, the greenhouse gas budget for grassland has been expressed as the overall budget of the gases CO_2, CH_4 and N_2O, even though the magnitude of greenhouse gases (impacting on global warming) per kg of respective gas is not similar. When assuming the global warming effect of CO_2 equivalents to one, CH_4 and N_2O become 23 and 296 times higher (2001 Report of Intergovernmental Panel on Climate Change; when thinking about the cumulative effect of next 100 years). Thus, the budget of the greenhouse gas with respect to the difference in size of the greenhouse effect according to the type of gas is called GWP.

In other words,

$$\begin{aligned}\text{GWP (Mg CO}_{2\text{eq}}\text{ ha}^{-1}\text{ y}^{-1}) &= \text{Annual budget of CO}_2\text{ or NBP (Mg C ha}^{-1}\text{ y}^{-1}) \times (44/12) \times 1\\ &+ \text{Annual budget of CH}_4\text{ (kg C ha}^{-1}\text{ y}^{-1}) \times (16/12) \times (1/1000) \times 23\\ &+ \text{Annual budget of N}_2\text{O (kg N ha}^{-1}\text{ y}^{-1}) \times (44/28) \times (1/1000) \times 296\end{aligned}$$

Here, the units「Mg CO_2 ha^{-1} y^{-1}」, 「kg C ha^{-1} y^{-1}」 and「kg N ha^{-1} y^{-1}」 represent how many mega grams (ton) of CO_2 are taken up or emitted from 1 hectare of land in a year, how many kilograms of CH_4 are taken up or emitted in terms of carbon conversion, and how many kilograms of N_2O are taken up or emitted in terms of N conversion. 「Mg CO_{2eq}」 represents how many tonnes of CO_2 equivalent the amount is (converted value to CO_2 density). The above-mentioned measurements (44/12), (16/12) and (44/28) are the factors of conversion from the density of carbon (nitrogen) to that of CO_2, CH_4 and N_2O and (1/1000) is also the factor for converting from kilogram to ton. In this study, for the sake of convenience, a positive numerical value is used when greenhouse gases are taken up by grasslands and a negative numerical value is used when grasslands emit greenhouse gases.

2) Estimating annual budget of respective gases

In this study, the annual inflow and outflow of greenhouse gases were measured by setting up two experimental plots using livestock manure and chemical fertilizer. The uptake and the emission of CO_2

between the grassland and the atmosphere were continuously measured by using an eddy-covariance method (Figure 2.4). The annual budget of CO_2 was calculated by the addition of the applied amount of carbon through livestock manure in the cumulative amount of uptake or emission obtained in every 30min (i.e. the annual NEP) and subtracting from it the CO_2 content taken out during harvest.

On the other hand, uptake and emission amounts of CH_4 and N_2O were measured regularly by using the chamber method (Figure 2.5) and the annual budget of the respective gases were calculated using the annual cumulative values. Since the uptake and emission of CO_2 vary greatly with time due to variation in light and temperature, it is necessary to measure these factors continuously. Unlike this, a continuous measurement of CH_4 and N_2O was not carried out in this study because the temporal variation in uptake and emission of these gases is more gradual compared to that of CO_2. However, the measurement by the chamber method is frequently carried out to reduce the estimation error of the annual budget as much as possible during the time when a large change in uptake and emission is forecasted, such as during the application of manure. A detailed explanation of the eddy-covariance method and the chamber method is given in the technical book.

Figure 2.5 Measurement conditions for CH_4 and N_2O uptake and emission by a chamber method (Shizunai observation site).

The NEP obtained by measurement using the eddy-covariance method is a quantity of the decomposition of soil organic matter (RH) subtracted from the amount accumulated in herbage plants as organic matter i.e. NPP. Therefore, if NPP and RH are measured beside the direct measurement of NEP by the eddy-covariance method, the annual NEP obtained by the eddy-covariance method can be verified. The whole carbon quantity in the plant body including the below-ground part is measured after a certain period, and NPP is obtained from the increment. Moreover, RH is measured by setting up a chamber at the ground level where the plant is removed.

In this study, two experimental plots of livestock manure and chemical fertilizer were set up in four respective observation sites in Japan which are all different in climate and vegetation conditions, and the measurements mentioned above were being conducted. As a result, the following could be performed: 1) analysis of the seasonal variation in uptake and emission of each gas that composes greenhouse gas budgets, 2) calculation of annual budgets of greenhouse gases and comparison between the experimental plots, and 3) comparison of the annual budgets among the observation sites.

Miyata Akira (National Institute for Agro-Environmental Sciences)

Chapter 3. Study results of each observation site

3.1 The greenhouse gas budget for the Shizunai site, classified as a cool temperate zone

Summary

CO_2, CH_4 and N_2O fluxes were measured for two years, by setting up two experimental plots on the permanent grassland in New-Hidaka Shizunai, classified as the cool temperate zone in Japan. Manure and chemical fertilizers were applied to both of these plots. The NEP indicated a positive value in both manure and chemical fertilizer plots, and a C fixation in the field was also confirmed. In 2005 and 2006, the NEP was 3.3 and 4.6 Mg C ha^{-1} y^{-1} in the manure plot and 4.7 and 5.8 Mg C ha^{-1} y^{-1} in the chemical fertilizer plot, respectively. It was found to be larger in the chemical fertilizer plot. The yield exceeded the NEP in all plots, except for the chemical fertilizer plot in 2006, where the harvested amount was larger than the C fixation content in the field. This is because the decomposition of organic matter in the soil continued during the non-growing period. Also, the NBP indicated a huge positive value of 5.2-5.6 Mg C ha^{-1} y^{-1} due to the C application of manure in the manure plot, and there was an indication of an adequate supplement of C that was lost during harvest. Furthermore, CH_4 emission did not vary between the experimental plots, ranging from the uptake of 0.1 kg C ha^{-1} y^{-1} to the emission of 0.4 kg C ha^{-1} y^{-1}. N_2O emission was 3.8 and 4.9 kg N ha^{-1} y^{-1} in the manure plot and 2.8 and 2.9 kg N ha^{-1} y^{-1} in the chemical fertilizer plot in 2005 and 2006, respectively, which was significantly larger compared to that of the control plot (0.5-0.8 kg N ha^{-1} y^{-1}). Although there was no significant difference in N_2O emission between the manure and chemical fertilizer plots, the manure plot tended to be high, indicating emission due to denitrification.

GWP values were -17.2 and -18.3 in the manure plot and 4.0 and -1.3 Mg C ha^{-1} y^{-1} in the chemical fertilizer plot in 2005 and 2006, respectively. The positive value of the CO_2 budget greatly contributed to the mitigation of global warming. However, the contribution of N_2O emission to global warming also showed that the manure plot had 1.4-1.7 times the emission of chemical fertilizer plot. Further studies on its mitigation are necessary.

3.1.1 Introduction

The area of the world's grasslands occupies 37.1% of the total terrestrial area on Earth. The grassland is an important ecosystem that supports livestock production in several regions. In Japan, manure is not appropriately applied to farmlands due to the livestock husbandry system depending on largely imported feed. As a result there is a disposal of livestock waste, and it is also causing water pollution. A law concerning the promotion of managing livestock waste and its proper use was enforced in November 1999, but the effective use of manure is still a growing problem. Based on evidence from a report, it has been found that application of organic matter is effective in soil C accumulation (Lal, 2004), and that there is a possibility of N_2O emissions increasing (Bouwman and Boumans, 2002). Although, it can be expected that use of manure has an effect in controlling global warming. Therefore, it is necessary to evaluate not only the CO_2 budget but also the uptake and emissions of CH_4 and N_2O to establish appropriate management technology for grasslands, where manure is applied.

This chapter compares a CO_2 budget and emissions of CH_4 and N_2O from manure and chemical fertilizer plots on the permanent grassland in Shizunai. It also clarifies the impact of applying manure on greenhouse gas budgets. It especially aims to compare between the eddy-covariance and the harvest methods with respect to estimating a CO_2 budget.

3.1.2 Materials and methods

1) Study site

The study was conducted on Shizunai Experimental Livestock Farm (N 42°26' E142°29'). The annual mean temperature is 7.9℃ and the annual precipitation is 1365 mm. The area of the study site is 6.98 ha and inclined to 1.5±0.2° from north to south. The soil is Tarumae b (Ta-b), Usu c (Us-c), Tarumae c (Ta-c) and Andosol originating from the air-fall deposit of Shikotsu (Spfa-1). The soil profile is shown in Table 3.1.1 and the physical as well as chemical properties of the soil are shown in Table 3.1.2. The Gley layer was confirmed in the chemical fertilizer plot.

The study field has been cultivated since 1975, and is currently being used as grassland. Renovation of the grassland was conducted only once before 1984.

The site was grazed for one to two weeks before snowfall in 1995, 1996 and 2000 through 2002. This was done in order to feed the remaining grasses. Harvesting was performed twice a year and fertilizer management of chemical fertilizer was conducted. The average rate of chemical fertilizer application was 89±8, 91±49 and 115±18 kg ha^{-1} y^{-1} for N, P_2O_5 and K_2O, respectively. Manure was applied 14 times between 1984 and 2004 at the average rate of 10.7±4.1 Mg FM ha^{-1}; and slurry was applied 4 times at the rate of 5.1±1.2 Mg FM ha^{-1}.

Major grass types are reed canarygrass (*Phalaris arundinacea* L.) and meadow foxtail (*Aleopecurus pratensis* L). The vegetation composition of 18th June 2005 is given in Table 3.1.3.

Experimental plots (100m×100m) of chemical fertilizer and manure were set up at 10m intervals (Figure 3.1.1). In addition, a measuring spot for the chamber method was

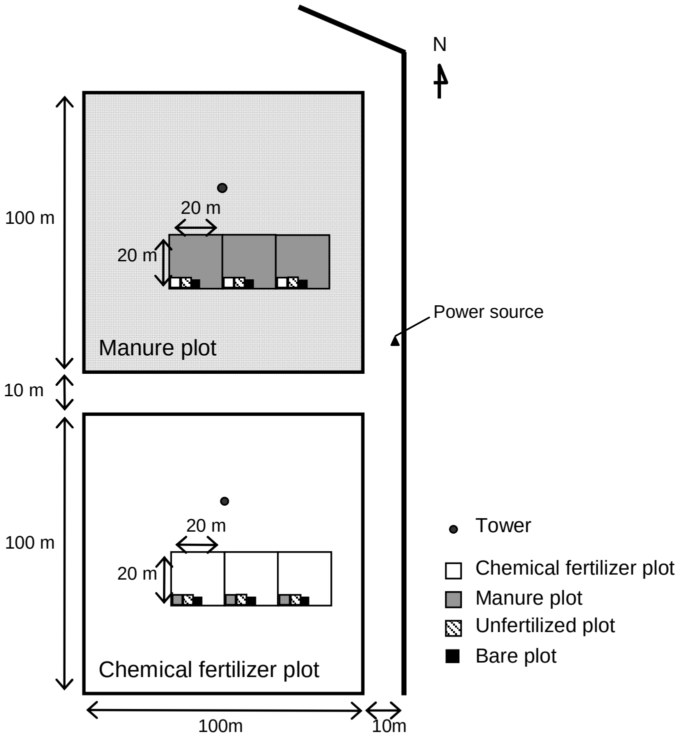

Figure 3.1.1 Distribution map of experimental sites

Table 3.1.1 Soil profile

Soil profile	Parent material	Depth (cm)	Humus	Gravel	Soil colour	Soil texture	Structure	Hardness(mm)
Manure plot								
1Ap1	Ta-b	0-6	Medium		10YR4/2	SL	Weak subangular blocky	6.2
1Ap2	Ta-b	6-26	Medium		10YR2/2	SL	Weak subangular blocky	20.4
2C	Us-c	26-30	Low		10YR7/4	SL	Strong single granular	10.8
3A	Ta-c	30-40	Medium	Few	7.5YR4/3	L	Weak subangular blocky	14.4
4A	Spfa-1	40-51	Medium	Common	7.5YR4.5/2.5	L	Weak subangular blocky	17.8
4B	Spfa-1	51-98+	Low	Few	7.5YR7/2	CL	Weak subangular blocky	20.4
Chemical fertilizer plot								
1Ap	Ta-b	0-18	Medium		10YR4/3	SL	Moderate subangular blocky	25.2
2C	Us-c	18-24	Low	Few	10YR7/4	SL	Strong single granular	19.4
3A	Ta-c	24-35	Medium		10YR4/1	LiC	Moderate angular blocky	19.4
4AB	Spfa-1	35-66	Low	Few	7.5YR5/8	CL	Moderate angular blocky	19.2
4G	Spfa-1	66-100+		Few	5BC5/1	CL	Weak angular blocky	17.2

The survey was conducted on 12 August 2004. Hardness was measured with a Yamanaka hardness meter.

Table 3.1.2 Soil physical and chemical properties

Soil profile	Depth (cm)	pH	CEC (meq 100g)	P absorption coefficient	Bulk density (g cm^{-3})	T-C(%)	T-N(%)
Manure plot							
1Ap1	0-6	4.7	17.5	899	0.57	4.4	0.40
1Ap2	6-26	5.4	10.6	790	0.75	3.5	0.32
2C	26-30	6.0	3.9	335	0.50	0.8	0.07
3A	30-40	5.8	28.2	1948	0.86	5.5	0.57
4A	40-51	6.0	20.7	911	1.04	2.2	0.21
4B	51-98+	6.2	20.0	1566	1.63	0.4	0.03
Chemical fertilizer plot							
1Ap	0-18	5.1	13.2	971	0.55	3.7	0.32
2C	18-24	5.7	6.5	616	0.81	1.5	0.13
3A	24-35	5.7	29.3	1400	0.85	5.2	0.45
4AB	35-66	6.0	16.9	851	1.46	0.7	0.05
4G	66-100+	6.1	25.0	1061	1.33	0.5	0.04

Table 3.1.3 Vegetation composition of 18th June 2005

	Manure plot	Chemical fertilizer plot
Proportion of plant cover (%)	99.3	98.2
Community height (cm)	117.9	116.3
Floristic coverage (%)		
Reed canarygrass	65.8	70.3
Meadow foxtail grass	32.4	26.4
Other gramineous plants	0.0	0.0
Broad-leaved weeds	1.1	1.4
Dry weight percentage (%)		
Reed canarygrass	56.4	71.3
Meadow foxtail grass	39.1	24.0
Other gramineous plants	4.5	4.3
Broad-leaved weeds	0.0	0.4

selected in such a way that spatial influence could be assessed. The four experimental plots being: manure, chemical fertilizer, unfertilized and bare (20m×20m in size). All were set up at the center of the respective chemical fertilizer and manure plots. The size of the experimental plots was set as 2m×2m for the bare plot and 4m×5m for remaining plots, so there would be no influences on the results of eddy-covariance.

2) Study period

The study was carried out from September 2004 to October 2006. The 1st of October 2004 to the 30th of September 2005 was assumed to be the year 2005, and the 1st of October 2006 to the 30th of September 2006 was assumed to be the year 2006.

3) Field management

In 2005, the basal applications of manure or chemical fertilizer and an additional application of chemical fertilizer were conducted on the 11th of May and 4thof July, respectively (Table 3.1.8). Harvesting was conducted on the 4th of July and 10-11th of August 2005. The first harvesting was conducted on 20-22nd June after fertilization on 11th of May. The additional fertilization was conducted on the 4th of July and the second harvesting was performed on 10-11th of August. In 2006, the basal applications of manure and/or chemical fertilizer and an additional application of chemical fertilizer were conducted on the 9th of May and 10th of July, respectively. Harvesting was conducted on 26-27th of June and 22-25th of August.

The manure applied was beef cow manure containing dung, urine and bedding litter of wood wastes from bark (Table 3.1.4). This was prepared by piling up livestock waste and bedding litter outdoors for about 8 months by beef cow farmers in Shintoku town. The applied quantity of manure was 44 and 43t FM ha^{-1} in 2005 and 2006, respectively. The amount of element emission from manure was calculated by multiplying the applied quantity by the emission rate. The emission rate of C and N was referring to Uchida's expression model (Agriculture, Forestry and Fisheries Research Council Secretariat, 1985) and that of phosphorus and potassium to the standard manure efficiency (Table 3.1.5) of Hokkaido

(Hokkaido Prefectural Agriculture Experiment Station and Animal Research Center, Domestic Animal Waste Project Study Team). First of all, the amount of element emission in 2005 was calculated by multiplying the applied quantity in 2005 by the emission rate of the initial year (Table 3.1.6). Moreover, the amount of element emission in 2006 was assumed to be the emission amount calculated by multiplying the applied quantity in 2005 by the emission rate of the second year, which, in turn, was the product of the harmony of the emission and the applied amount in 2006 multiplied by the emission rate of the first year (Table 3.1.7). Furthermore, the amount of chemical fertilizer applied to the manure plot was assumed to be a difference between the applied amounts in the chemical fertilizer plot and the quantity of the element emission from manure. Table 3.1.8 shows the amount of applied chemical fertilizer in 2005 and 2006.

Table 3.1.4 Applied quantity and nutreint composition of manure

Year	Applied quantity (Mg ha^{-1})	Composition (FM%)				
		Moisture content	T-C	T-N	P_2O_5	K_2O
2005	44	72	13.3	0.54	0.43	0.61
2006	43.2	68	13.8	0.71	0.49	0.39

Table 3.1.5 Element emission rate from manure

Passed year after application	Emission rate (%)			
	T-C	T-N	P_2O_5	K_2O
First year	18.8	13.2	20.0	70.0
Second year	6.8	7.0	10.0	10.0

Table 3.1.6 Element emission rate of manure in 2005

	Item	Unit	Element				Calculation method
			T-C	T-N	P_2O_5	K_2O	
A	Applied elements by manure in 2005	kg ha^{-1}	5830.0	236.0	191.0	266.0	
B	Element emission rate of appliedmanure in 2005	%	18.8	13.2	20.0	70.0	
C	Emission from manure in 2005	kg ha^{-1} y^{-1}	1098.0	31.0	38.2	186.4	A×B/100

Table 3.1.7 Element emission rates of manure in 2006

	Item	Unit	Element				Calculation method
			T-C	T-N	P_2O_5	K_2O	
A	Applied elements by manure in 2005	kg ha^{-1}	5830.0	236.0	191.0	266.0	
B	Applied elements by manure in 2006	kg ha^{-1}	5960.0	310.0	212.0	167.0	
C	Element emission rate of manure in2005	%	6.8	7.0	10.0	10.0	
D	Element emission rate of manure in2006	%	18.8	13.2	20.0	70.0	
E	Element emission from manure in 2005	kg ha^{-1} y^{-1}	398.0	16.5	19.1	26.6	A×/100
F	Element emission from manure in 2006	kg ha^{-1} y^{-1}	1121.0	40.8	42.5	117.0	B×/100
G	Total emission from manure in 2006	kg ha^{-1} y^{-1}	1519.0	57.3	61.6	143.6	E＋F

Table 3.1.8 Applied amount of fertilizers

Experimental plot	Year	Fertilizer type	Applied date	Applied amount (kg ha^{-1})			
				T-C	T-N	P_2O_5	K_2O
Season-wise applied amount							
Manure plot	2005	Manure	2005/5/11, 12,17	5830	236	191	266
		Chemical fertilizer	2005/7/4	0	133	7	70
	2006	Manure	2006/5/9	5960	310	212	167
		Chemical fertilizer	2006/5/9	0	71	0	33
		Chemical fertilizer	2006/7/10,11	0	59	6	97
Chemical fertilizer plot	2005	Chemical fertilizer	2005/5/11	0	103	23	168
		Chemical fertilizer	2005/7/4	0	61	23	97
	2006	Chemical fertilizer	2006/5/9	0	124	50	177
		Chemical fertilizer	2006/7/10,11	0	59	18	97
Yearly applied amount							
Manure plot	2005			5830	369	198	337
	2006			5960	440	218	297
Chemical fertilizer plot	2005			0	164	45	265
	2006			0	183	68	273

4) Weather

Precipitation data was obtained from the AMeDAS (Sasayama) which is about 5 km away from the study site. The information on temperature, duration of sunshine and snow depth was obtained from the AMeDAS Shizunai observation site which is located about 15 km away from the study site.

5) Yield and plant biomass

(1) Yield

The harvesting survey was conducted on the 5cm height of grassland, immediately before the first and the second harvest. 6 to 8 replications were conducted for each experimental plot, using a quadrate of 1m. The collected samples were dried at 70℃ with a ventilating dryer for more than 72h, and then a dry matter weight and CN content were measured.

(2) Plant biomass

Plant biomass was measured four times a year including the month of April, immediately before the first and second harvest and in October. The part above-ground was reaped at 6-8 replications using a quadrate of 1m. However, for measurement immediately before the first and second harvest, the residue was reaped at 6-8 replications using a quadrate of 0.5m after collecting the harvested parts. The part below-ground was dug out using a 50cm×25cm×depth 30cm size at 4 replications. The dug out part below-ground was washed by water using a sieve of 0.5mm. The collected samples were dried at 70℃ with a ventilating dryer for more than 72h. Dry matter weight and CN content were both measured.

6) CO_2 budget

(1) Measurement of the net ecosystem production (NEP)

Continuous measurement of a CO_2 flux was carried out using the eddy-covariance method of the open-path type at 2.4m height. The tower for observation was set up at the site 20m from the center of the experimental plots on the northern side. This considered the fact that the main direction of the wind during the growing period was towards the south (Figure 3.1.1). Correction and quality control tests were conducted on the obtained 10Hz data. The CO_2 storage flux was calculated by considering the CO_2 concentration at the measurement height to be same as the CO_2 concentration under the height, and the NEP was estimated as the sum of the CO_2 flux and the CO_2 storage flux. The friction speed correction has not been done. The missing values were supplemented using an interpolation method for up to one and a half hours and a table retrieval method for what was above it. In the table retrieval method, the lost data was supplemented by the value of the same class, and the mean flux value was calculated for each class of photosynthetic photon flux density (PPFD) and temperature.

(2) Net biome production（NBP）

The net biome production was calculated by the following equation, where the NEP obtained from the eddy-covariance method was used:

NBP = NEP + Applied manure - Yield

7) CH_4, N_2O and NO fluxes

A closed chamber method was used for measuring CH_4, N_2O and NO fluxes. Gas samples were collected between 800 and 1100h at 6 replications in each experimental plot and the sealed up time was 20-30m. The sampling frequency was once in two months during the snowfall period, once during the snow melting period and 1-3 times a week for about a month after fertilization.

CH_4 concentration was analyzed with an FID gas chromatograph (GC-8A; SHIMADZU, Kyoto, Japan), N_2O by an ECD gas chromatograph (GC-14B; SHIMADZU) and NO by a chemiluminescence N oxide analyzer (MODEL-265P; KIMOTO, Osaka, Japan). The cumulative value was calculated by linear interpolation of the average flux between the measurements and then addition of the results over the total time period.

8) Global warming potential (GWP)

The GWP values were estimated by the following equations:

$$\mathrm{GWP\ (Mg\ CO_2eq\ ha^{-1}\ y^{-1}) = GWPCO_2 + GWPCH_4 + GWPN_2O}$$

$$\mathrm{GWPCO_2\ (Mg\ CO_2eq\ ha^{-1}\ y^{-1}) = -NBP\ (Mg\ C\ ha^{-1}\ y^{-1}) \times 44/12}$$

$$\mathrm{GWPCH_4\ (Mg\ CO_2eq\ ha^{-1}\ y^{-1}) = CH_4\ emission\ (Mg\ C\ ha^{-1}\ y^{-1}) \times 16/12 \times 23}$$

$$\mathrm{GWPN_2O\ (Mg\ CO_2eq\ ha^{-1}\ y^{-1}) = N_2O\ emission\ (Mg\ N\ ha^{-1}\ y^{-1}) \times 44/28 \times 296}$$

9) Emission factor (EF)

The EF per unit of applied fertilizer N due to chemical fertilizer (EF_F) was estimated by the following equation:

EF_F（%）＝（〔N_2O emission ｛chemical fertilizer plot｝〕－〔N_2O emission ｛unfertilized plot｝〕）/〔Fertilizer N ｛chemical fertilizer plot｝〕×100

The amount of N_2O emission from the fertilizer N due to chemical fertilizer, was estimated from the EF_F, and the amount of N_2O emission from the fertilizer N due to manure, was calculated by the balance. This was because both manure and chemical fertilizer had been applied to the manure plot. The N_2O emission factor per unit of fertilizer N due to manure (EF_M) was estimated by the following equation:

EF_M（%）＝（〔N_2O emission ｛manure plot｝〕－〔Fertilizer N ｛manure plot｝〕× EF_F / 100－〔N_2O emission ｛unfertilized plot｝〕）/〔Manure N ｛manure｝〕× 100

10）Chemical properties of soil

After the gas flux measurement by the chamber method, the disturbed soil sample of the 5cm surface layer under the root-mat around each chamber was collected. The sample was passed through a sieve of 2mm, and soil solution was extracted using soil: water = 1:5. The concentration of nitrate and soluble organic C were then measured. The nitrate concentration was analyzed with an ion chromatograph (QIC Analyzer; Dionex) and soluble organic C was analyzed with an organic C analyzer (TOC-5000A; SHIMADZU). Furthermore, soil water was extracted using soil:2MKCL=1:10, and ammonium concentration was measured. The indophenol blue spectrophotometry was used to analyze ammonium.

3.1.3 Results and discussion

1) Climate

Precipitation, temperature and duration of sunshine are given in Table 3.1.9. The precipitation was 999mm from October 2004 to September 2005, 1133mm from October 2005 to September 2006, and both were comparatively smaller than the average value of 1365mm. Moreover, the annual mean temperature was 8.3 and 8.2℃ in 2005 and 2006, respectively. This was almost normal. The duration of sunshine was 1607 and 1775h, respectively, being comparatively larger than the average value of 1529h, and it was especially large during the growing period.

Table 3.1.9 Precipitation, temperature and duration of sunshine

	Annual			Growing period		
	Precipitation (mm)	Temperature (℃)	Duration of sunshine (h)	Precipitation (mm)	Temperature (℃)	Duration of sunshine (h)
2004/10/1 – 2005/9/30	999	8.3	1607	806	14.3	949
2005/10/1 – 2005/9/30	1133	8.2	1775	833	15.0	1066
Average	1365	7.9	1529	1021	14.0	801

2) Yield and plant biomass

(1) Yield

The fresh weight yield of green forage in manure and chemical fertilizer plots was 42.5 and 55.6 Mg ha^{-1} in 2005 and 50.7 and 53.0 Mg ha^{-1} in 2006, respectively. The targeted yield in the local area was 45-50 Mg ha^{-1} (Hokkaido Agricultural Policy Planning Department and 2002), and the yield exceeded the targeted amount in all plots except for the manure plot in 2005. Table 3.1.10 shows the dry weight yield. There was a significant difference between chemical fertilizer and manure plots only during the first harvest in 2005. Only manure was used as the basal fertilizer on the manure plot in 2005, and the amount of N emission from the manure at this time was 31 kg N ha^{-1} from Uchida's model. It fell significantly lower than the 103 kg N ha^{-1} of the chemical fertilizer plot. Therefore, it was supposed that there could have been an insufficient amount of inorganic N supply, the growth of herbage plants could have been controlled, and the yield of the first harvest in the manure plot was lower than that of the chemical fertilizer plot in 2005. Also, because the deficit N had been supplemented with the chemical fertilizer for the basal application in the manure plot in 2006, the same yield in both plots was obtained.

Table 3.1.10 Yield

(Mg DM ha^{-1})

		Manure plot	Chemical fertilizer plot	
2005	First harvest	4.0 (1.0)	7.3 (0.5)	**
	Second harvest	5.0 (0.7)	4.6 (1.3)	n.s.
	Total	9.0	11.9	
2006	First harvest	6.7 (1.2)	6.6 (0.8)	n.s.
	Second harvest	4.4 (1.0)	4.8 (0.8)	n.s.
	Total	11.1	11.4	

Standard deviations are shown in parentheses. Regarding each reaping, the difference in experimental plots was judged and t-test was used.
**, P=1%; *, P=5%; n.s., not significant

(2) Plant biomass

The seasonal variation in plant biomass of parts above the ground (hereafter referred to as above-ground biomass) and below the ground (hereafter referred to as below-ground biomass) is presented in Figure 3.1.2. Although the below-ground biomass largely decreased in the summer of 2005, it changed to 19-28 Mg DM ha^{-1} and a marked decrease was not observed. Compared to the above-ground biomass, the below-ground biomass showed results of 2.6 - 3.1 times during the first

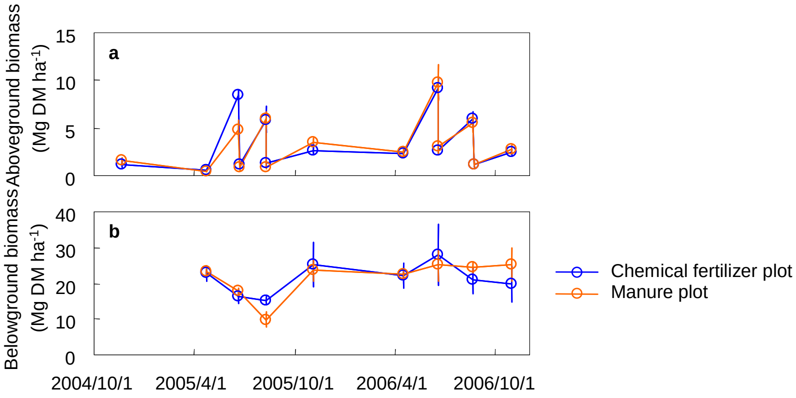

Figure 3.1.2 Seasonal change in biomass of above-ground parts (a) and below-ground parts (b).
Error bars indicate standard deviation.

harvest in 2006, and it was remarkably as large as 3.5 - 44 times during the second harvest. The below-ground biomass of reed canarygrass, which is sufficiently grown even on poor drained soil, is well developed and it suggested that the cumulative amount of below-ground biomass is increased if the drain-defect land is used in the long run without renovation. However, a distinct increase or decrease in the below-ground biomass was not observed at this study site, and it can be considered that there was possibility of the below-ground biomass reaching a stable condition.

3) CO$_2$ budget

(1) Net ecosystem production (NEP)

The NEP showed the uptake of CO$_2$ until the end of November and changes until mid April because of a little emission (Figure 3.1.3). The NEP has showed uptake again since the end of April and it has increased with the growth of herbage plants. Uptake was observed again in about two weeks although it was changed to the emission after the first and second harvests. The annual amount of NEP is given in Table 3.1.11. The NEP indicated a positive value in both the manure and

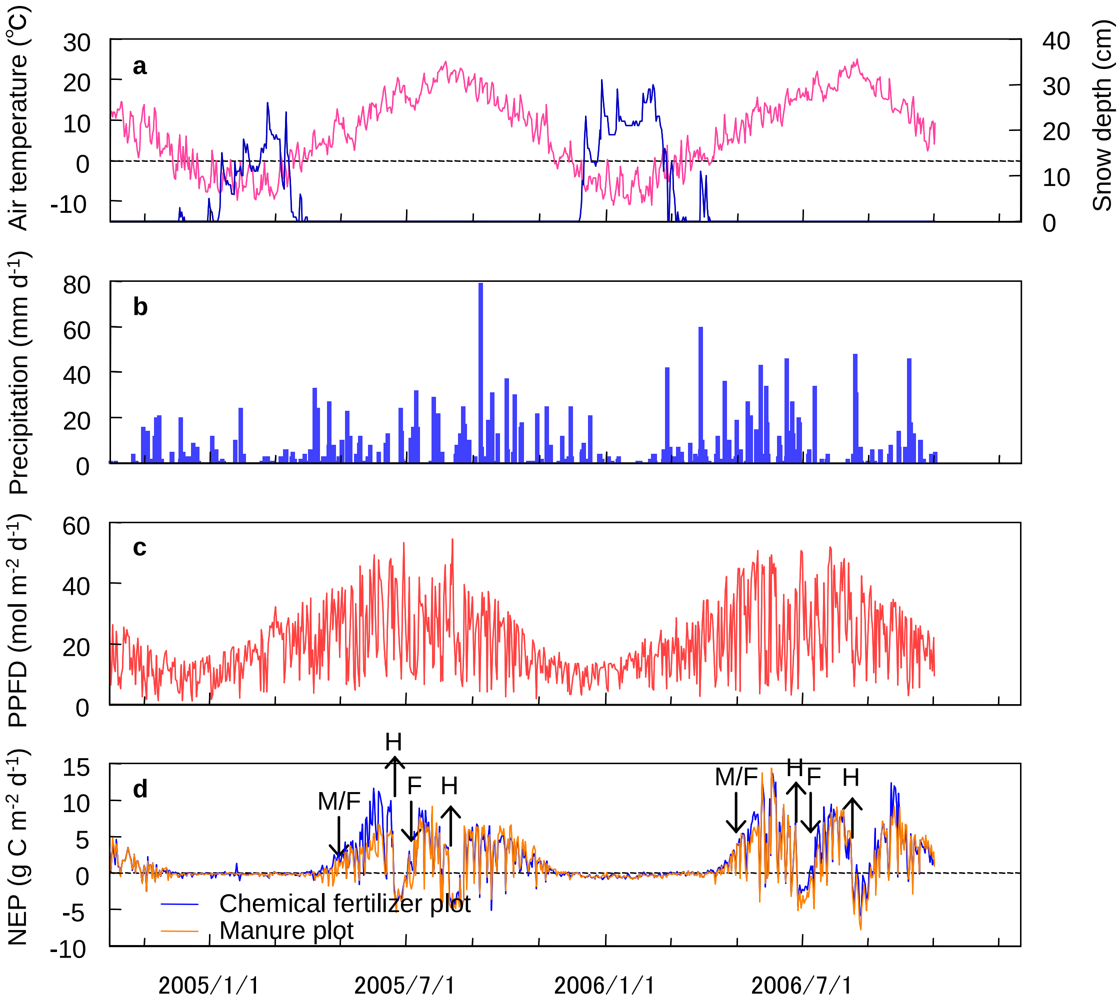

Figure 3.1.3 Seasonal change in temperature (a), precipitation (b), Photosynthetic photon flux density (PPFD) (c),and NEP (d).
Temperature indicates the daily mean value and others indicate daily cumulative values.
H, harvest; M, applied manure; F, applied chemical fertilizer

chemical fertilizer plots. Also the C fixation in the field was confirmed. Moreover, the NEP was 3.3 and 4.6 Mg C ha^{-1} y^{-1} in the manure plot and larger in the chemical fertilizer plot at 4.7 and 5.8 Mg C ha^{-1} y^{-1} in 2005 and 2006, respectively. It tended to be larger in 2006 than in 2005 in both of these experimental plots.

(2) Net biome production (NBP)

Although the NEP showed the fixation of C in 2005 and 2006 in both these experimental plots, it was always equal to the NEP, or more C than the NEP was taken out by harvest (Table 3.1.11). This means there was decomposition of the soil organic matter. However, because the C was introduced by manure in the manure plot, the NBP became a positive value and showed a fixation of C (Table 3.1.11). Therefore, the application of manure was effective in controlling the decomposition of soil organic matter. Manure was applied for two years in this study, and such an application increased the amount of the remaining element. However, since manure is decomposed over a long time, it is necessary to clarify the amount of C stabilized in the soil. For this, it is necessary to clarify the turnover of manure C by a long-term study on manure decomposition.

Table 3.1.11 Net biome production (NBP)

（Mg C ha^{-1} y^{-1}）

	Manure plot				Chemical fertilizer plot		
	NEP	Harvested amount	Applied manure	NBP	NEP	Harvested amount	NBP
2004/10 – 2005/9	3.3	4.0	5.8	5.2	4.7	5.4	-0.7
2005/10 – 2006/9	4.6	5.0	6.0	5.6	5.8	5.1	0.7
Average	4.0	4.5	5.9	5.4	5.3	5.3	0.0

4) CH_4 flux

The seasonal change in CH_4 flux is shown in Figure 3.1.4. CH_4 fluxes showed both uptake in and emission from all experimental plots. The maximum value was 47.5μg C m^{-2} h^{-1} on 15th July 2006 in the manure plot and 33.2μg C m^{-2} h^{-1} on 13th October 2004 in the chemical fertilizer plot. A distinct seasonal variation was not observed in the CH_4 flux. Correlation coefficients of the relations between the CH_4 flux and the environmental and chemical elements in soil are given in Table 3.1.12. There was a tendency of positive correlation between the CH_4 flux and NH_4-N concentration in the soil, though it was not significant. From this result, it is considered that there could be a possibility of the obstruction of CH_4 oxidation, resulting from the rise in the NH_4-N concentration.

The annual amount of CH_4 emission is given in Table 3.1.13. The result of a two-way ANOVA indicated that there was no significant difference in CH_4 emission between the experimental plots, but a significant difference (at 1% level) was found between the years being emitted (0.20－0.56 C ha^{-1} y^{-1}) in 2005 compared to while consumed (-0.16－-0.06 C ha^{-1} y^{-1}) in 2006.

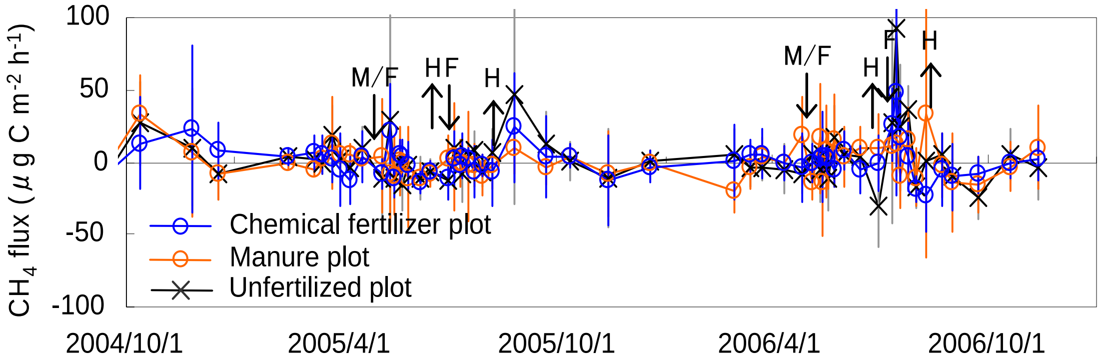

Figure 3.1.4 Seasonal variation in CH$_4$ fluxes.
The error bar shows standard deviation.
H, harvest; M, applied manure; F, applied chemical fertilizer

Table 3.1.12 Correlation coefficients between a CH$_4$ flux and the environmental and chemical elements in soil

Particulars	Correlation coefficients		
	Manure plot	Chemical fertilizer plot	Unfertilized plot
5cm Soil temperature	0.03	0.11	0.21
Soil moisture content	0.38	-0.03	0.17
Soil chemical properties			
pH	0.19	-0.03	0.29
Ammonium-N	0.24	0.26	0.00
Nitrate-N	-0.04	-0.01	0.56
Dissolved inorganic N	0.24	0.25	0.29
Dissolved organic N	-0.09	-0.27	0.35
Dissolved organic C	0.04	-0.06	-0.16

**, 1% significance level; *, 5% significance level

Table 3.1.13 CH$_4$ emission

(kg C ha^{-1} y^{-1})

	Manure plot	Chemical fertilizer plot	Control plot	Average
2004/10 – 2005/9	0.45 (0.37)	0.20 (0.60)	0.56 (0.56)	0.40
2005/10 – 2006/9	-0.16 (0.33)	-0.12 (0.36)	-0.06 (0.75)	-0.12
Average	0.14	0.04	0.25	

Factor	Result of a two-way ANOVA				
	Degree of freedom	Sum of squares deviation	Mean squares	F value	P value
Year	1	2.4	2.41	9.04	0.005
Experiment	2	0.3	0.13	0.48	0.625
Year×experiment	2	0.2	0.08	0.32	0.732
Error	30	8.0	0.27		
Total	35	10.8			

Standard deviations are shown in parentheses. Variations in years and experiments were analyzed by a two-way ANOVA. When a significant variation was found, each standard was verified by Tukey-test and the level of significance was set as 5%.

5) N$_2$O Fluxes

A seasonal variation in N$_2$O fluxes is given in Figure 3.1.5. N$_2$O fluxes increased both in chemical fertilizer and manure plots after manure application. The maximum value was 1290 μg N m^{-2} h^{-1} in the manure plot on 11th May 2006 immediately after the application of basal fertilizer and was 313.8μg N m^{-2} h^{-1} on 18th July 2005, after one week of applying additional fertilizer. On the other hand, the N_2O flux gradually increased with an increase in soil temperature, indicating a maximum value of 50.3 - 66.2 μg N m^{-2} h^{-1} in August, and a decrease afterwards. The N_2O flux that increased after applying fertilizers decreased to the same level as the control plot in 1-2 months. Table 3.1.14 shows the correlation coefficients of the relation between the N_2O flux and the environmental and chemical elements in the soil. The N_2O flux showed a significant positive correlation with soil temperature (5cm) in all experimental plots at 1% level of significance. Moreover, the N_2O flux had a significant positive correlation with soil NH_4-N concentration in both manure and chemical fertilizer plots （$p<0.05$） and with the soil NO_3-N concentration in the chemical fertilizer plot ($p<0.05$). The results of the N_2O flux measured at the same time showed that the N_2O:NO ratio was about a 100 when a large N_2O flux was observed (Figure 3.1.6). It is reported that the denitrification was superior when the N_2O/NO value increased above 100 (Lipschultz et al., 1981). It also showed a large N_2O emission indicating that the denitrification process was contributing to it. However, although the result is not shown here, there was a significant positive correlation (at 1% level) between N_2O and CO_2 fluxes measured at the same time. This indicated that the denitrification occurred during the decomposition of organic matter, and that there is a high possibility of an increase in denitrification by the application of fresh organic matter due to the application of manure.

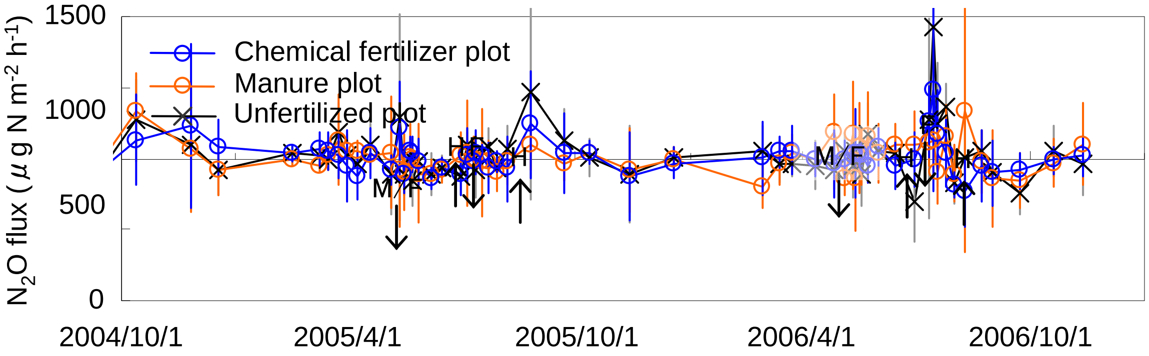

Figure 3.1.5 Seasonal variation in N_2O fluxes.
Error bars represent standard deviation.
H; harvest, M; applied manure and F; applied chemical fertilizer

The annual amount of N_2O emission is given in Table 3.1.15. The ANOVA result revealed that there was no significant difference in N_2O emission between years, but there was a significant difference (at 1% level) between the experimental plots. N_2O emission from manure and chemical fertilizer plots were significantly larger (at 1% level) than the control plot, and it was confirmed that the application of N fertilizers increased the N_2O emission. Furthermore, the N_2O emission from the chemical fertilizer plot was significantly larger ($p<0.05$) than that from the manure plot, suggesting that application of manure enhances the N_2O emission. The N_2O emission factor of chemical fertilizer was 1.3% and that of manure (EF_M) was 0.59-0.86% (Table 3.1.16).

Table 3.1.14 Correlation coefficients between N_2O fluxes, climatic factors and soil chemical properties

Factor	Correlation coefficient Manure plot	 Chemical fertilizer plot	 Control plot
Soil temperature (5cm)	0.29 *	0.63 **	0.62 **
Soil moisture content	0.04	0.01	-0.31 *
Soil chemical properties			
pH	-0.19	-0.41 **	0.06
Ammonium-N	0.36 *	0.36 *	-0.34
Nitrate-N	0.23	0.50 *	0.31
Dissolved inorganic N	-0.46 **	0.01	0.20
Dissolved organic N	0.36 *	0.39 *	-0.11
Dissolved organic C	-0.25	-0.38 *	-0.11
CO_2 fluxes	0.56 **	0.46 **	0.66 **

**, 1% significance level; *, 5% significance level

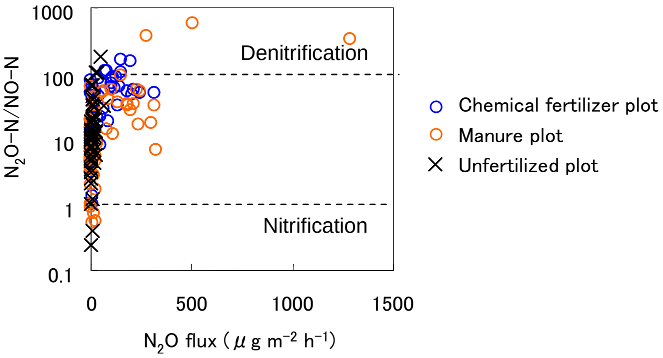

Figure 3.1.6 The relationship between N_2O fluxes and N_2O/NO

Table 3.1.15 N_2O emission

($kg\ N\ ha^{-1}\ y^{-1}$)

	Manure plot	Chemical fertilizer plot	Control plot	Average
2004/10 – 2005/9	3.8 (1.2)	2.8 (0.7)	0.8 (0.4)	2.5
2005/10 – 2006/9	4.9 (2.8)	2.9 (0.7)	0.5 (0.3)	2.8
Average	4.4	2.9	0.6	

Factor	Result of a two-way ANOVA Degree of freedom	 Sum of squares deviation	 Mean squares	 F value	 P value
Year	1	2.4	2.41	9.04	0.005
Experiment	2	0.3	0.13	0.48	0.625
Year×experiment	2	0.2	0.08	0.32	0.732
Error	30	8.0	0.27		
Total	35	10.8			

Standard deviations are shown in parentheses. Variance in years and experiments were performed by a two-way analysis of variance. When a significant variation was found, each standard was verified by Tukey and the level of significance was set as 5%.

Table 3.1.16 Emission factor

(%)

	Manure	Chemical fertilizer
2004/10 – 2005/9	0.6	1.3
2005/10 – 2006/9	0.9	1.3

6) Global warming potential (GWP)

The GWP values were -17.2 and -18.3 Mg CO_2eq ha^{-1} y^{-1} in the manure plot and 4.0 and -1.3 Mg CO_2eq ha $^{-1}$ y^{-1} in the chemical fertilizer plot in 2005 and 2006, respectively. Furthermore, a large negative value was observed in the manure plot (Table 3.1.17). This demonstrated that, the manure plot had a function in mitigating global warming. This also made the CO_2 budget (NBP) positive, due to the application of C through manure, and greatly contributing to this, N_2O was found to exert a constant influence on global warming while CH_4 hardly exerted an influence. The N_2O emission increased due to the application of manure 1.4 to 1.7 times more than the chemical fertilizer plot. On the whole, it was found that the application of manure could mitigate global warming but could also increase N_2O emissions. Sufficient consideration is necessary in this regard.

Table 3.1.17 Global warming potential (GWP)

（Mg CO_2 eq ha^{-1} y^{-1}）

	Manure plot				Chemical fertilizer plot			
	GWP components			GWP	GWP components			GWP
	CO_2	CH_4	N_2O		CO_2	CH_4	N_2O	
2004/10 – 2005/9	-19.0	0.0	1.8	-17.2	2.7	0.0	1.3	4.0
2005/10 – 2006/9	-20.6	0.0	2.3	-18.3	-2.6	0.0	1.3	-1.3
Average	-19.8	0.0	2.0	-17.7	0.0	0.0	1.3	1.4

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3.2 The greenhouse gas budget for the Nakashibetsu site, classified as a sub-polar zone

Summary

An average of 41 tons ha^{-1} of manure was applied in the late autumn of 2004 and 2005 on the grassland (common Andosols) located in the sub-polar zone in Japan. Primarily this is cultivated with timothy grass, where soil freezing occurs during the winter. A grassland field with only an application of chemical fertilizer was also set up for comparison. The manure was prepared by piling up beef cow waste and bedding materials outdoors for about 8 months. The manure was then applied onto the experimental plots (moisture content, T-C and T-N contents were 71, 41 and 0.6%, respectively).

The annual amount of NEP was 3.4 and 2.1 Mg C ha^{-1} yr^{-1}, and the annual NBP was -0.4 and 3.4 Mg C ha^{-1} yr^{-1} in the chemical fertilizer and manure plots, respectively. That is to say, although the application of manure increased the CO_2 emission, it also increased the C accumulation of the grassland.

Additionally, using the manure remarkably increased the amount of N_2O emission. The influence was not observed on the amount of CH_4 emission.

The GWP in the chemical fertilizer and manure plots ranged from -0.2 to 3.4 Mg CO_2 eq ha^{-1} yr^{-1} and from -12.8 to -10.7 Mg CO_2 eq ha^{-1} yr^{-1}, respectively, and furthermore the global warming mitigation effect of the manure application was found.

3.2.1 Introduction

Due to concern about actualizing the environmental load resulting from the surplus of livestock waste because of the large scale dairy farming management, a "Law concerning the promotion of livestock waste management and its proper use" was absolutely enforced in Japan in November 2004. Appropriate use of livestock waste on grasslands will become a big problem with respect to dairy farming management in the future. On the other hand, it is expected that the application of livestock waste, which is a vast source of C and N, could have an impact on emission and uptake of major greenhouse gases such as CO_2, CH_4 and N_2O occurring in grasslands. In Japan, grasslands occupy 13% of the total agricultural land, and evaluating this human impact with respect to global warming cannot be ignored. Eighty percent of the Japan's grassland is located in Hokkaido. The most substantial is the grassland area of the Konsen region in eastern Hokkaido, which has the largest dairy farming area in Japan. This occupies 30% of the country's total grassland area. Moreover, this region is cool and has poor sunshine during the summer. It is located in a region where severe weather conditions occur, and conditions such as soil freezing takes place much more during the winter every year, compared to other dairy farming and livestock regions in Hokkaido. It is expected that the emission and uptake of greenhouse gases occurring in this region are remarkably different from other regions. This study, therefore, was conducted to evaluate the actual circumstances of such greenhouse gases and the impact of applying manure by measuring uptake and emission of CO_2, CH_4 and N_2O for two years in a real scale on grasslands of the Konsen region. This result contributes to a comparative study with three other sites (New-Hidaka Shizunai Town in Hokkaido, Nasushiobara City in Ibaraki Prefecture, and Kobayashi City in Miyazaki Prefecture).

3.2.2 Materials and methods

1) Study site

This study was conducted in the Hokkaido Prefectural Konsen Agriculture Experiment Station (Hokkaido Shibetsu Gun Nakashibetsu Town Sakuragaoka 1 Chome, 43°32' N 144°E'). The annual mean temperature from 1971 to 2000 was 5.6℃, the annual precipitation was 1160mm and the annual duration of sunshine was 1604h.

The soil profile of the study site is given in Table 3.2.1, and the physical and chemical properties of the soil are given in Table 3.2.2. The soil of the study site is common andosols (black volcano ash soil) with parent materials of volcanic ash erupted from the Meakan dake, Kamuinupuri dake and Mashu dake. It has abundant light humus together with an extremely large phosphorus absorption coefficient.

Table 3.2.1 Soil profile of the study site

Soil profile	Depth(cm)	Humus	Gravel	Soil colour	Soil texture	Soil structure	Hardness
1	2 - 20	Very high	Common	7.5YR1/1	L	Thin blocky	15 - 20
2	20 - 33	High	Abundant	7.5YR2/2	L	Blocky	24
3	33 - 43	Medium	Abundant	10YR3/4	S	Thin blocky	25

Table 3.2.2 Soil physical and chemical properties of the study site

Soil profile	Depth(cm)	Bulk density g m L^{-1}	pH	C	N	Exchangeable K	Exchangeable Mg	Exchangeable Ca	CEC	Phosphoric acid absorption coefficient
				Dry soil proportion%		me100g dry soil^{-1}				
1	0 - 20	0.67	5.8	6.05	0.44	0.11	0.27	4.58	5.50	1829
2	20 - 33	0.60	5.9	4.78	0.38	0.13	0.28	2.84	3.65	2197
3	33 - 43	0.63	6.0	1.81	0.16	0.11	0.04	0.79	1.26	1450

The study site has mixed grasslands of timothy (*Phleum pratense* L.) and white clover (*Trifolium repens* L.). The largest cultivated area of timothy is in Hokkaido, due to its preference by milk cows, and its excellence for winter-hardness. Moreover, white clover mixed with timothy grass is widely used because of its improvement to mineral composition in fodder by its mixing with gramineous plants. In addition, there is a reduction in N fertilizer by N fixation from rhizobium

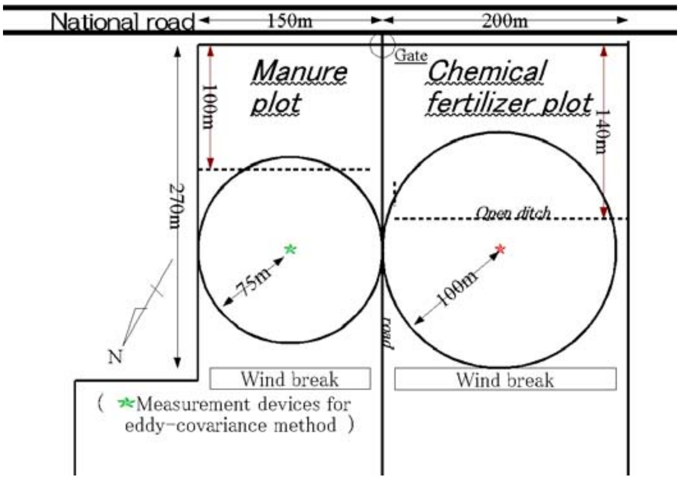

Figure 3.2.1 Location map of the experimental plots.

bacteria that live together in the root zones.

Figure 3.2.1 shows the layout of the experimental plots. The area of the chemical fertilizer and the manure plots is 5.40 and 4.05 ha respectively, and the surroundings are experimental fields of the Konsen Agriculture Experiment Station. The experimental grassland was renovated in August 1998 and May 1997 for chemical fertilizer and manure plots, respectively and was broadcasted with timothy and white clover seeds (Table 3.2.3). Since the renovation of the grasslands, these have been used as a meadow for harvesting, and biannual harvests have been carried out. Furthermore, as shown in Table 3.2.5, both of these experimental plots were managed under the same fertilization condition from 1999 to the beginning of this study. The major vegetation type in the experimental site until the beginning of this study was timothy. Also white clover cultivation decreased regardless of the fertilization experiment 2005 onwards (Table 3.2.5).

Table 3.2.3 Seeding grass types and rate during the renovation of grasslands

Chemical fertilizer plot1)		Manure plot 2)	
Seeding grass type (Breed)	Seeding rate (kg ha^{-1})	Seeding grass type (Breed)	Seeding rate (kg ha^{-1})
Timothy grass(Kirutappu)	20	Timothy grass(Kunbu)	12
White clover(Sonya)	20	White clover(Sonya)	3

1) Renovated in August 1998; 2) Renovated in May 1997

Table 3.2.4 Fertilizer application since the renewal of grasslands to the beginning of this study (kg ha^{-1})

Year	Chemical fertilizer plot			Manure plot		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O
1997				40	80	80
1998	40	80	80	80	140	300
1999	60	105	225	60	105	225
20001)	69	102	214	69	102	214
20012)	68	68	68	68	68	68
2002	67	93	173	67	93	173
2003	60	84	156	60	84	156
20043)	61	61	61	61	61	61

1) Manure 18ton ha^{-1} (common for both experimental plots)
2) Manure 3.3ton ha^{-1} (common for both experimental plots)
3) Manure 44ton ha^{-1} (only manure plot, fertilization experiemnt of this study)

Table 3.2.5 Proportion of floristic composition in experimental grasslands (fresh weight of grass %)

Year	Number of yield	Survey date	Manure plot			Chemical fertilizer plot		
			Forage grass1)	Herbage Legume2)	Broad-leaved Weed3)	Forage grass1)	Herbage Legume2)	Broad-leaved Weed3)
2004	1	1 July	87	12	0	81	19	1
	2	19 August	79	14	7	79	19	1
2005	1	21 June	88	7	5	94	5	1
	2	24 August	76	4	20	88	3	9
2006	1	29 June	93	3	4	98	1	1
	2	4 September	90	1	9	97	0	3

1)Main is timothy grass (*P. Pratense L.*), and orchard grass (*D. glomerata L.*) and reed canary grass (P. arundinacea) are also partly mixed.
2)Almost all is white clover (*T. repens*)
3)Mainly broadleaf dock (*R. obtusifolius*)

2) Study period

The study was carried out from October 2004 to September 2006. However, from now on, the period from October 2004 to September 2005 is referred to as 2005, and October 2005 to September 2006 is referred to as 2006. The annual cumulative amounts of the variables mentioned above were calculated accordingly.

3) Fertilizer management

The manure and chemical fertilizer plots were established as experimental plots. The manure used for the experiment was beef cow manure containing dung, urine, bedding material and wood waste from bark (Table 3.2.6). This was prepared by piling the manure outdoors for about 8 months, by beef cow farmers in Shintoku town.

The manure mentioned above was continuously used on the manure plot in the autumn of 2005 and 2004. The quantity of the manure used was the standard amount determined by soil chemical properties and vegetation of experiment grasslands (Hokkaido Fertilizer Guide, Hokkaido Agricultural Policy Planning Department, 2002). The upper limit of the application of dairy cow waste was set as 40 Mg ha^{-1} (Table 3.2.4).This was calculated using the content of nourishment in the manure sample that was collected from manure selling farmers on August 6th 2004 and from the standard fertilizer efficiency converted into chemical fertilizer (Livestock Waste Experimental and Use Guideline, 2004 Hokkaido Agriculture, Livestock Experiment Station Livestock Waste Project Team). The amount of chemical fertilizer decreased due to the use of manure being 27, 31 and 170 kg ha^{-1} in 2005 (Table 3.2.7) and 50, 54 and 209 kg ha^{-1} in 2006 (Table 3.2.8) for N, P_2O_5 and K_2O, respectively. On the basis of the content of nourishment in the manure and Uchida's model (N, used parameters of the fermented waste of cattle) and the standard fertilizer efficiency rate (P_2O_5 and K_2O, Livestock Waste Experimental and Use Guideline, 2004; Hokkaido Agriculture, Livestock Experiment Station Livestock Waste Project Research Team) that was converted from the dairy cow waste and applied onto the grasslands. Manure was applied by a manual spreader. In order to measure CH_4 and N_2O fluxes using the closed chamber method, the manure must be spread onto the measurement plots accurately and evenly. Therefore, manure consisting of 44 Mg ha^{-1} was applied by human power onto these plots (2.5m×2.5m×6 plots) on 11th November 2004 and 29th October 2005.

The chemical fertilizer was applied in the early spring and after the first harvesting. The application rate between these times was set at 2:1 in the chemical fertilizer plot (Table 3.2.9).

The application of chemical fertilizer was divided into the early spring and after the first harvesting, and the distribution was set at 2:1 in the chemical fertilizer plot (Table 3.2.9).

Table 3.2.6 Application rate and chemical characteristics of the manure

Year	Date of application		Applied amount (Mg ha^{-1})	(Fresh manure proportion %)						
	Beginning	Finish		Moisture content	T-C	T-N	P_2O_5	K_2O	CaO	MgO
2005	2004/11/08	2004/11/11	44.2	72	42.7	0.47	0.35	0.55	0.90	0.20
2006	2005/10/27	2005/10/28	38.1	69	40.0	0.71	0.50	0.69	0.72	0.28

Table 3.2.7 Possible decreased amount of fertilizer in 2005 by using manure

Symbol	Item	Unit	Nutrients			Calculation method
			N	P_2O_5	K_2O	
A	Amount of nutrients through applied manure in autumn 2004	kg ha^{-1}	208	156	243	
B	Emission proportion of the nutrients from manure	%	13	20	70	
C	Possible amount of fertilizer reduction	kg ha^{-1}yr^{-1}	27	31	170	A * B / 100

*: N was calculated by using the Uchida's Expression Model (Fermented excrement), P and K were calculated by using the standard efficiency of fertilizer for the conversion of applied dairy cow waste to the chemical fertilizer (Livestock Excrement Experimental and Use Guideline, 2004 Hokkaido Agriculture and Animal Research Center).

Table 3.2.8 Possible decreased amount of fertilizer in 2006 by using manure

Symbol	Item	Unit kg ha^{-1}	Nutrients			Conversion method
			N	P_2O_5	K_2O	
A	Amount of nutrients through applied manure in autumn 2004	kg ha^{-1}yr^{-1}	208	156	243	
B	Amount of nutrients through applied manure in autumn 2005		271	192	264	
C	Emission proportion of the nutrients from manure in 2004*	%	7	10	10	
D	Emission proportion of the nutrients from manure in 2005*		13	20	70	
E	Possible amount of fertilizer reduction in 2004	kg ha^{-1}yr^{-1}	15	16	24	A * C / 100
F	Possible amount of fertilizer reduction in 2005		35	38	185	B * D / 100
G	Possible amount of fertilizer reduction	kg ha^{-1}yr^{-1}	**50**	**54**	**209**	E + F

*: N was calculated by using the Uchida's Expression Model (Femented cattle excrement), P and K were calculated by using the standard efficiency of fertilizer for the conversion of applied dairy cow waste to the chemical fertilizer (Livestock Excrement Experimental and Use Guideline, 2004 Hokkaido agriculture and Animal Research Center).

Table 3.2.9 Applied chemical fertilizer (kg ha^{-1})

Experimental plot	Year	Fertilizer type	Applied date	Applied amount（kg ha^{-1}）			
				T-C	T-N	P_2O_5	K_2O
Season-wise applied amount							
Manure plot	2005	Manure	2004/11/8-11	5270	208	156	243
		Chemical fertilizer	2005/05/12	0	44	44	15
		Chemical fertilizer	2005/07/21	0	30	30	10
	2006	Manure	2005/10/27-28	4720	271	192	264
		Chemical fertilizer	2006/05/15	0	60	72	0
		Chemical fertilizer	2006/07/14	0	20	24	0
Chemical fertilizer plot	2005	Chemical fertilizer	2005/05/12	0	65	71	142
		Chemical fertilizer	2005/07/21	0	33	36	71
	2006	Chemical fertilizer	2006/05/15	0	67	73	145
		Chemical fertilizer	2006/07/14	0	33	36	73
Yearly applied amount							
Compost manure plot	2005			5270	282	230	268
	2006			4720	351	288	264
Chemical fertilizer plot	2005			0	98	107	213
	2006			0	100	109	218

4) Field management

Chemical fertilizer was applied twice a year to both the manure and chemical fertilizer plots. A biannual harvest was conducted together in both these experimental plots (Table 3.2.10). Moreover, manure was applied to the manure plot at the end of fall.

Table 3.2.10 Schedule of the field management

Particulars	2005		2006	
	Manure plot	Chem. Fertil. plot	Manure plot	Chem. Fertil. plot
Manure application	2004/11/8-9	-	2005/10/27-28	-
Below-ground part survey in early spring	-	-	2006/05/12	
Early spring fertilization	2005/05/12		2006/05/15	
Survey of the yield of first crop	2005/06/21		2006/06/29	
First crop harvesting	2005/06/23-24		2006/07/05	2006/07/08
Additional fertilization	2005/07/21		2006/07/14	
Survey of the yield of second crop	2005/08/24		2006/09/04	
Second crop harvesting	2005/8/29-30		2006/09/06	

5) Net ecosystem production (NEP)

A continuous observation of the CO_2 flux in a 2.5 m height was conducted by the eddy-covariance method. A measurement device was installed at the center of each experimental plot from 30th August to 1st September in 2004 (Figure 3.2.1 and Figure 3.2.2). A three-dimensional wind velocity was measured with a sonic anemometer-thermometer (CSAT3; Campbell Scientific Instruments, UT, USA) and the atmospheric CO_2 concentration was measured with an open path non-dispersive infrared (NDIR) analyzer (LI-7500; LI-COR Inc., NE, USA) 10 times per second in the 2.5 m height. NEP was calculated by supplementing the missing data from the temperature and the observed value of PPFD with the look-up table method, after a quality inspection of the 30 m average value of 10 Hz data, for the period from October 2005 to September 2006 and using the 10 Hz data for the period from October 2004 to September 2005.

Figure 3.2.2 Measurement device for eddy-covariance method

6) Net biome production (NBP)

The NBP was calculated by the following equation:

$$\text{NBP (Mg C ha}^{-1}\text{ yr}^{-1}\text{)} = \text{NEP} + \text{applied manure} - \text{yield}$$

7) CH_4 and N_2O fluxes

CH_4 and N_2O fluxes were measured by a closed chamber method. After closing the chamber, the 20mL of air inside the chamber was taken into a 10 mL empty vial bottle in 0 and 30min. The number of replication was six for each experimental plot.

8) Global warming potential (GWP)

The GWP values were calculated by the following equations (IPCC, 2001):

$\mathrm{GWP}\ (\mathrm{Mg\ CO_2eq\ ha^{-1}\ y^{-1}}) = \mathrm{GWPCO_2} + \mathrm{GWPCH_4} + \mathrm{GWPN_2O}$

$\mathrm{GWPCO_2}\ (\mathrm{Mg\ CO_2eq\ ha^{-1}\ y^{-1}}) = -\mathrm{NBP}\ (\mathrm{Mg\ C\ ha^{-1}\ y^{-1}}) \times 44/12$

$\mathrm{GWPCH_4}\ (\mathrm{Mg\ CO_2eq\ ha^{-1}\ y^{-1}}) = \mathrm{CH_4\ emission}\ (\mathrm{Mg\ C\ ha^{-1}\ y^{-1}}) \times 16/12 \times 23$

$\mathrm{GWPN_2O}\ (\mathrm{Mg\ CO_2eq\ ha^{-1}\ y^{-1}}) = \mathrm{N_2O\ emission}\ (\mathrm{Mg\ N\ ha^{-1}\ y^{-1}}) \times 44/28 \times 296$

9) Yield

The yield of grassland was measured by reaping grass on a 1m^2 circular quadrate at 10 sites in each of the experimental plots. The height of reaping was set at 5cm. Out of the collected samples, a 100g was separated for the measurement of dry matter proportion and for analyzing C and N. Another 500g was separated for analyzing the composition of grass type. The former samples were dried at 70℃ with a ventilating dryer for more than 72h, dry matter weight was measured, and finally the samples were ground by a Wiley mill and then used for analyzing C and N contents. The latter was classified into gramineous plants, leguminous grass and broad-leaved weeds. Their fresh weights were measured. Those could not be classified immediately were wrapped in a newspaper and a plastic bag and were put into the refrigerator at 5℃. After classification, the samples were dried at 70℃ with a ventilating dryer for above 72h and the dry matter weight was measured.

10) Root biomass

After the grass was harvested, a surface layer of the grassland (50cm×25cm×20cm) was dug out and beaten with the back of a kitchen knife. After separating it from the soil, the root parts were washed in clear water with a carwash machine (Figure 3.2.3). In addition to this, after being soaked in water, separated by hand and having removed the unnecessary parts from the soil, the samples were dried at 70℃ with a ventilating dryer for more than 48h, and a total dry matter weight of root and stubble was measured. The samples were separated into roots and stubble. Dry matter weight was measured after drying it at 70℃ with a ventilating dryer for more than 48h, and the samples were crushed by a Wiley mill for analyzing C and N.

Figure 3.2.3 Survey on the below-ground parts of the grassland (May 2006).

3.2.3 Results and discussion

1) Weather

There was a tendency of a little annual precipitation compared to the normal year, though the annual mean temperature and the annual duration of sunshine changed to almost normal (Table 3.2.11). Furthermore, the mean temperature of the period from May to September 2006 was higher than the average years and the duration of sunshine also tended to be longer.

The continuous snow cover period was from 5th December 2004 to 16th April 2005 and from 10th December 2005 to 22nd April 2006. The ending of snowfall was ten days later than in average years. The maximum snow coverage depth was 83 and 65cm in 2005 and 2006, respectively. Whereas the previous year was almost normal, the latter was shallower than it. The soil freezing depth was 13cm on 20th February 2005 and 7cm on the same day in 2006, both being shallower than in average years.

The sprouting time of timothy was as normal as on 26th April 2005 and 28th April 2006.

Table 3.2.11 Precipitation, temperature and duration of sunshine during the study

Period	Annual			May - September		
	Precipitation (mm)	Mean temperature (℃)	Duration of sunshine(h)	Precipitation (mm)	Mean temperature(℃)	Duration of sunshine (h)
2004/10 – 2005/9	1,009	5.7	1,631	553	14.2	541
2005/10 – 2006/9	1,069	6.0	1,693	649	14.7	630
Annual average	1,160	5.6	1,604	658	13.8	529

2) Yield

The fresh weight yield of the above-ground part reached the targeted yield (45-50 Mg ha^{-1}, Hokkaido Fertilizer Guide, Hokkaido Agricultural Policy Planning Department, 2002) in both 2005 and 2006 (Table 3.2.12). The dry weight yield indicated a high value in 2006. There was no significant difference in the dry weight yield in 2004 before the fertilizer experiment, and in both 2005 and 2006 after the fertilizer experiment.

Table 3.2.13 shows the quantity of harvested parts, stubble and below-ground biomass. The biomass above-ground and its C content increased. In particular, those of harvested parts remarkably increased during the period of early spring to the time of surveying the first harvested yield (Table 3.2.13 and 3.2.14). However, there was no distinct increase and decrease in the stubble and the below-ground biomass.

Table 3.2.12 Annual yield of above-ground part (Mg ha^{-1})

Experimental plot	Average amount of harvested fresh matter±SD				Average amount of harvested fresh matter±SD			
	2004	2005	2006	3-year average	2004	2005	2006	3-year average
Chemical fertilizer plot	39 ±5	55 ±6	50 ±6	48 ±9	8.0 ±1.1	8.3 ±0.9	9.8 ±1.2	8.7 ±1.3
Manure plot	42 ±4	49 ±8	54 ±6	48 ±8	8.6 ±0.8	7.7 ±1.1	10.4 ±1.1	8.9 ±1.5

Table 3.2.13 Change in biomass and amount of its composition part on 12th May 2006 and 29th June 2006 (Mg ha^{-1})

Experimental plot	Early spring				
	Harvested part	Stubble	Above-ground biomass*	Below-ground biomass	Total biomass
Chemical fertilizer plot	1.5	2.2	3.7	4.5	8.2
Manure plot	1.5	1.4	2.9	3.3	6.3
	First harvesting time				
	Harvested part	Stubble	Above-ground biomass*	Below-ground biomass	Total biomass
Chemical fertilizer plot	5.7	2.5	8.2	3.8	12
Manure plot	6.3	2.2	8.5	3.8	12.3

* Above-ground biomass is given by adding up amount of harvesting part and stubble

Table 3.2.14 Change in the carbon content of pasture (12th May 2006 and 29th June2006, Mg C ha^{-1})

Experimental plot	Early spring				
	Harvested part	Stubble	Above-ground biomass*	Below-ground biomass	Totalbiomass
Chemical fertilizer plot	1.5	2.2	3.7	4.5	8.2
Chemical fertilizer plot	0.6	0.9	1.5	1.7	3.3
Manure plot	0.6	0.6	1.2	1.3	2.6
	First harvesting time				
	Harvested part	Stubble	Above-ground biomass*	Below-ground biomass	Total biomass
Chemical fertilizer plot	5.7	2.5	8.2	3.8	12
Chemical fertilizer plot	2.4	1.0	3.4	1.5	4.9
Manure plot	2.7	0.9	3.6	1.6	5.2

* Above-ground biomass is given by adding up amount of harvested part and stubble

3) Net ecosystem production (NEP)

The NEP showed a diurnal variation of a positive value during the day time and a negative value during the nighttime in each fertilizer experiment. Moreover, a positive value of NEP was observed during the grass growing season, and a negative value was observed after the harvest (Figure 3.2.4). Remarkable emission or uptake was not observed during the snow covered period. However, there was a difference between the experimental plots in the first period until the first harvesting time (May-June 2005) and in the second period between first and second harvesting times (July-August 2006), and it was also observed that the daily mean value of the chemical fertilizer plot exceeded that of the manure plot. Although NEP is the difference between the CO_2 uptake due to the photosynthesis of plants and the CO_2 emission from plants and soil respiration, as well as decomposition of organic matter, it would be difficult to assume that there would be a big difference in the uptake and emission amount due to photosynthesis and respiration of herbage plants (Table 3.2.12). This is because the yield of herbage plants was almost equal in both of these experimental plots. It is supposed that CO_2 could have been emitted, after the decomposition of manure that was applied to the surface in the autumn of the previous year.

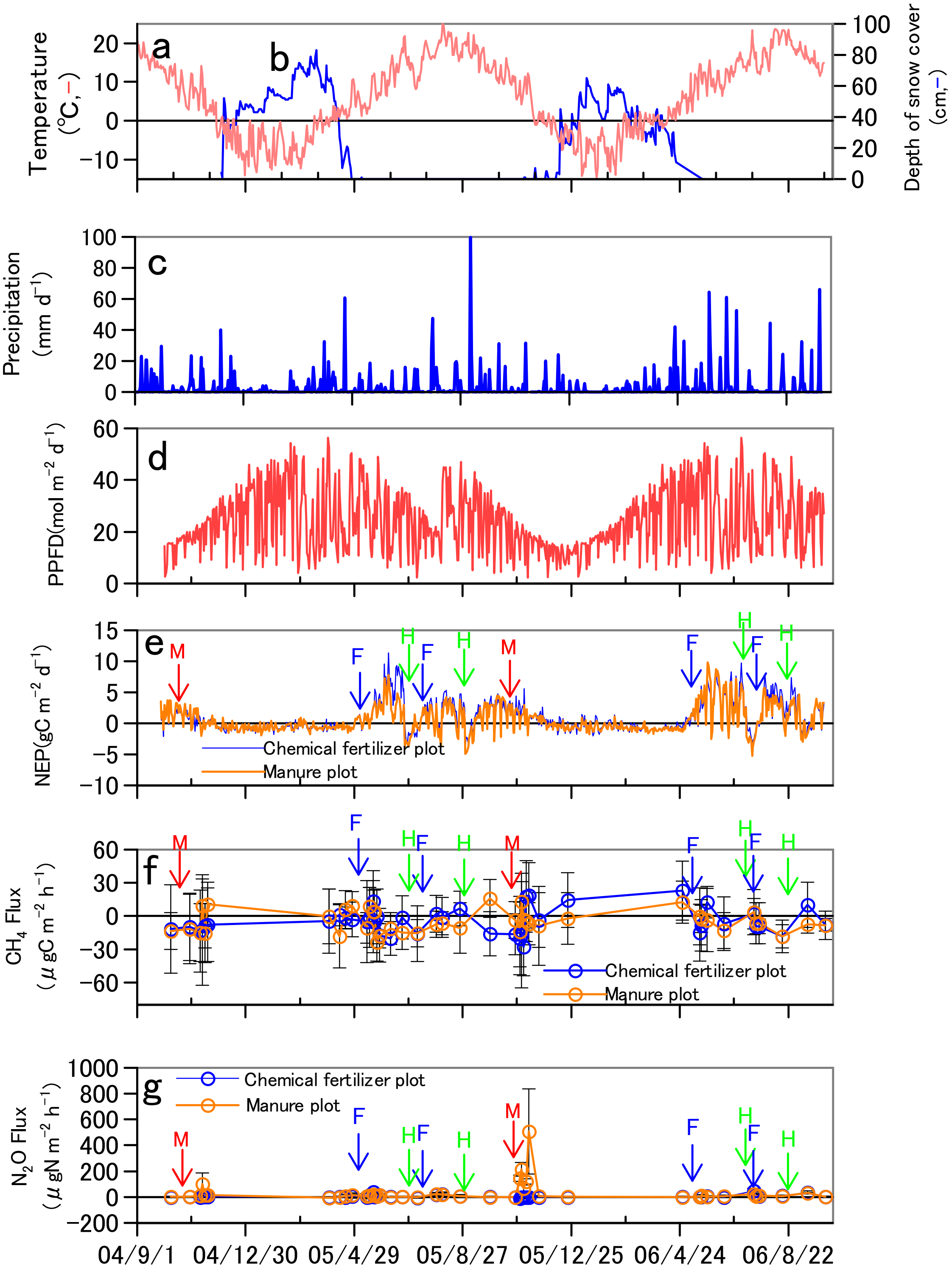

Figure 3.2.4 Seasonal variations in temperature (a) snow cover depth (b) precipitation (c) photosynthetic photon flux density (d) net ecosystem production (e) CH_4 fluxes (f) N_2O fluxes (g). (Temperature and snow cover depth are the daily mean values and all others are cumulative values. F, chemical fertilizer application; M, manure application; H, harvest)

4) Net biome production (NBP)

The NBP in the studied grassland from October 2004 to September 2006 is given in Table 3.2.15. A large difference in NBP from October 2004 to September 2005 and from October 2005 to September 2006 was not observed in both of these experimental plots. On the other hand, the NEP indicated a large value in the period from October 2005 to September 2006 compared with that from October 2004 to September 2005. The difference in these annual values corresponded well to the difference in the grass yield. When comparing between these experimental plots, a constant tendency was observed in both of these fiscal years. That is, although it was equal in the yield, a larger value of NEP was found in the chemical fertilizer plot than in the manure plot. However, the amount of an increase by the application of manure was large, and the annual NBP per ha of land was -0.39 (-0.90 – 0.11) Mg and 3.37 (3.17 – 3.57) Mg in the chemical fertilizer and manure plots, respectively; the NBP of the manure plot greatly exceeded that of the chemical fertilizer plot.

Table 3.2.15 NBP in the studied grassland (October 2004 – September 2006, Mg C ha^{-1} y^{-1})

Period	Manure plot				Chemical fertilizer plot		
	NEP	Harvested part	Applied manure amount	NBP	NEP	Harvested part	NBP
2004/10 - 2005/9	1.27	3.29	5.27	3.57	2.67	3.57	- 0.90
2005/10 - 2006/9	2.91	4.46	4.72	3.17	4.22	4.11	0.11
Annual average	2.09	3.88	5.00	3.37	3.45	3.84	- 0.39

5) CH_4 flux

CH_4 fluxes showed negative values in the period from summer to autumn while occasionally indicating positive values in the spring (Fig. 3.2.4). The annual amount of CH_4 emission is presented in Table 3.2.16. The result of a two-way ANOVA showed that although there was no significant difference in CH_4 emission, either between the experimental plots or between the study years, uptake was observed in 2005, while emission was observed in 2006.

Table 3.2.16 CH_4 emission (kg C ha^{-1} y^{-1}) from the study grasslands

	Manure plot	Chemical fertilizer plot	Average
2004/10 – 2005/9	- 0.23(0.83)	- 0.55(1.04)	-0.39
2005/10 – 2006/9	0.03(0.55)	0.41(0.54)	0.22
Average	- 0.10	- 0.07	

Factor	Result of a two-way ANOVA Degree of freedom	Sum of squares	Mean squares	F value	P value
Year	1	2.2	2.2	3.8	0.067
Experiment	1	0.0	0.0	0.0	0.947
Year×experime	1	0.7	0.7	1.2	0.279
Error	20	11.9	0.6		
Total	23	14.9			

Standard deviations are shown in parentheses. Variations in years and experiments were analyzed by a two-way ANOVA. When a significant variation was found, each standard was verified by Tukey-test and the level of significance was set as 5%.

6) N_2O flux

N_2O fluxes apparently rose after the application of manure (Figure 3.2.4) and it also tended to rise after the application of chemical fertilizer. The annual amount of N_2O emission is given in Table 3.2.17. The result of a two-way ANOVA showed that the annual amount of N_2O emission had a significant interaction between the experimental plots and the study years at 1% significance level. There was also a strong tendency of larger values in the manure plot, compared to the chemical fertilizer plot; and both were larger in 2006 than in 2005.

Table 3.2.17 N_2O emission （kg N ha^{-1} y^{-1}）

	Manure plot	Chemical fertilizer plot	Average
2004/10 – 2005/9	0.63 (0.22)	0.31 (0.13)	0.47
2005/10 – 2006/9	1.91 (0.60)	0.46 (0.10)	1.19
Average	1.27	0.38	

	Result of a two-way ANOVA				
Factor	Degree of freedom	Sum of squares	Mean squares	F value	P value
Year	1	3.1	3.1	28.8	0.000
Experiment	1	4.7	4.7	43.9	0.000
Year × experiment	1	1.9	1.9	18.0	0.000
Error	20	2.2	0.1		
Total	23	11.9			

Standard deviations are shown in parentheses. Variations in years and experiments were analyzed by a two-way ANOVA. When a significant variation was found, each standard was verified by Tukey-test and the level of significance was set as 5%.

7) Global warming potential (GWP)

The GWP was significantly different between the chemical fertilizer and manure plots (Table 3.2.18). That is, the GWP values equivalent to CO_2 in the manure and chemical fertilizer plots were -11.8 and 1.6 Mg ha^{-1} yr^{-1} and the manure plot showed a tendency of mitigating global warming. While the chemical fertilizer plot showed the opposite tendency of enhancing it. Moreover, although the contribution of CH_4 was remarkably small compared to that of CO_2 regardless of the year, the contribution of N_2O in the chemical fertilizer plot was at a level that can not be disregarded in the second year.

Table 3.2.18 Global warming potentials in the study grassland (Mg CO_2eq ha^{-1} y^{-1})

Period	Manure plot			
	$GWPCO_2$$^{1)}$	$GWPCH_4$	$GWPN_2O$	GWP$^{2)}$
2004/10 - 2005/9	-13.1	-0.01	0.29	-12.8
2005/10 - 2006/9	-11.6	0.00	0.89	-10.7
Average	-12.3	0.00	0.59	-11.8
	Chemical fertilizer plot			
	$GWPCO_2$$^{1)}$	$GWPCH_4$	$GWPN_2O$	GWP$^{2)}$
2004/10 - 2005/9	3.3	-0.02	0.14	3.4
2005/10 - 2006/9	-0.4	0.01	0.21	-0.2
Average	1.4	0.00	0.18	1.6

1) NBP was used for $GWPCO_2$. Positive values represent enhancement of global warming.

2) $GWP=GWPCO_2+GWPCH_4+GWPN_2O$

8) Remaining issues

It is necessary to further examine and to clarify the annual change in C content in grassland. For example, the whole pasture including the below-ground biomass, soil and manure applied to the surface, and also to confirm the consistency in the estimated C budget value in our study. In addition, the influence of meteorological conditions on greenhouse gas budgets has not been studied yet.

9) Presentation

Kouda,Y., Saigusa,T., Miyata,A., Mano, M., Matsuura, S., Hojito, M., (2006) CO_2 flux on grasslands in Konsen plot of eastern Hokkaido, Obihiro Asia and the Pacific Seminar on Education for Rural Development, Expert meeting

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3.3 The greenhouse gas budget for the Nasushiobara site, classified as a temperate zone

Summary

Fluxes of CO_2, CH_4 and N_2O were measured for about two years on a real scale on grasslands, by setting up two experimental plots of manure and chemical fertilizer in Nasushiobara City located in the temperate zone in Japan.

In the first year, the NEP exceeded the C yield in both the manure and chemical fertilizer plots. Although the value of NEP was smaller in the manure plot than that in the chemical fertilizer plot, the NBP in the manure plot exceeded that of the chemical fertilizer plot because of application of C through manure. CH_4 showed a little uptake tendency, while N_2O showed a peak emission immediately after the manure application and during July through September. Regarding the GWP, the influence was large in the order of CO_2 and N_2O, the annual GWP showed negative values in both these experimental plots, and the effect of mitigating global warming was observed.

In the second year, the NEP fell below the C yield in both these experimental plots. Therefore, NBP indicated a negative value in the chemical fertilizer plot, and degradation loss of soil organic C was considered. The manure plot indicated a negative value of the NBP although the values were smaller than the previous year. CH_4 indicated a similar tendency to the previous year, but it had many emission peak frequencies compared to the previous year. In addition, the total emission of N_2O was almost as twice large as the previous year. From all these impacts, the influence of N_2O on GWP was relatively larger, and GWP showed some negative values in the manure plots while showing positive values in the chemical fertilizer plots.

In this study site, control of the NBP balance and N_2O emission was suggested by the GWP values. In order to improve the effect of global warming mitigation, clarifying the relationships among grassland management, N_2O emission and the environmental condition in which a high NBP could be maintained is required.

3.3.1 Introduction

The grassland ecosystem occupies one-fourth of the total terrestrial area in the world. This is an important ecosystem with respect to the greenhouse gas budget. Greenhouse gases are emitted to the atmosphere by a variety of human activities. The emission of greenhouse gases originating from the husbandry of livestock is becoming a serious concern. The livestock husbandry in Japan has adopted a system that depends on huge imported feed, and this in turn is creating problems of water pollution because of livestock waste. This is because the system of applying the manure onto the farmland is inappropriate and the livestock waste is disposed. From these circumstances, it can be said that although promoting proper utilization of livestock waste to the grassland is necessary, it is very important to clarify the impact of applying the manure on grasslands and on greenhouse gas budgets. Therefore, a long term monitoring of greenhouse gas fluxes on grasslands was initiated, aiming at clarifying the impact of applying manure on grasslands on the greenhouse gas budget. This chapter reports on the monitoring results of CO_2, CH_4 and N_2O fluxes on the grassland at Nasushiobara City in Ibaraki Prefecture.

3.3.2 Materials and methods

1) Study site

The study was conducted at the National Institute of Livestock and Grassland Science, Grassland Research Center (36°55′N, 139°58′E, altitude 320m) located in Nasushiobara City, Ibaraki Prefecture. The annual mean temperature of the study site is 12°C and the annual rainfall is 1561mm. For the study, two grassland sites adjacent to each other inside the research center were set up as experimental plots. Out of which one was applied with both manure and chemical fertilizer (manure plot) and the other with only chemical fertilizer (chemical fertilizer plot). Topography of both these experimental plots was almost flat. The area of the manure plot was 2.4ha while that of chemical fertilizer plot was 2.3ha.

The results of the soil profile study and the physical and chemical properties of the soil are given in Table 3.3.1 and 3.3.2, respectively.

Table 3.3.1　Soil profile study results of the studied grassland

(a) Manure plot

Study date 2004/8/1

Japanese classification：Epi-humic Andosols
Parent rock：Volcaniclastic material/Alluvial fan sediment, Volcanic ash/Igneous rocks
Mode of deposition: Eolian/Aqueous
Landform：Alluvial fan
Altitude：
Slope：

Erosion：
Land use：Grassland
Vegetation：
Drainage condition：Good drainage Bare rock
Investigators：Kohyama Kazunori, Matsuura Soji

Depth(cm)	Humus	Gravel	Soil color	Soil texture	Structure	Mottling	Pore	Root	Hardness	Remarks
0－23	High		10YR2/3	CL	Very weak subangular blocky			Common	22	
23－40	High		10YR2/3	CL	Very weak subangular blocky			Common	19	
40－59	Medium		10YR4/3	LiC	Very weak subangular blocky			Common	15	
59－76			10YR5/4	LiC	Very weak subangular blocky			Few	15	
76－		Gravel layer								

(b) Chemical fertilizer plot

Study date 2004/8/1

Japanese classification：Epi-humic Andosols
Parent rock：Volcaniclastic material/Alluvial fan sediment, Volcanic ash/Igneous rocks
Mode of deposition：Eolian/Aqueous
Landform：Alluvial fan
Altitude：
Slope：

Soil erosion：
Land use：Grassland
Vegetation：
Drainage condition: Moderate drainage condition
Bare rock：
Investigators：Kohyama Kazunori, Matsuura Soji

Depth(cm)	Humus	Gravel	Soil color	Soil texture	Soil structure	Mottling	Pore	Root	Hardness	Remarks
0－25	High	Common	10YR2/2	CL	Weak subangular blocky			Many	16	
25－47	High	Common	10YR3/2	CL	Very weak subangular blocky	Filmy, Root-like iron, common(7.5YR3/3)		Common	22	
47－57	Medium		2.5Y4/1	CL	Very weak subangular blocky	Filmy, Root-like iron, Abundant(7.5YR4/6)		Few	24	
57－72			2.5Y5/4	L	Very weak subangular blocky				30	
72－96+		Few	2.5Y5/4	CoSL						

Table 3.3.2 Physical and chemical properties of the soil

(a) Manure plot — Study date 2004/8/1

Depth cm	pH	Bray P_2O_5 mg100g DM^{-1}	Ex- K_2O mg100g DM^{-1}	Ex- MgO mg100g DM^{-1}	Ex- CaO mg100g DM^{-1}	P absorp- tion	CEC me 100g^{-1}	Dry bulk concentration g/cm^{-3}	C %	N %
0－10	5.4	0.4	10.8	21.0	116.6	1304	15.8	1.04	4.08	0.32
10－23	5.6	86.9	5.1	26.6	201.5	1317	16.9	0.89	4.20	0.32
23－40	5.7	16.0	2.7	19.7	115.5	1766	16.5	0.61	4.00	0.22
40－59	6.1	20.4	2.1	27.6	117.6	1189	10.3	0.76	1.30	0.10
59－76	6.4	2.0	2.0	17.9	119.7	821	9.4	1.01	0.47	0.06

(b) Chemical fertilizer plot — Study date 2004/8/1

Depth cm	pH	Bray P_2O_5 mg100g DM^{-1}	Ex-K_2O mg100g DM^{-1}	Ex-MgO mg100g DM^{-1}	Ex-CaO mg100g DM^{-1}	P absorp- tion	CEC me 100g^{-1}	Dry bulk concentration g/cm^{-3}	C %	N %
0－15	5.2	1.6	3.0	8.7	72.9	1709	18.6	1.01	5.77	0.37
15－25	5.6	6.2	1.8	11.8	137.4	1751	21.0	0.93	5.63	0.37
25－35	5.8	5.8	1.5	11.6	173.7	1780	18.5	1.00	5.63	0.34
35－47	5.8	2.4	1.3	8.4	134.1	1607	17.9	1.04	5.63	0.33
47－57	5.5	0.5	1.3	5.2	38.2	890	7.9	1.29	1.83	0.13
57－72	5.2	0.4	1.7	8.6	30.8	388	4.7	1.67	0.19	0.04

The study grassland was renovated in September of 2001 and orchardgrass seeds were broadcasted (Table 3.3.3). The first harvest was carried out in autumn in 2001. After the first year, four harvests were carried out every year until the beginning of the study.

Table 3.3.3 Fertilization history of the study site

Year	Annual fertilizer amount N-P_2O_5-K_2O (kg ha^{-1})	Number of harvest
2001	106-106-106	1 (Nov.)
2002	160-100-160	4
2003	160-100-160	4
2004	154-154-154（Manure plot） 151-151-151（Chemical fertilizer plot）	4

Remarks: Renovated in 20th September 2001 and broadcasted orchardgrass seed (33 kg ha^{-1})

Table 3.3.4 shows the change of vegetation in the study grassland. Vegetation of the study grassland was almost similar at both these plots in the beginning of measurement. The main grass types were Italian ryegrass (*L. Multiflorum*) and orchardgrass until the first and second harvest, while weeds such as *D. ciliaris* and *E. crus-galli* dominated the third and fourth harvesting time. In this way, this vegetation showed seasonal changes. Furthermore, the growth of the cool season-type grasses in summer was depressed because the daily maximum temperature of 30℃ or more exceeded 20 days a year and *D. ciliaris* and *E. crus-galli* grew thickly in the northern part of the Kanto region. In addition, when autumn begins, the fallen seed of the Italian ryegrass in the second plot germinates together with the growth recovery of orchardgrass. This allows Italian ryegrass and orchardgrass to become major in the next spring. The seasonal change in such vegetation does not usually become a big problem during feed production since the use of *D. ciliaris* and *E. crus-galli* as feed is possible. However, in the regions west of Kanto, maintaining the cool season-type grasslands over many years is difficult, and people are generally required to renovate it once in every seven years.

Table 3.3.4 Change of vegetation in the study grassland

(a) Manure plot

Survey date	2004/7/7	2004/10/27	2005/5/13	2005/9/9	2006/5/15	2006/9/28*
Vegetation coverage (%)	96.5	96.5	95.6	98.1	95.9	92.6
Canopy height (cm)	89.7	31.9	68.3	66.6	71.6	18.6
Proportion of vegetation type (%)						
Orchardgrass	50.00	27.00	26.63	1.05	5.22	0.10
Italian ryegrass	44.00	47.00	62.40	0.05	78.00	0.70
White clover			4.03	0.50		
D. ciliaris	2.05	35.00		71.00		25.13
E. crus-galli		7.50		25.02		10.60
P. asiatica	15.10	8.63	1.85	1.67	2.63	25.20
D. chrysantha	1.50	2.33	1.98	0.77	7.50	15.93
R. obtusifolius	2.40	0.73	0.08	1.08	0.15	5.13
R. indica	0.40	0.93	0.05	0.08	0.20	4.65
E. philadelphicus	0.73	1.60	1.73	1.40	2.97	7.72
C. gracile	0.78	0.55	0.08	0.17	0.13	4.93

*The ground coverage of grass was low because the study in September 2006 was conducted when the grass was not grown enough after the third harvesting.

(b) Chemical fertilizer plot

Survey date	2004/7/7	2004/10/27	2005/5/13	2005/9/9	2006/5/15	2006/9/28*
Vegetation coverage (%)	95.7	97.0	95.5	97.9	79.4	99.0
Canopy height (cm)	82.1	38.1	75.7	75.9	50.1	27.1
Proportion of vegetation type (%)						
Orchardgrass	51.50	70.50	33.60	3.53	13.63	10.52
Italian ryegrass	42.50	7.90	54.00		17.77	0.08
White clover	0.20	3.50	5.00		2.53	5.00
D. ciliaris	0.53	23.40		51.13		25.40
E. crus-galli		4.70		42.83		2.22
P. asiatica	7.50	5.50	3.55	0.30	8.90	28.40
D. chrysantha	1.40	2.80	3.33	0.45	27.13	30.90
R. japonicus	0.70	6.80	0.43	0.15		6.43
R. indica	1.50	0.50	0.05	0.08	3.17	2.92
E. philadelphicus	0.70	3.60	3.47	0.03	0.82	0.93
C. gracile	1.63	2.53	0.55	0.13		0.73

*The ground coverage of herbage was low because the study in September 2006 was conducted when herbage was not grown enough after the third harvesting.

Overseeding of Italian ryegrass was conducted, since the ground coverage of Italian ryegrass decreased in the autumn of 2005 and onwards in the chemical fertilizer plot. However, the grassland with broadcasted seed did not grow properly, as the grassland coverage continued to be low and weeds such as *P. asiatica* and *D. chrysantha* increased. It seems that *D. chrysantha* increased because there were some faults in drainage due to the building marks in the chemical fertilizer plot. However, these grass types are of a lower plant height, and do not contribute to the yield. The ground coverage of orchardgrass grew to be higher in the chemical fertilizer plot compared to that in the manure plot.

This site was investigated for the grassland dominated by orchardgrass, and that is a representative of the cool region-type grassland. However, it has a high temperature in the summer (exceeding 30℃) and is often in depressed conditions for the growth of the cool season-type grasslands, in a periphery of the area. A similar type of grassland is seen surrounding the area, especially in public grassland. Therefore, the study site can be called general grassland. In such a severe environmental condition, it is usual for there to be a gradual decrease in the vegetation density of the cool season-type grass three years after the seed sowing. Therefore, this study site was set up as a research example of the process to which vegetation gradually changes under high temperature conditions in the summer and low temperatures in the winter.

2) Study period

The study was carried out from mid September 2004 to mid November 2006. Data analysis was performed dividing into the different periods of 8th November 2004 to 15th November 2005 and 16th November 2005 to 8th November 2006, according to the management of the study grasslands.

3) Field management

Harvest was carried out four times a year in the study grassland, and chemical fertilizer was applied to both these experimental plots after the harvest and in early spring. Moreover, dairy cow manure with bark of 15 t ha^{-1} was applied to the manure plot on 16-17th November 2004 and 32 t ha^{-1} on 25-29th November 2005 was applied to the manure plot. Manure was applied by scattering it on the soil surface. The amount of fertilizer application during the study period is given in Table 3.3.5 and the chemical properties of the applied manure are given in Table 3.3.6

Table 3.3.5 Applied amount of fertilizer

Experimental plot	Period	Fertilizer type	Applied date	Applied amount (kg ha^{-1})			
				C	N	P_2O_5	K_2O
Manure plot	2004/11 – 2005/11	Manure	2004/11/16～17	1850	75.3	117	236
		Chemical fertilizer	2005/3/15	0	59.8	59.8	59.8
		Chemical fertilizer	2005/5/26	0	60.1	25.3	0
		Chemical fertilizer	2005/7/19	0	60.1	25.3	0
		Chemical fertilizer	2005/9/15	0	30.1	12.7	0
		Total		1850	285	241	296
	2005/11 – 2006/11	Manure	2006/11/25～29	3790	195	287	373
		Chemical fertilizer	2006/3/16	0	29.9	12.3	0
		Chemical fertilizer	2006/5/25	0	53.8	22.1	0
		Chemical fertilizer	2006/7/15	0	44.8	18.5	0
		Chemical fertilizer	2006/9/8	0	26.9	11.1	0
		Total		3790	351	351	373
Chemical fertilizer plot	2004/11 – 2005/11	Chemical fertilizer	2005/3/15	0	60.4	60.4	60.4
		Chemical fertilizer	2005/5/26	0	59.5	29.7	59.5
		Chemical fertilizer	2005/7/19	0	59.5	29.7	59.5
		Chemical fertilizer	2005/9/15	0	29.7	14.9	29.7
		Total		0	209	135	209
	2005/11 – 2006/11	Chemical fertilizer	2006/3/16	0	59.5	29.7	59.5
		Chemical fertilizer	2006/5/25	0	59.5	29.7	59.5
		Chemical fertilizer	2006/7/15	0	49.6	24.8	49.6
		Chemical fertilizer	2006/9/8	0	29.7	14.9	29.7
		Total		0	198	99.1	198

Furthermore, as decay of vegetation was observed in the chemical fertilizer plot after the fourth harvesting in 2005, a further 80kg of Italian ryegrass seed (Ace) was broadcasted on the 20th of March and 1st of August 2006, assuming the natural falling of grass seed.

Table 3.3.6 Chemical properties of the applied manure

Year	Applied date		Applied amount kg ha^{-1}	Nutrient content (% FM)				
	Start	End		Moisture content	T-C	T-N	P_2O_5	K_2O
2004	11/16	11/17	15059	69.0	12.31	0.50	0.78	1.57
2005	11/25	11/29	31970	68.4	11.84	0.61	0.90	1.17
2006	11/13	11/14	30520	67.2	11.76	0.41	0.47	1.00

4) Weather

Measured weather data of the research station was used for the duration of sunshine and a part of temperature and precipitation data appearing in this chapter. However, the main general weather element in the study of grasslands was assumed (Table 3.3.7).

5) Yield

(1) Above-ground part

Before each respective harvest, a yield survey was conducted immediately by a pro-mower using a swath of 130cm. Such reaping and measurements, were conducted at 8 to 30 sites in a straight line in each experimental plot. For a portion of the above-ground part of the plant body reaped in each point, dry matter content was measured by drying the sample at 70℃ with a ventilating dryer for more than 72h and C and N content rates were measured by a CN corder (JM1000CN; J-SCIENCE LAB).

(2) Below-ground part

The below-ground part of the plant body was surveyed on the 21st of August 2006. Four points in each experimental plot were selected, and the size was set as 25cm×50cm. The above-ground part of the plant body inside the study site was reaped almost at the same height of the stubble, and both dry matter weight and CN content were measured similarly to that during the yield survey. The stubble and the root in the study site were dug up to a depth of 25cm (with the soil) and were then removed. The collected sample was dried at 70℃ with a ventilating dryer for more than 72h after flushing the soil using a two tank-type washing machine, and was then followed by separating the stubble and root. After this, dry matter weight and CN content were also measured.

Table 3.3.7 Measurement items and its outline regarding CO_2 and steam fluxes

Measurement items	Used device	Height and depth setting (cm)	Experimental plots setting
Wind velocity of three components	Sonic anemometer-thermometer (CSAT3; Campbell Scientific)	Manure plot: +232 Chemical fertilizer plot : ＋245	Both plots
CO_2, and steam density	Open path infrared gas analyzer (LI-7500 ; LI-COR)	Same height of Sonicanemometer-thermometer	Both plots
Incidenced Photosynthetic photon flux density	Photon sensor (LI-190SA; LI-COR)	＋150	C.F. plot
Reflected Photosynthetic photonflux density	Photon sensor (LI-190SA; LI-COR)	＋150	Both plots
Air temperature and relative humidity	Temperature humidity sensor (HMP45A; Vaisala)	＋234	Manure plot
Soil temperature	T type thermocouple	－5, －10, －30	Both plots
Soil moisture content	Soil moisture probe (EC-20; Decagon)	－5, －10, －30	Both plots
Net radiation	Ultra shortwave radiometer (MR-40; EKO)	＋150	Manure plot
Soil heat flux	Heat flux censor (MF-81; EKO)	－2～3	Manure plot
Rain gauge	Fall-type rain gauge	＋54	Manure plot

[a] ＋, above-ground; －, below-ground

[b] 10Hz records the measured value of 10 Hz surrounding. For other items, it records the average values of a 30min period

[c] Data logger 21X Campbell was used for data recording. CR23X (Campbell) was used for other items

C.F., chemical fertilizer

6) CO_2 budget

(1) Measurement of the net ecosystem production by the eddy-covariance method

The measurement of CO_2 by the eddy-covariance method and the measurements of steam flux began in September of 2004. The eddy-covariance system is composed of a sonic anemometer-thermometer and an open path infrared gas analyzer. The system was then set up almost at the center of the experimental plots together with the measuring instrument of related meteorological elements. The measurement items and their outline are given in Table 3.3.7. The measurement was done at a frequency of 10Hz, and correction and quality control were applied to the acquired data. The data of every 30min was averaged. The amount of storage flux below the height of the measurable limit was ignored, and NEP was calculated. The u* correction was not performed. The missing data was supplemented by an interpolation method for up to one and half hours and by the table retrieval method for what was above it. In the table retrieval method, the mean value of the PPFD and the average value of flux for each category of temperature were calculated, and the missing data was supplemented by the values of the same category.

(2) Net biome production (NBP)

The net biome production (NBP) was calculated by the following equation:

NBP = NEP + Applied manure – yield

7) CH_4 and N_2O fluxes

The flux measurement of CH_4 and N_2O by the closed chamber method was begun in September 2004. The chamber used was a cylindrical shape, with a diameter of 40cm and height of 30cm. The upper part of the chamber was sealed after setting it up on the surface of the grassland, and air inside the chamber was taken into vial bottles by a syringe after 0 and 30min. The vial bottles were sent to Hokkaido University; and CH_4 was analyzed with an FID gas chromatograph (GC-8A; SHIMADZU), N_2O was analyzed with an ECD gas chromatograph (GC-14B; SHIMADZU) and fluxes of these gases were calculated.

8) Global warming potential (GWP)

The GWP values were estimated by the following equations:

$\mathrm{GWP}\ (\mathrm{Mg\ CO_2eq\ ha^{-1}\ y^{-1}}) = \mathrm{GWPCO_2} + \mathrm{GWPCH_4} + \mathrm{GWPN_2O}$

$\mathrm{GWPCO_2}\ (\mathrm{Mg\ CO_2eq\ ha^{-1}\ y^{-1}}) = -\mathrm{NBP}\ (\mathrm{Mg\ C\ ha^{-1}\ y^{-1}}) \times 44/12$

$\mathrm{GWPCH_4}\ (\mathrm{Mg\ CO_2eq\ ha^{-1}\ y^{-1}}) = \mathrm{CH_4\ emission}\ (\mathrm{Mg\ C\ ha^{-1}\ y^{-1}}) \times 16/12 \times 23$

$\mathrm{GWPN_2O}\ (\mathrm{Mg\ CO_2eq\ ha^{-1}\ y^{-1}}) = \mathrm{N_2O\ emission}\ (\mathrm{Mg\ N\ ha^{-1}\ y^{-1}}) \times 44/28 \times 296$

3.3.3 Results

1) Weather

The annual quantity of precipitation, temperature and duration of sunshine is given in Table 3.3.8. The monthly values of air temperature, precipitation, the duration of sunshine are not mentioned in the chapter, which are given in appendices. This also applies for the values of soil temperature.

The average temperature in each month from September 2004 to October 2005 was approximately normal. The annual average temperature was 12.3℃ and was almost equal to the average yearly value. There were plenty of months in this period, which had a large difference in the average yearly value. For example, the annual precipitation was 1503.5mm, falling a little below the annual average value of 1561.0mm.

During the period from November 2005 to October 2006, the average temperature was 11.6℃. This equaled the average yearly value, although, the average temperature of December 2005 and January 2006 fell below the average annual temperature of between 1 to 3℃. The average temperature of other months was almost normal. On the other hand, several months had precipitation higher than in the average year, and the annual precipitation of 1781.5mm greatly exceeded the average year values.

Furthermore, the duration of sunshine in one month changed to a value that was lower than the normal year throughout the study period. From April to July of 2006, the duration of sunshine was especially shorter than usual and there were some months where they had only one-third of the average yearly value.

Table 3.3.8 Annual precipitation, temperature and duration of sunshine during the study period

	Precipitation (mm)	Temperature (℃)	Duration of sunshine (h)
2004/11 – 2005/10	1503.5	12.3	1841.0
2005/11 – 2006/10	1781.5	11.6	1568.8*
Mean annual value	1561.0	12.0	2224.8

* Reference value because of the lack of measured value on 7-14 February and 15-30 March 2006.

2) Yield

The result of the survey on yield is given in Table 3.3.9. The first to the third harvesting in 2005 showed a similar growth tendency in both these experimental plots, and a significant difference in dry weight yield was not observed. Deterioration in forage plants was observed in the chemical fertilizer plot after the fourth harvesting of 2005; also the yield in the manure plot was significantly large in the fourth harvest of 2005 and first harvest of 2006. Afterwards, the deterioration also occurred in the manure plot. On the fourth harvest, the yield decreased in the manure plot, although on the second and third harvesting in 2006 the yield was similar in both the experimental plots. In 2006, there was an increase in the creeping-type of weeds such as *P. asiatica* and *D. chrysantha*, but these weeds did not have any role in the grass yields. The majority of the yield however, was occupied by Italian ryegrass and orchardgrass in the first and second harvesting. While, in the third and fourth harvestings the yield was occupied by *D. ciliaris* and *E. crus-galli* in both manure and chemical fertilizer plots.

Also, although the weight proportion of the harvested plant species could not be described accurately because the grass type-wise weight data was not acquired, it is thought that the weight ratio of grass (OG+IR) would have been approximately 80% in 2004, 70% in 2005 and 50% in 2006 in view of the crown coverage.

3) Biomass

The survey result on biomass and its composition showed that the below-ground biomass was 3.64 Mg DM ha^{-1} in the manure plot and 2.66 Mg DM ha^{-1} in the chemical fertilizer plot (Table 3.3.10). Furthermore, the amount of stubble was 1.13 Mg DM ha^{-1} in the manure plot and 0.85 Mg DM ha^{-1} in the chemical fertilizer plot. In addition, the amount of harvested biomass was 3.74 Mg DM ha^{-1} in the manure plot and 3.05 Mg DM ha^{-1} in the chemical fertilizer plot. This resulted in the below-ground biomass being 0.7 times the biomass above-ground. Also for the amount of C, the below-ground biomass was about 0.7 times the biomass above-ground (Table 3.3.10). Moreover, when the amounts of C in both these experimental plots were compared, a significant difference was found only in the amount of C in the below-ground biomass.

Table 3.3.9 Annual yield and the yield of each harvesting time

	Yield (Mg DM ha^{-1})		
	Manure plot	Chemical fertilizer plot	
2004/11-2005/11	11.18	10.43	
1st harvesting	3.84 (0.73)	3.81 (0.60)	n.s.
2nd harvesting	2.97 (0.15)	2.80 (0.22)	n.s.
3rd harvesting	3.13 (0.41)	3.22 (0.57)	n.s.
4th harvesting	1.24 (0.22)	0.60 (0.13)	*
2005/11-2006/11	9.62	9.01	
1st harvesting	4.36 (1.05)	3.47 (1.48)	*
2nd harvesting	3.05 (0.30)	2.78 (0.51)	n.s.
3rd harvesting	1.16 (0.25)	1.37 (0.30)	n.s.
4th harvesting	1.05 (0.28)	1.39 (0.33)	*

Standard deviations are shown in parentheses. A t-test was performed to confirm significant variation, and a significant level was set as 5%.

Table 3.3.10 Carbon content in the plant body (Survey results of below-ground biomass)

	Carbon content (Mg C ha^{-1})		
	Manure plot	Chemical fertilizer plot	
Total	3.76	2.89	
Above-ground biomass	1.63 (0.49)	1.35 (0.48)	n.s.
Stubble	0.50 (0.12)	0.37 (0.09)	n.s.
Below-ground biomass	1.63 (0.22)	1.17 (0.16)	*

Standard deviations are shown in parentheses. A t-test was performed to confirm significant variation, and a significant level was set as 5%.

3) CO_2 budget

(1) NEP estimated from an eddy-covariance method

The seasonal change in meteorological elements and NEP are given in Figure 3.3.1. NEP changed to a slightly more positive value during the winter in 2005. The NEP during this period showed a diurnal change in CO_2 uptake during the day time and CO_2 emission during the night time. Since the middle of March in 2005, a pattern of temporary CO_2 emission, immediately after harvest and an increase in CO_2 uptake with the regrowth of grass was repeated during the growing period in both plots. Although NEP of the manure and chemical fertilizer plots showed similar seasonal change, little difference was observed in their values. Particularly, the CO_2 uptake in the chemical fertilizer plot greatly exceeded that in the manure plot after the growing season of the second harvesting and during the midst of it, to after the growing season of the third harvesting in 2005.

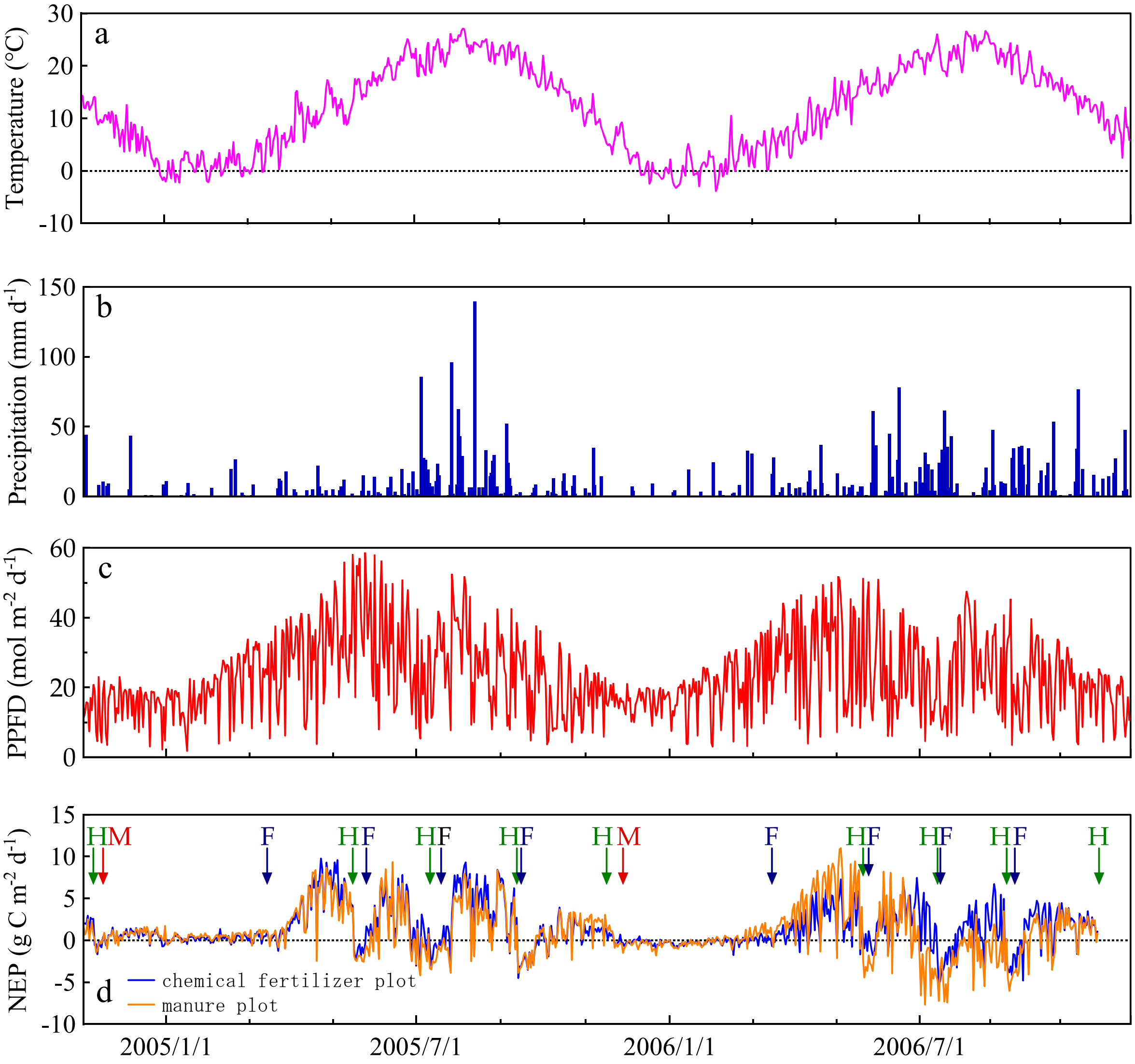

Figure 3.3.1 Seasonal change in temperature (a), precipitation (b), Photosynthetic photon flux density (c), and net ecosystem production (d).
Temperature shows daily average values while others show daily accumulated values.
H, Harvest; M, Manure application; F, Chemical fertilizer application

In 2006, although NEP during the winter changed to a negative value contrary to the previous year, a pattern in diurnal change of uptake during the day time and emission during the night time similar to the previous year was confirmed. The pattern of a seasonal change similar to that in 2005 was observed in mid March and onwards. However, the difference in NEP was found to be large in both these experimental plots; NEP of the manure plot greatly exceeded that of the chemical fertilizer plot during the first harvesting, and after that, the NEP of the chemical fertilizer plot exceeded that of the manure plot. The NEP inclined towards the CO_2 emission side, until the first half of the growing season of the fourth harvest in the manure plot.

2) NBP

The NBP of the study period is given in Table 3.3.11. The NEP was greater than the yield in the first and third harvestings. It was smaller than the yield in the second and fourth harvestings of the year. The NEP exceeded the yield in yearly cumulative values because it was first in both of the experimental plots. Although, the value of NEP was smaller in the manure plot than that of the chemical fertilizer plot, the annual NBP was 2.35 Mg C ha^{-1} in the manure plot and 1.83 Mg C ha^{-1} in the chemical fertilizer plot. This meant the manure plot exceeded the chemical fertilizer plot by 0.52 Mg C ha^{-1} due to the application of C through manure.

On the other hand, the value of NEP was remarkably smaller in 2006 than in 2005. This was found to be the same in both of the experimental plots. Comparison between the NEP and C yield indicated that the NEP was smaller than the yield, except for the first harvesting in the manure plot and the fourth harvesting in the chemical fertilizer plot, so that the NEP fell below the yield in annual cumulative values. The NEP values of the manure plot were smaller than that of the chemical fertilizer plot similar to the previous year, but the NBP in the manure plot exceeded the chemical fertilizer plot by 2.06 Mg C ha^{-1}, resulting as 1.83 Mg C ha^{-1} in the manure plot and −0.23 Mg C ha^{-1} in the chemical fertilizer plot.

Table 3.3.11 Annual amount of NBP

(Mg C ha^{-1} y^{-1})

	Manure plot				Chemical fertilizer plot		
	NEP	Yield	Applied manure	NBP	NEP	Yield	NBP
2004/11-2005/11*	5.27	4.78	1.85	2.35	6.36	4.53	1.83
1st harvesting	2.88	1.66			2.89	1.68	
2nd harvesting	0.61	1.28			1.08	1.21	
3rd harvesting	1.39	1.31			2.20	1.38	
4th harvesting	0.40	0.52			0.20	0.26	
2005/11-2006/11†	2.03	3.98	3.79	1.83	3.60	3.82	−0.23
1st harvesting	2.72	1.80			1.23	1.44	
2nd harvesting	0.01	1.27			1.18	1.19	
3rd harvesting	−0.93	0.48			0.29	0.59	
4th harvesting	0.24	0.44			0.90	0.60	
Average	3.65	4.38	2.82	2.09	4.98	4.18	0.80

*The cumulative period was 373 days beginning immediately after the fourth harvesting in 2004 to immediately before the fourth harvesting in 2005.

† The cumulative period was 357 days beginning immediately after the fourth harvesting in 2005 to immediately before the fourth harvesting in 2006.

4) CH_4 fluxes

The CH_4 flux showed the uptake tendency as a whole since the beginning of measurement, but the tendency decreased in the manure plot in 2006. Especially during the growing period until the third harvesting (from mid July to mid September) showed a tendency of larger values in the manure plot compared to those in the chemical fertilizer plot (Figure 3.3.2). The result of the amount of annual emissions is given in Table 3.3.12. The result of a two-way ANOVA showed that although there was no significant difference in the annual CH_4 emission between the experimental plots, a significant difference between the years was found at 1% level, indicating a larger uptake in 2005 than in 2006.

Table 3.3.12 Annual CH_4 emission

(kg C ha^{-1} y^{-1})

	Manure plot	Chemical fertilizer plot	Average
2004/11-2005/11	-0.75 (0.33)	-0.86 (0.30)	-0.80
2005/11-2006/11	-0.15 (0.51)	-0.50 (0.23)	-0.32
Average	-0.45	-0.68	

Result of a two-way ANOVA

Factor	Degree of freedom	Sum of squares	Mean squares	F value	P value
Year	1	1.4	1.4	10.9	0.004
Treatment	1	0.3	0.3	2.5	0.133
Year×Treatment	1	0.1	0.1	0.7	0.426
Error	20	2.6	0.1		
Total	23	4.4			

Standard deviations are shown in parentheses. Variations in years and experiments were analyzed by a two-way ANOVA. When a significant variation was found, each standard was verified by Tukey-test and the level of significance was set as 5%.

5) N_2O fluxes

The N_2O flux showed a distinct peak in the manure plot immediately after the application of manure (Figure 3.3.2). Both these experimental plots showed distinct peaks starting during the growing period until the third harvesting (from mid July to mid September). Both soil moisture and soil temperature increased during this time. However, the annual amount of emissions increased in the second year in both these plots (Table 3.3.13). The result of a two-way ANOVA showed that there was a significant difference (at 1% level) in annual N_2O emission between the years. Also, the year 2006 showed a larger emission than 2005. Moreover, the manure plot showed tendencies of a larger emission than in the chemical fertilizer plot (p=0.063), although a significant difference between the experimental plots was not observed.

Table 3.3.13 Annual N_2O emission

(kg N ha^{-1} y^{-1})

	Manure plot	Chemical fertilizer plot	Average
2004/10-2005/9	7.1 (2.8)	4.8 (1.0)	5.9
2005/10-2006/9	10.9 (3.6)	9.1 (2.2)	10.0
Average	9.0	6.9	

Result of a two-way ANOVA

Factor	Degree of freedom	Sum of squares	Mean squares	F value	P value
Year	1	101.6	101.6	15.5	0.001
Treatment	1	25.4	25.4	3.9	0.063
Year×Treatment	1	0.4	0.4	0.1	0.820
Error	20	131.4	6.6		
Total	23	258.7			

Standard deviations are shown in parentheses. Variations in years and experiments were analyzed by a two-way ANOVA. When a significant variation was found, each standard was verified by Tukey-test and the level of significance was set as 5%.

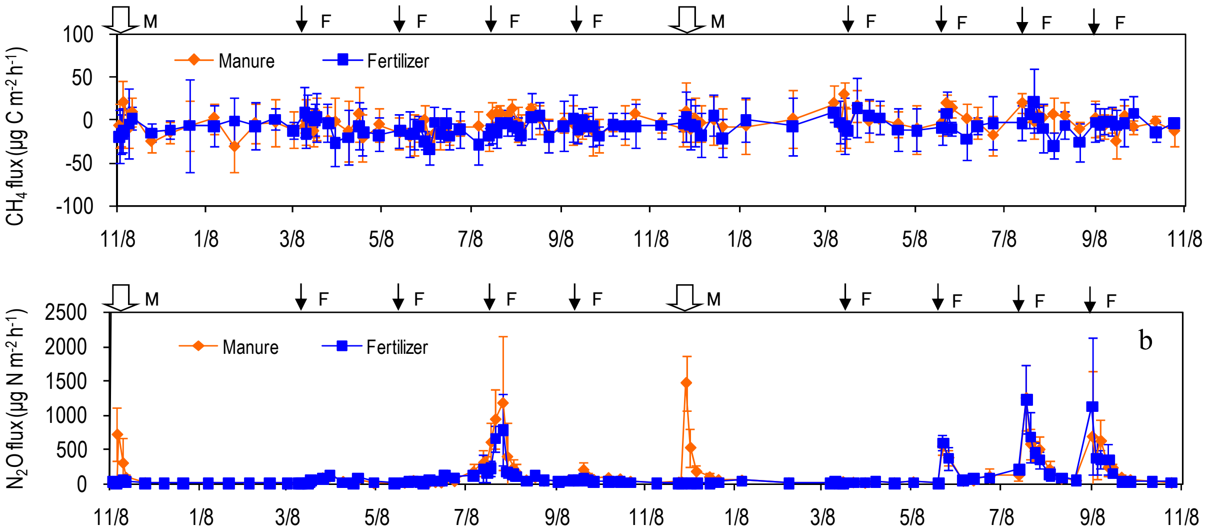

Figure 3.3.2 Seasonal change in CH_4 (a) and N_2O flux (b)
M, Manure application; F, Chemical fertilizer application

6) Global warming potential (GWP)

Table 3.3.14 shows the GWP values. Both these experimental plots indicated negative values of CO_2 in 2005, and its absolute value was larger in the manure plot. CH_4 in both of the experimental plots was almost zero. Moreover, N_2O showed positive values in both these experimental plots, and the value of the manure plot slightly exceeded that of the chemical fertilizer plot although there was no significant difference between the experimental plots. The GWP (with respect to the three greenhouse gases mentioned above) indicated negative values, and the results in the manure plot was lower than the chemical fertilizer plot by 0.8 Mg CO_2eq ha^{-1} y^{-1}.

In 2006, CO_2 showed negative values in the manure plot while positive values in the chemical fertilizer plot. CH_4 was almost zero in both of the experimental plots, and was similar to the previous year. Moreover, the value of N_2O exceeded the first year in both the experimental plots. As a result, the influence of N_2O on total GWP (due to the three greenhouse gases) appeared significant. A large positive value was observed in the chemical fertilizer plot, while a negative value was seen in the manure plot. The difference in GWP between both these experimental plots was 6.7 Mg CO2eq ha^{-1} y^{-1}.

Table 3.3.14 Annual GWP and its components

(Mg CO_2eq ha^{-1} y^{-1})

	Manure Plot				Chemical fertilizar plot			
	GWP CO_2	GWP CH_4	GWP N_2O	GWP	GWP CO_2	GWP CH_4	GWP N_2O	GWP
2004/11-2005/11	-8.6	-0.02	3.3	-5.3	-6.7	-0.03	2.2	-4.5
2005/11-2006/11	-6.7	-0.005	5.1	-1.7	0.8	-0.02	4.2	5.0
Average	-7.7	-0.01	4.2	-3.5	-2.9	-0.02	3.2	0.27

NBP was used for GWPCO_2. Positive values indicate the enhancement of global warming.

3.3.4 Discussion

1) CO_2 budget

A CO_2 flux had been measured by the eddy-covariance method for about two years. This indicated seasonality regarding the amount of CO_2 exchange between the grassland and the atmosphere (Figure 3.3.1). It was thought that the herbage plants kept performing considerable amounts of photosynthesis or respiration for this period because the NEP showed a variation in uptake during the day time, and emission during the night time even in the winter. Moreover, although NEP in the winter changed from a positive value in 2005 to a negative value in 2006, the monthly mean temperature from November to January was larger in 2005 by a margin of 0.5 to 3.9℃. It is guessed that this difference in temperature might have exerted an influence on the NEP in the winter. CO_2 uptake in the chemical fertilizer plot exceeded that in the manure plot for a certain period of time of the grass-growing period. However, it was thought that the CO_2 emission by the decomposition of manure in the manure plot might have exerted influence on it, because this phenomenon was observed remarkably in the late second growing period, in the third growing period and during times of high temperature.

Although the magnitude of NEP and C yield varied depending on time, the NEP exceeded the C yield in annual gross weight in 2005 in both of the experimental plots (Table 3.3.11). This result indicated that C was fixed to the grassland in both the experimental plots, and it was considered that the study grassland was a sink of CO_2. On the other hand, in the annual gross weight in the second year in both these experimental plots, showed the NEP fall below the C yield and it was thought that the soil organic C could have been decomposed.

Comparison of NEP in both the experimental plots showed that the annual gross weight in the chemical fertilizer plot exceeded that in the manure plot because of the difference between the amounts of NEP in the two plots from the second to third harvesting (as mentioned above). However, the applied C amount by the application of manure in the manure plot was larger than that difference, and this made the annual NBP in the manure plot exceed as a result. This also indicated that the C fixation amount of the manure plot was larger, suggested a possibility to consider that the application of manure could have increased C fixation amounts in the grassland. Also in 2006 when NEP fell below the C yield, the NBP indicated a positive value in the manure plot as an effect of manure application and it also indicated that C was fixed to the grassland.

2) CH_4 and N_2O fluxes

The CH_4 flux during the growing period until the third harvesting (mid July to mid September) was larger in the manure plot than that found in the chemical fertilizer plot. The N_2O flux had a tendency to rise in both these experimental plots in the growing period of the third harvesting. This period had a high temperature and this could have possibly influenced the phenomenon mentioned above. Due to the increase in precipitation, soil moisture increased in this season. Moreover, the CH_4 had a consistent tendency to decrease in the uptake amount compared to the N_2O flux, which had the tendency of an increase. The main grass types such as Italian ryegrass and orchardgrass were also obviously declining and there is a possibility that these could have had an influence on the change in the amount of uptake and emission fluxes, because of a decreasing tendency in the amount of annual production of main grass types. In addition, a tendency of slightly higher soil pH values was found in the manure plot compared to that of the chemical fertilizer plot where it was recognized.

It would be necessary to analyze the relationship between these environmental factors and the fluxes of CH_4 and N_2O in more detail in the future.

3) GWP

The GWP values were negative in both these experimental plots in the first year, indicating that the study grassland had an effect of mitigating global warming, despite the difference in fertilizer management. Moreover, with respect to the influence on GWP, CH_4 hardly influenced the GWP whereas; CO_2 had the largest influence followed by N_2O.

The GWP in 2006 indicated slightly negative values in the manure plot due to the impact of a decrease in NBP and an increase in N_2O emission, and further, positive values in the chemical fertilizer plot. With respect to the influence on GWP, N_2O was relatively large, and the influence of N_2O became larger in the chemical fertilizer plot. In both years, CH_4 hardly had an influence on the GWP.

From what was mentioned above, it was suggested that GWP was greatly controlled by the balance of NBP and N_2O emission in this study grassland. Furthermore, in order to improve the effect of global warming mitigation, it is necessary to manage grasslands by highly maintaining the NBP, and clarify in more detail the relationship between N_2O emission and various soil conditions.

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3.4 The greenhouse gas budget for the Kobayashi site, classified as a warm temperate zone

Abstract

Greenhouse gas budgets were investigated on the grassland in Kobayashi City, Miyazaki Prefecture. The study site absorbed CO_2, emitted N_2O and slightly absorbed CH_4. During application of manure, the uptake of CO_2 slightly decreased while the emission of N_2O and the cumulative amount of C increased. The result of calculating the GWP from these numerical values indicated that the study site contributed to the control of global warming. Among these, the emission of N_2O had a large effect on enhancing global warming. Therefore, the necessity of improving the accumulation of C by the application of manure, and such management that controls N_2O emission, were considered to be very important with respect to global warming.

3.4.1 Introduction

Recently, with respect to the concern towards global warming, the greenhouse gases being emitted to the atmosphere are becoming a problem. These gases are emitted to the atmosphere due to agricultural production activity, while another part of it is acquired by the plant ecosystem. To date, many studies concerning greenhouse gas dynamics, used to be conducted in the forest, and examples of studies in the grassland are extremely few. Grasslands are not the only places from where livestock are fed, and it is an ecosystem that plays an important role in the way manure is produced, along with the production of livestock. It is expected that the greenhouse gases are absorbed because of this and the accumulation functions of C exist. A study was therefore carried out on the dynamics of greenhouse gases together with C accumulation, and it also included exploring the impact of applying manure to the grassland located in a mountainous area, classified as the warm temperate zone in Japan.

3.4.2 Materials and methods

1) Outline of the study site

The study was conducted at the independent administrative agency, National Livestock Breeding Center, Miyazaki Station (31°58′N, 130°56′E, elevation 298-301m) for three years, starting in 2004. This station is located at the foot of the eastern slope of Kirishima mountain. The annual mean temperature is about 16℃, and the annual mean rainfall is

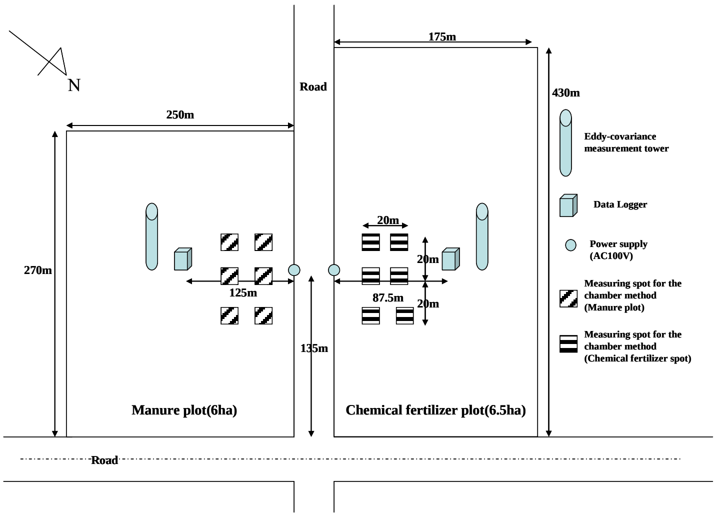

Figure 3.4.1 Layout of the experimental plots

about 2,500mm. Snow is very rare. As for the study site, two plots of grassland, adjacent to each other (having a road for agriculture purpose in between these as shown in Figure 3.4.1) were used. Both manure and chemical fertilizer were applied to the grassland (6ha) on the eastern side (manure plot) and only chemical fertilizer was applied to the grassland (6.5ha) on the western side (chemical fertilizer plot). The manure and chemical fertilizer plots were improved in 1998 and 1997, respectively where orchardgrass and tall fescue had dominated growth for two to three years. After this occurred, these grasses deteriorated and weeds dominated during the summer. Therefore orchardgrass and tall fescue seeds were broadcasted on both plots in 2003 and 2004 (Table 3.4.1). However, during the study period, Italian ryegrass (*L. Multiflorum*) dominated the grassland from autumn to spring and crab grass (*D. ciliaris)* dominated in the summer as shown in Figure 3.4.2 and Table 3.4.1.

Incidentally, the annual mean temperature of the study site is about 16℃ as mentioned above, and it is classified as a warm region-type grassland belt from the prospects of the weather zone division as designated by the MAFF Livestock Industry Bureau. From the prospect of transition of grass-type composition along with time, as shown in Figure 3.4.2 and Table 3.4.2, the ground coverage of temperate grass in summer (August) was almost zero. As a standard, the summer slump of the cool region-type grass and the dry matter production of the cool season-type grasses of August falling lower than 3.5 $gm^{-2} day^{-1}$ is apparent. In addition, the study site is located at an altitude of 300m, and

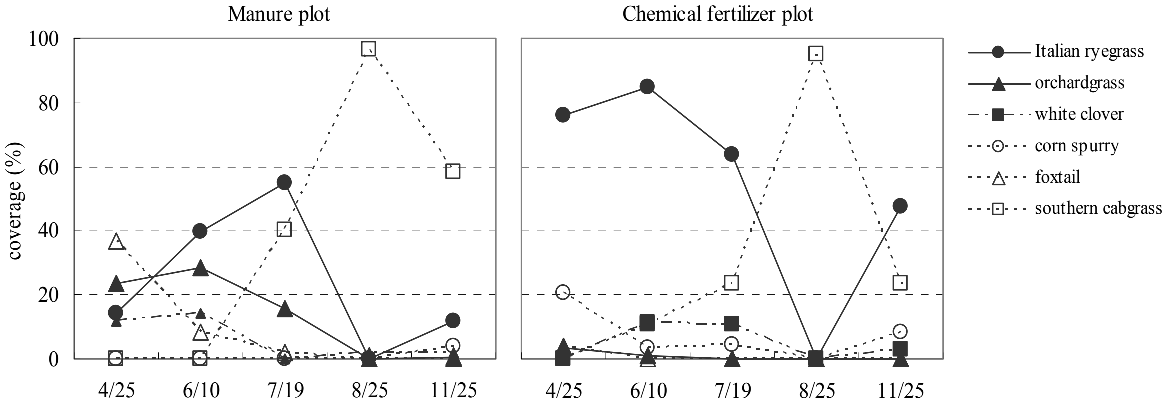

Figure 3.4.2 Variation in coverage of major 3 grass types and three weed types (2005)

has fallen 400m below what should be the standard of a suitable altitude for cultivating cool season-type perennial grass on Kyushu Island. Therefore, even if it were compared with either an index or standard, it is difficult to say that the sustainability of the cool season-type grassland can be secured for many years on the study site, and the report of such a case is plenty (Ikeda et al. 2003).

Geology of the soil demonstrates that the soil is volcanic ash humus that was made by the parent material of volcanic ash which gushed from Mt. Kirishima. The soil profile survey result of both study sites is given in Table 3.4.3.

Although the study began from the beginning of the fiscal year 2004, actual measurement of the main study items was only started in November 2004, due to preparation. This included things such as the installation of the measurement devices. Therefore, November 2004 to October 2005 is assumed to be the first year and November 2005 to October 2006 is assumed to be the second year of the study hereafter.

Table 3.4.1 Previous history of the study grassland

Year	Experimental plot	Fertilizer application ($kg\ ha^{-1}\ y^{-1}$) $N–P_2O_5–K_2O$	Harvest ($t\ ha^{-1}\ y^{-1}$)	Remarks
1997	Chemical fertilizer plot		22.9	Grass composition (Orchardgrass and tall fescue)
1998	Manure plot		14.0	Grass composition (Orchardgrass and tall fescue)
	Chemical fertilizer plot		15.0	
1999	Manure plot	112–112–112	9.3	
	Chemical fertilizer plot	112–112–112	12.4	
2000	Manure plot	115–115–115	6.3	Overseeding (Orchardgrass and tall fescue)
	Chemical fertilizer plot	116–73–82	9.1	
2001	Manure plot	112–112–112	7.3	Overseeding (Orchardgrass and tall fescue)
	Chemical fertilizer plot	126–126–126	7.9	Overseeding (Orchardgrass and tall fescue)
2002	Manure plot	140–140–140	4.0	
	Chemical fertilizer plot	102–68–150	3.1	Simple renovation and overseeding (Orchardgrass and tall fescue)
2003	Manure plot	136–136–136	9.9	Simple renovation and overseeding (Orchardgrass and tall fescue)
	Chemical fertilizer plot	148–141–178	11.1	Simple renovation and overseeding (Orchardgrass and tall fescue)

Table 3.4.2 Coverage proportion of the grass-type composition (2006)

Grass type	2006/5/2		2006/6/19	
	Manure plot	Chemical fertilizer plot	Manure plot	Chemical fertilizer plot
Orchardgrass	13.7	0.0	0.1	0.0
Tall fescue	12.5	2.4	0.0	0.0
Italian ryegrass	19.5	50.0	0.0	0.0
R. acetosa	0.7	0.3	0.0	0.0
White clover	30.6	3.8	0.0	0.0
V. hirsuta	4.3	0.0	0.0	0.0
Reed canarygrass	2.0	0.0	0.0	0.0
A. tsukushiense var. transiens	3.9	2.6	0.0	0.0
B. sitchensis	0.5	0.0	0.0	0.0
D. ciliaris	0.0	0.0	69.2	65.8
E. indica	0.0	0.0	0.0	1.3
E. esculenta	0.0	0.0	14.1	13.6
C. microiria	0.0	0.0	14.8	25.0
I. cylindrical	0.0	0.0	1.8	0.0
S. viridis var. minor	0.0	0.0	1.3	2.5
Others	17.8	8.9	0.0	2.5

Table 3.4.3 Results of the soil profile survey on the study grassland

(a) Manure plot
Japanese classification: Andosols
Parent rock : Volcaniclastic
Material : Alluvial fan sediment, Volcanic ash/Igneous rocks
Mode of deposition : Transported/Pleistocene
Landform: Recent terrace, alluvial fan

Study date 2004/11/17
Soil erosion
Land use: grassland
Vegetation:
Drainage condition: Good drainage

Depth	Humus	Gravel	Soil Color	Soil texture	Structure	Mottling	Root	Hardness	Remarks
0－17	High	High	7.5YR2/1	CL	Weak subangular blocky		Very high	8	
17－35	High	Few	7.5YR2/1	CL	Weak subangular blocky		Very high	16	
35－56	Very high	Few	2.5Y2/1	CL	Weak subangular blocky		High	18	
56－80		Few	10YR3/4	LiC	Very weak subangular blocky	Gray mottling, iron mottling with root-like morphologies; Common			Horizon boundary is wavy
80－115+		Few	10YR4/4	LiC	Very weak subangular blocky	Gray mottling, iron mottling with root-like morphologies; Common		30	Moderately moist
0－17		Few	10YR4/4	LiC	Very weak subangular blocky	Gray mottling, iron mottling with root-like morphologies; Few	Very high	8	

(b) Chemical fertilizer plot
Japanese Classification: Andosols
Parent rock : Volcaniclastic material/ Alluvial fan sediment, Volcanic ash/Igneous rocks
Mode of deposition : Transported/Pleistocene
Landform: Recent terrace, alluvial fan

Study date: 2004/11/17
Soil Erosion:
Land use: grassland
Vegetation:
Drainage condition: Good drainage

Depth	Humus	Gravel	Soil colour	Soil texture	Soil structure	Mottling	Root	Hardness	Remarks
0－13	High	High	7.5YR2/1	CL	Weak subangular blocky		High	25	
13－26	High	Few	7.5YR2/1	CL	Weak subangular blocky			21	
26－45	Very high	Few	2.5Y2/1	CL	Weak subangular blocky			23	
45－63		Few	10YR3/4	LiC	Very weak subangular blocky	Gray mottling, iron mottling with root-like morphologies; Common		21	
63－85		Few	10YR4/4	LiC	Very weak subangular blocky	Gray mottling, iron mottling with root-like morphologies; Common		22	
85－100+		Few	10YR4/4	LiC	Very weak subangular blocky	Gray mottling, iron mottling with root-like morphologies; Few		23	

2) Fertilization

Application of fertilizer in the first year was conducted on 15th November 2004, 14th March, 9th May and 14th July in 2005 and during the second year was conducted on the 24th of October and 7th November in 2005 and 27th February, 12thJune and 16th August in 2006. Regarding manure, all things used were produced at Miyazaki Station. Manure of beef cows (the piling up period was about eight months) and manure of dairy cows (the piling up period was about six months, mixed with about 20% fodder and litter) was applied 10 t FM ha^{-1} and 20 t FM ha^{-1} on 15th November 2004 and 24th October 2005, respectively (Table 3.4.4).

Table 3.4.4 Application rate of manure and its chemical composition

Applied date	Applied amount(Mg ha^{-1})	Nutrient content (% FM)				
		Moisture content	T–C	T–N	P_2O_5	K_2O
2004/11/15	10	38.3	18.7	1.19	1.77	4.41
2005/10/24	20	41.4	16.0	1.42	–	–

The applied amount of fertilizer nutrient on the respective fertilization days is given in Table 3.4.5. In one year (out of the total applied quantity), the amount of each fertilizer nutrient in the second year was about twice that of the first year. Almost the same amount of three elements (N, P_2O_5 and K_2O) was applied to both the experimental plots in the first year, while P_2O_5 and K_2O were used in a somewhat large amount in the manure plot in the second year.

Table 3.4.5 Fertilizer application date and the rate of fertilizer (composition) application

	Experimental plot	Fertilizer type	Applied date	Applied amount (kg ha^{-1})			
				C	N	P_2O_5	K_2O
2004/11-2005/10	Manure plot	Manure	2004/11/15	1,874	23.8	88.2	159.3
		Chemical fertilizer	2005/3/14	0	58.6	41.9	0.0
		Chemical fertilizer	2005/5/9	0	39.9	0.0	21.0
		Chemical fertilizer	2005/7/14	0	42.0	0.0	0.0
			Total	1,874	164.3	130.1	180.3
	Chemical fertilizer plot	Chemical fertilizer	2004/11/15	0	80.0	130.0	120.0
		Chemical fertilizer	2005/5/9	0	42.0	0.0	60.0
		Chemical fertilizer	2005/7/14	0	42.0	0.0	0.0
			Total	0	164.0	130.0	180.0
2005/11-1006/10	Manure	Manure	2005/10/24	3,410	56.8	176.4	318.6
		Chemical fertilizer	2006/2/27	0	57.0	0.0	0.0
		Chemical fertilizer	2006/6/12	0	49.0	0.0	0.0
		Chemical fertilizer	2006/8/16	0	70.0	49.0	49.0
			Total	3,410	232.8	225.4	367.6
	Chemical fertilizer plot	Chemical fertilizer	2005/10/24	0	57.0	110.0	102.0
		Chemical fertilizer	2005/11/7	0	57.0	110.0	60.0
		Chemical fertilizer	2006/6/12	0	49.0	0.0	42.0
		Chemical fertilizer	2006/8/16	0	70.0	0.0	120.0
			Total	0	233.0	220.0	324.0

3) Weather

For the data on the duration of sunshine, precipitation and a part of the temperature data, the data of AMeDAS (Kobayashi) was used.

4) Yield

Harvesting was carried out on 27th April, 24th June and 14th September 2005 in the first year and on 28th March, 24th May, 2nd August, and 17th October 2006 in the second year. In these cases, the average weight was calculated by measuring the weight of several packed roll bales, and then this was multiplied by the total number of rolled bales to calculate the total yield of both the experimental plots. Moreover, the harvest part (the part 5cm above the ground level) in the vicinity of the gas collection chamber was collected at almost the same time of harvest, and crushed after drying at 70℃ with a ventilating dryer for 24h. Dry matter content was measured, after drying by an air dry method. In addition, C content was measured by the CN corder, and C yield was calculated by multiplying the C content by the yield. Additionally, the parts up to 5cm from the ground (stubble) and the below-ground parts were collected in the spring (8th May) and in the autumn (27th September) of the second year and were processed by a similar method.

5) CO_2 budget

(1) Measurement of the net ecosystem production (NEP) by the eddy-covariance method

Continuous measurement of the CO_2 flux was conducted by using the eddy-covariance method that combined a sonic anemometer-thermometer and an open path infrared gas analyzer at the position of 2.5m in height. Moreover, the measurement of the related meteorological elements was conducted at the same time. The measurement items and their outlines are presented in Table 3.4.6.

The missing values were supplemented by an interpolation method, a look-up table method and mean diurnal variation method while performing appropriate correction and quality control tests on the obtained 10Hz data. NEP was estimated as the sum of the CO_2 flux and the CO_2 storage flux.

(2) Net biome production (NBP)

The net biome production was calculated by the following equation:

NBP = NEP + applied amount of manure – yield

Table 3.4.6 CO_2 flux and related measurement items and its outline

Measurement items	Used devices	Set up height and depth[a](cm)	Set up experimental plot
Wind velocity of the three components	Sonic anemometer-thermometer (C-SAT3:Campbell Scientific)	Manure plot:+254 Chemical fertilizer plot:+254	Both plots
CO_2, and steam density[b]	Open path infrared gas analyzer (LI–7500:LI–COR)	Same height as Sonic anemometer-thermometer	Both plots
Incidenced Photosynthetic photon flux density	Photon sensor (LI–190SA: LI–COR)	+150	Manure plot
Reflected Photosynthetic photon flux density	Photon sensor (LI–190SA: LI–COR)	+150	Both plots
Air temperature and relative humidity	Temperature humidity sensor (HMP45A:Vaisala)	+230	Manure plot
Soil temperature	T type thermocouple	–5,–10,–30	Both plots
Soil moisture content	Soil moisture probe (EC-20:Decagon)	–5,–10,–30	Both plots

[a] + indicates above-ground and – indicates below-ground. [b] 10Hz weekly measured data was recorded. The items other than these were recorded an average values of 30 m.
Regarding all items, CR23X (Campbell Scientific) was used.

6) CH_4 and N_2O fluxes

A closed chamber method was used for measuring the fluxes of CH_4 and N_2O. Gas samples were collected between 1600 to 1700 hours in 6 replications for each experimental plot and the seal up time was set as 30m. The sampling frequency was 1-3 times a week for one month after fertilizer application and once in three weeks for the rest.

The CH_4 concentration was analyzed with an FID gas chromatograph (GC-8A; SHIMADZU, Kyoto, Japan) and N_2O was analyzed with an ECD gas chromatograph (GC-14B; SHIMADZU). The cumulative value was calculated by linear interpolation of the average flux between the measurements and adding the results over the total time period.

7) Global warming potential (GWP)

The GWP values were estimated by the following equations:

$\mathrm{GWP}\ (\mathrm{Mg\ CO_2eq\ ha^{-1}\ y^{-1}}) = \mathrm{GWP\ CO_2} + \mathrm{GWP\ CH_4} + \mathrm{GWP\ N_2O}$

$\mathrm{GWPCO_2}\ (\mathrm{Mg\ CO_2eq\ ha^{-1}\ y^{-1}}) = -\mathrm{NBP}\ (\mathrm{Mg\ C\ ha^{-1}\ y^{-1}}) \times 44/12$

$\mathrm{GWPCH_4}\ (\mathrm{Mg\ CO_2eq\ ha^{-1}\ y^{-1}}) = \mathrm{CH_4\ emission}\ (\mathrm{Mg\ C\ ha^{-1}\ y^{-1}}) \times 16/12 \times 23$

$\mathrm{GWPN_2O}\ (\mathrm{Mg\ CO_2eq\ ha^{-1}\ y^{-1}}) = \mathrm{N_2O\ emission}\ (\mathrm{Mg\ N\ ha^{-1}\ y^{-1}}) \times 44/28 \times 296$

3.4.3 Results and discussion

1) Weather

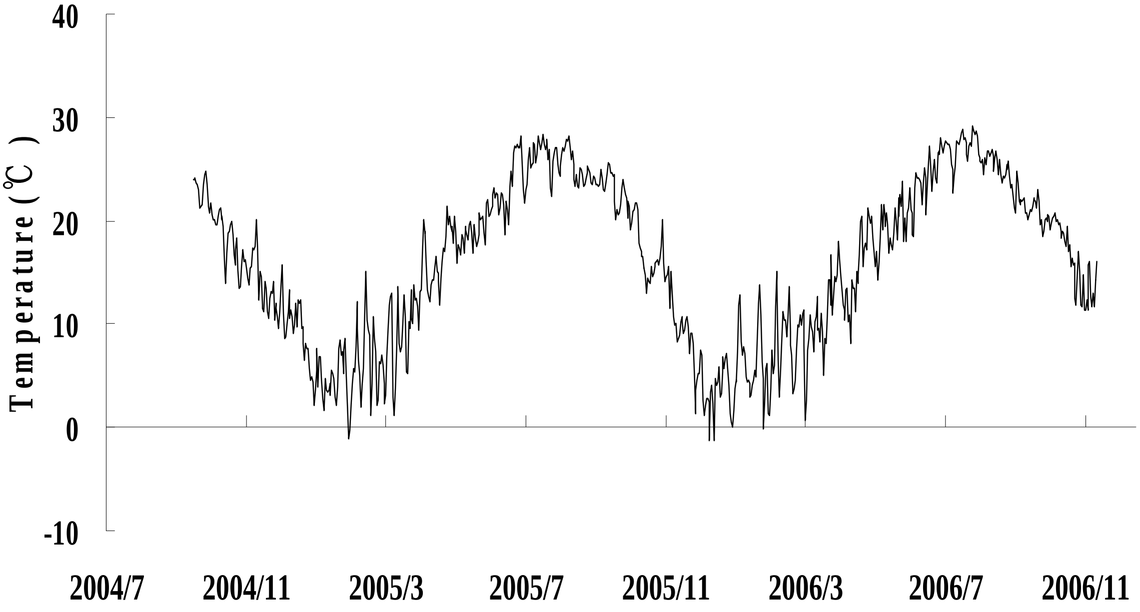

Figure 3.4.3 Seasonal variation in temperature.

The outline of the weather condition from January 2004 to December 2006 is presented in Figures 3.4.3 and 3.4.4, and Tables 3.4.6 and 3.4.7. The annual mean temperature of the first and second years of study were 16.1℃ and 16.1℃, respectively, being slightly higher than that of the average year. The annual rainfall was 2,170mm in the first year and 2,085mm in the second year, and the first year had about 300mm less than that of the average year value. Also the second year was about 500mm higher. The annual duration of sunshine was 1,822h (almost similar to the first year) and was 120h longer in the second year.

Table 3.4.7 Precipitation, temperature and duration of sunshine during the study period

	Precipitation(mm)	Temperature(℃)	Duration of sunshine(h)
2004/11-2005/10	2,170	16.1	1,944
2005/11-2006/10	3,085	16.1	1,792
Annual mean	2,499	15.3	1,822

2) Yield

The yield is given in Table 3.4.8 and the amount of stubble and below-ground biomass collected in the simultaneous period is given in Table 3.4.9. A comparison on the yield between both these experimental plots showed that the chemical fertilizer plot had a total yield of about 15% more than the manure plot because the yield in the chemical fertilizer plot was about 1.5 times the manure plot on the 28th of June. Even though, both these experimental plots had almost similar yields on the 27th of April and 14th September of the first year. In the second year, the harvest was conducted only in the chemical fertilizer plot (on 24th March) because the growth of the chemical fertilizer plot in the early spring was remarkably vigorous. The yield in May was higher in the manure plot than the chemical fertilizer plot and was almost at the same level on the 2nd of August and the 17th of October. However, the total annual yield was influenced by the harvest carried out on 28th March, and as a result, the yield in the chemical fertilizer plot increased to about 1.3 times that of the manure plot. In this way, the larger yield in the chemical fertilizer plot in both years was due to the difference in the yield in spring, and it was especially due to the difference in growth of Italian ryegrass (*L. Multiflorum*) that dominated the grasslands during that time.

Moreover, when comparing the total annual yield in both years, the yield in the second year was somewhat larger in both the experimental plots. It was about 1.1 times greater than the first year in the manure plot and about 1.2 times in the chemical fertilizer plot. Furthermore, the amount of stubble was greater in the manure plot than the chemical fertilizer plot in the study conducted on the 8th of May and the 27th of September, and on the contrary, the amount of below-ground biomass was greater in the chemical fertilizer plot, being twice the value than that in the manure plot.

Table 3.4.8 Yield

	Harvest date	Yield (Mg DM ha^{-1})	
		Manure plot	Chemical fertilizer plot
2004/11-2005/10	2005/4/27	2.42	2.39
	2005/6/28	2.93	4.26
	2005/9/14	3.47	3.58
	Total	8.82	10.22
2005/11-2006/10	2006/3/28		3.83
	2006/5/24	3.71	2.29
	2006/8/2	2.33	2.46
	2006/10/17	3.92	3.93
	Total	9.96	12.52

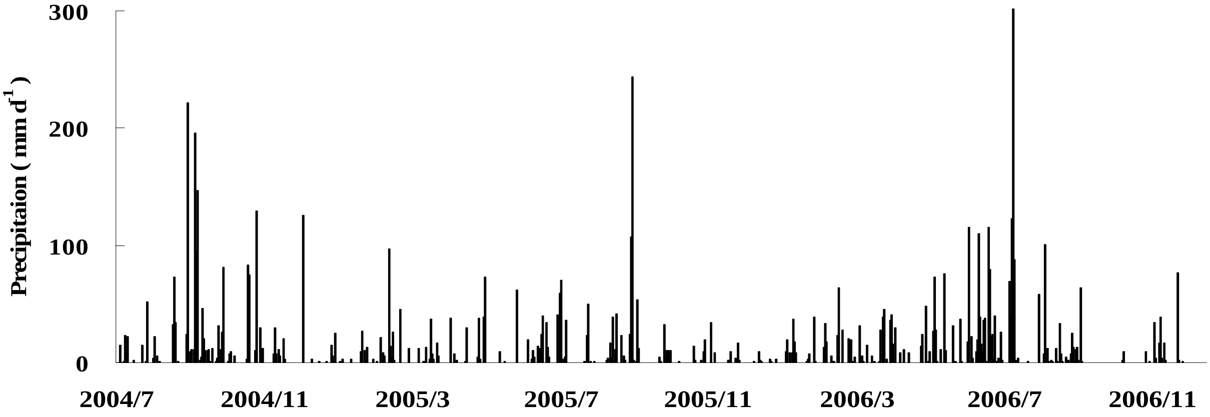

Figure 3.4.4 Variation in the amount of daily accumulated precipitation.

Table 3.4.9 Dry matter and C content (2006) of stubble and below-ground biomass

	Stubble (Mg ha^{-1})		Below-ground biomass (Mg ha^{-1})	
	Manure plot	Chemical fertilizer plot	Manure plot	Chemical fertilizer plot
5/8	1.20 (0.55)	0.82 (0.36)	4.22 (1.74)	9.05 (3.04)
9/27	1.11 (0.49)	0.83 (0.38)	1.99 (0.74)	3.74 (1.45)

(Data in parentheses denote C content)

3) CO_2 budget

(1) Measurement of NEP by the eddy-covariance method

Variation in the amount of NEP measured by the eddy-covariance method is given in Figure 3.4.5. Emission of CO_2 (negative values) was observed for a while immediately after the harvest and after that it changed to the uptake of CO_2 (positive values). This was due to the growth of herbage plants. This phenomenon was observed during each harvest. The influence of fertilizer application was not observed.

In both of these experimental plots, the uptake of CO_2 was observed also in the winter when above-ground biomass became extremely rare. Soil surface on the study site was not covered by snow. Moreover, regarding the meteorological condition, the daily average temperature was 6.1℃ in January and 8.0℃ in February, but the daily maximum temperature was 20.4℃ in January and 20.0℃ in February (in 2006, Appendix 2). Although the growth of herbage parts of the cool season-type grasses including Italian ryegrass was controlled during the low temperature period and the amount of growth was more limited than the time of the so-called "Spring flash" since March, the sprouting of tillers and development of the leaves were well-known to be advanced even in the low temperature period. It is speculated that Italian ryegrass and other temperate grasses were germinated and established by natural reseeding after the harvest of summer-type herbage plants and weeds on the study site. It was also analogized, that the leaf area index (LAI) of the cool region-type grass canopy during the period from January to March was considerably high, because harvesting was not carried out at all during this period in both years. Moreover, it is supposed that the canopy photosynthesis potential in the daytime would have been considerably high also in the low temperature period of January and February since the regression curve between photosynthesis and temperature above 10℃ and below 25℃ is said to be almost flat (constant) in the cool season-type grass. Furthermore, respiration and decomposition are controlled due to the decrease in temperature of the environment. From these, it seems that the budget of CO_2 could have been consistently positive values from the winter to the spring.

When examining the difference in treatments, the chemical fertilizer plot showed a higher uptake than the manure plot in the winter, although there was almost no difference in CO_2 uptake in the summer between the experimental plots. The above-ground biomass in the chemical fertilizer plot was larger than that in the manure plot, which could be due to the influence of comparatively active photosynthesis, and this could have possibly resulted in the difference in yield.

The values of PPFD showed a repeat pattern of decreasing from autumn to winter (February), then increasing until the summer (July), and decreasing again after it (Figure 3.4.6).

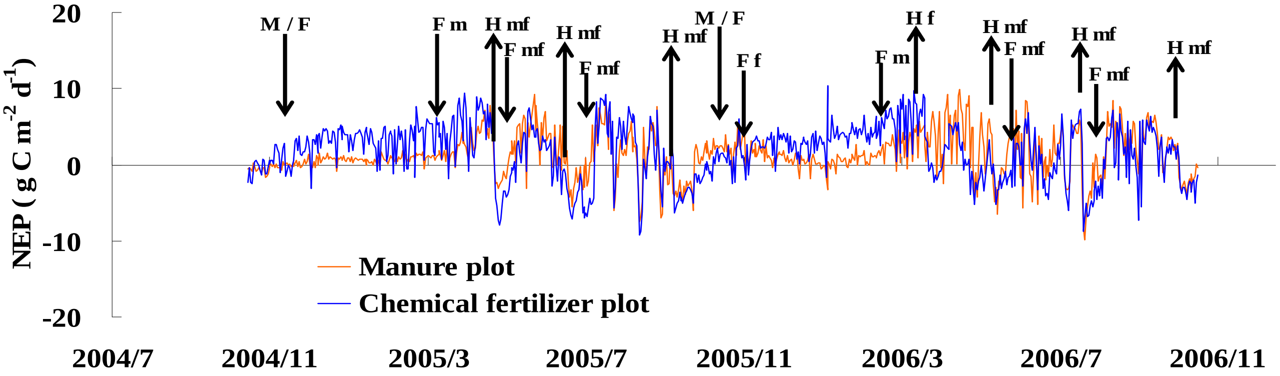

Figure 3.4.5 Seasonal variation in net ecosystem production (NEP).
M, Manure application; F, Chemical fertilizer application; H, Harvest
m, Fertilizing or harvest in the manure plot; f, Fertilizing or harvest in the chemical fertilizer plot

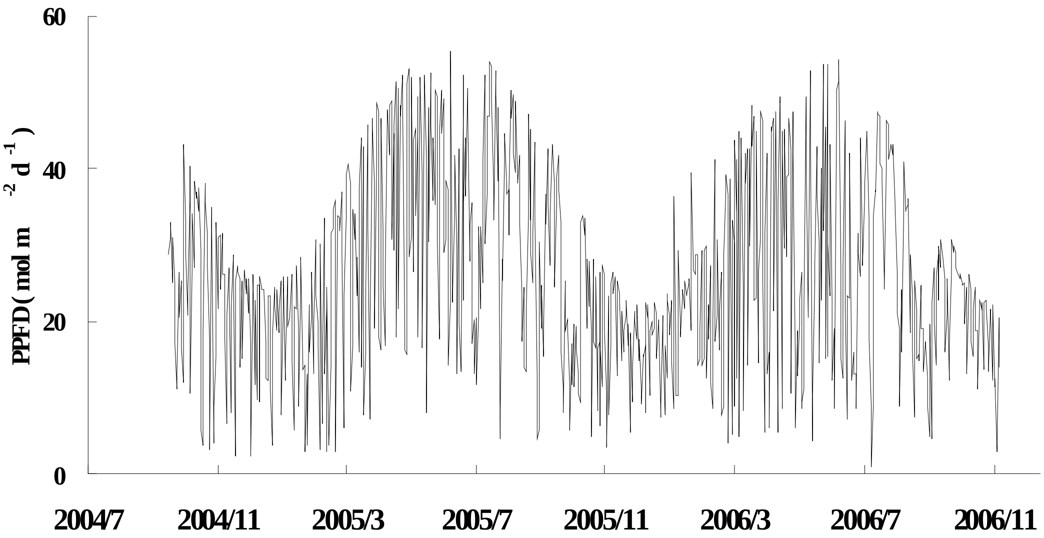

Figure 3.4.6 Seasonal change in photosynthetic photon flux density Seasonal variation in Figure 3.4.6

(2) Net biome production (NBP)

The annual amount of NBP is given in Table 3.4.10. Both manure and chemical fertilizer plots ndicated positive values of NBP and it was confirmed that C was fixed in the study grassland. The amount of C fixation was larger in the manure plot in both years, which was due to the application of manure.

Table 3.4.10 Annual amount of net biome production (NBP)

	NBP (Mg C ha^{-1} y^{-1})						
	Manure plot				Chemical fertilizer plot		
	NEP	Harvest	Applied manure	**NBP**	NEP	Harvest	**NBP**
2004/11-2005/10	3.81	3.91	1.87	1.77	5.98	4.50	1.49
2005/11-2006/10	6.14	4.50	3.19	4.83	6.84	5.53	1.30
Total	9.95	8.41	5.07	6.60	12.82	10.03	2.79
Annual mean	4.97	4.21	2.53	3.30	6.41	5.02	1.40

4) CH_4 flux

A variation in CH_4 flux is illustrated in Figure 3.4.7. Both manure and chemical fertilizer plots had a CH_4 flux ranging from –37 to 28μg C m^{-2} h^{-1}. A clear difference in the variation in CH_4 flux was not observed during the study period in both the experimental plots. The influence of the fertilizer application and yield on CH_4 emission was also not found. Moreover, there was no significant correlation between the air temperature and the soil temperature during flux measurement (Table 3.4.11). However, the annual cumulative emission of CH_4 was slightly larger in the manure plot in the first year, while slightly larger in the chemical fertilizer plot in the second year, and there was almost no difference in the sum of the second year, because the difference between the two was very small (Table 3.4.12).

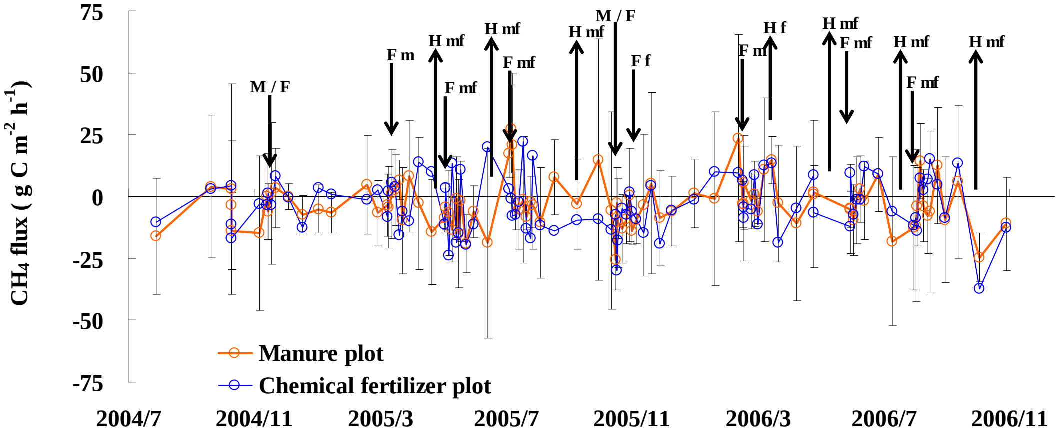

Figure 3.4.7 Seasonal variation in CH4 fluxes.
M, Manure application; F, Chemical fertilizer application; H, Harvest.
m, Fertilization or harvest in the manure plot; f, Fertilization or harvest in the chemical fertilizer plot.

Table 3.4.11 Correlation coefficient between CH_4 flux and temperature

	Manure plot	Chemical fertilizer plot
Temperature	0.01 NS	0.08 NS
Soil temperature (Below site 5cm)	–0.02 NS	–0.01 NS
Soil temperature (Below site 10cm)	–0.02 NS	–0.02 NS

Based on two years data; NS, not significant

Table 3.4.12 CH_4 emission

	Manure plot	Chemical fertilizer plot	Average
	(kg C ha^{-1} y^{-1})		
2004/11-2005/10	–0.26 (0.42)	–0.23 (0.28)	–0.24
2005/11-2006/10	–0.21 (0.35)	–0.23 (0.77)	–0.22
Total	–0.47	–0.46	
Annual mean	–0.24	–0.23	

	Result of a two-way ANOVA				
Factor	Degree of freedom	Sum of squares	Mean squares	F value	P value
Year	1	0.003	0.003	0.011	0.919
Experiment	1	0.000	0.000	0.001	0.979
Year×Experiment	1	0.003	0.003	0.014	0.906
Error	20	4.872	0.244		
Total	23	4.878			

Standard deviations are shown in parentheses. Variations in years and experiments were analyzed by a two-way ANOVA. When a significant variation was found, each standard was verified by Tukey-test and the level of significance was set as 5%.

5) N_2O flux

A variation in N_2O fluxes is given in Figure 3.4.8. The N_2O flux ranged from 0 to 500 μg N m^{-2} h^{-1} in the chemical fertilizer plot. A drastic variation was not observed, but there was a tendency of slight rising immediately after the application of fertilizer. On the other hand, an abrupt increase (2,387μg N m^{-2} h^{-1}) was observed in the manure plot at the end of March 2005. Since this time corresponded to the time of applying additional chemical fertilizer (14th March), influence of the flux was suggested. After the end of March 2005, there was a tendency of some increase immediately after the application of fertilizer in both these plots, however, a drastic variation was not observed.

The result of calculating correlation coefficients between the N_2O flux and temperature elements measured during the gas flux measurement showed that there was a significant positive correlation in the chemical fertilizer plot (Table 3.4.13). The correlation was significant even in the manure plot only in the second year of the study.

Regarding the annual cumulative N_2O emission (Table 3.4.14), there was a significant interaction between the experimental plots and the study years at 1% significance level. N_2O emission from the manure plot was 11.3 N ha^{-1} y^{-1} and that from the chemical fertilizer plot was 1.9 N ha^{-1} y^{-1} in the first year. Also, the manure plot increased to about six times that of the chemical fertilizer plot. A rapid increase in N_2O emission, immediately after the application of fertilizer in March 2005 could have influenced it. In the second year, N_2O emission from the manure plot had a 5.3 kg N ha^{-1} y^{-1} and that from the chemical fertilizer plot had a 3.1 kg N ha^{-1} y^{-1}; a reduction in the manure plot by half compared to the previous year. N_2O emission from the manure plot showed higher values than those from the chemical fertilizer plot. This was similar to the previous year, although N_2O emission from the chemical fertilizer plot was almost doubled. However, the amount of cumulative emission in the manure plot settled twice within the chemical fertilizer plot and this was unlike the previous year and could have been due to a lack of abrupt increase in the early spring of 2006.

Table 3.4.13 Correlation coefficient between N_2O flux and temperature

	Manure plot	Chemical fertilizer plot
Temperature	–0.02 NS	0.34**
Soil temperature (Below site 5cm)	–0.02 NS	0.32**
Soil temperature (Below site 10cm)	–0.01 NS	0.31**

Based on the data of two years, NS: Not significant
** $p<0.01$

Table 3.4.14 N_2O emission

Study period	Manure plot	Chemical fertilizer plot	Average
	(kg N ha^{-1} y^{-1})		
2004/11-2005/10	11.3 (3.0)	1.9 (0.6)	6.6
2005/11-2006/10	5.3 (2.0)	3.1 (0.6)	4.2
Total	16.6	5.0	
Annual average	8.3	2.5	

Result of a two-way ANOVA

Factor	Degree of freedom	Sum of squares	Mean squares	F value	P value
Year	1	35.0	35.0	10.3	0.004
Experiment	1	203.5	203.5	59.9	0.000
Year×Experiment	1	78.3	78.3	23.0	0.000
Error	20	68.0	3.4		
Total	23	384.7			

Standard deviations are shown in parentheses. Variations in years and experiments were analyzed by a two-way ANOVA. If a significant variation was found, each standard was verified by Tukey-test and the level of significance was set as 5%.

6) Global warming potential (GWP)

The GWP values are given in Table 3.4.15. The $GWPCO_2$ was –6.49 Mg CO_2 eq ha^{-1} y^{-1} and –17.72 Mg CO_2 eq ha^{-1} y^{-1} in the manure plot while –5.45 Mg CO_2 eq ha^{-1} y^{-1}, and –4.78 Mg CO_2 eq ha^{-1} y^{-1} in the chemical fertilizer plot in the first and second year, respectively. In the view point of the C budget, both these experimental plots indicated an effect on mitigating global warming.

Because $GWPN_2O$ indicated a positive value in both these experimental plots over the two years, a tendency of enhancing global warming due to N_2O was presumed. This tendency was stronger in the manure plot in both years.

When converting the sum of GWP equivalent to CO_2, it is believed that the study grassland could have been mitigating global warming because both these experimental plots showed negative values, regardless of the difference in fertilizer application methods. When thinking about the influence from the respective gases on the total GWP, it appeared that CO_2 seemed to be mitigating global warming, N_2O enhancing global warming, and CH_4 appeared to have no influence on global warming. Although the N_2O emission is smaller among emitted greenhouse gases, it was 3.08 - 11.32 kg N ha^{-1} y^{-1} as shown in Table 3.4.12. It also showed that the impact of N_2O emission becomes larger if it is converted into GWP because its GWP value is high. From this result, it appeared that the management of N_2O especially, would be quite important for grasslands. In this investigation, it was found that the N_2O emission increased after the application of fertilizer and that it had a significant positive correlation with the air as well as the soil temperature. Therefore, it is recommended that the N fertilizer should be applied at standard and recommended amounts and during times of low temperature.

Table 3.4.15 Global warming potential (GWP)

Experiment year	Manure plot				Chemical fertilizer plot			
	$GWPCO_2$	$GWPCH_4$	$GWPN_2O$	GWP	$GWPCO_2$	$GWPCH_4$	$GWPN_2O$	GWP
2004/11-2005/1	–6.49	–0.01	5.26	–1.23	–5.45	–0.01	0.88	–4.59
2005/11-2006/10	–17.72	–0.01	2.46	–15.27	–4.78	–0.01	1.43	–3.36
Total	–24.21	–0.01	7.73	–16.50	–10.24	–0.01	2.31	–7.94
Average	–12.11	–0.01	3.86	–8.25	–5.12	–0.01	1.15	–3.97

GWP of CO_2 was assumed to be a minus of NBP, and CH_4 and N_2O were calculated as an equivalent to CO_2 (Mg CO_2eq ha^{-1} y^{-1}).

Positive sign represents enhancement of global warming.

3.4.4 Summary

The dynamics of greenhouse gases on the study site at the grassland in a mountainous warm temperate zone was examined. This was done by incorporating an influence by the application of manure.

In regards to CO_2, its uptake was observed, and the uptake of its equivalent extent in winter was noticed especially throughout the year. Although, CO_2 was temporarily turned into emission due to the harvest of above-ground biomass. The amount of CO_2 uptake was higher in the chemical fertilizer plot than also the plot where manure was applied together with the chemical fertilizer. Although again, this agrees with the fact that the yield of the above-ground and below-ground biomass of the chemical fertilizer plot was larger than that of the combined manure and chemical fertilizer plots. However, it is indistinct whether such difference between both the experimental plots occurred due to the difference in fertilization methods.

Accumulation of C by herbage production on the study site was suggested, because an approximately positive value was observed when the amount of C taken out by the harvest is subtracted from the uptake amount of CO_2. Application of manure is supposed to increase this cumulative amount.

In regard to the CH_4, it appeared to show little uptake when synthesizing it, although uptake and emission were repeated. There was almost no difference observed due to the difference in fertilizer application methods.

N_2O was obviously emitted, and the emission from the manure plot was higher than in the chemical fertilizer plot.

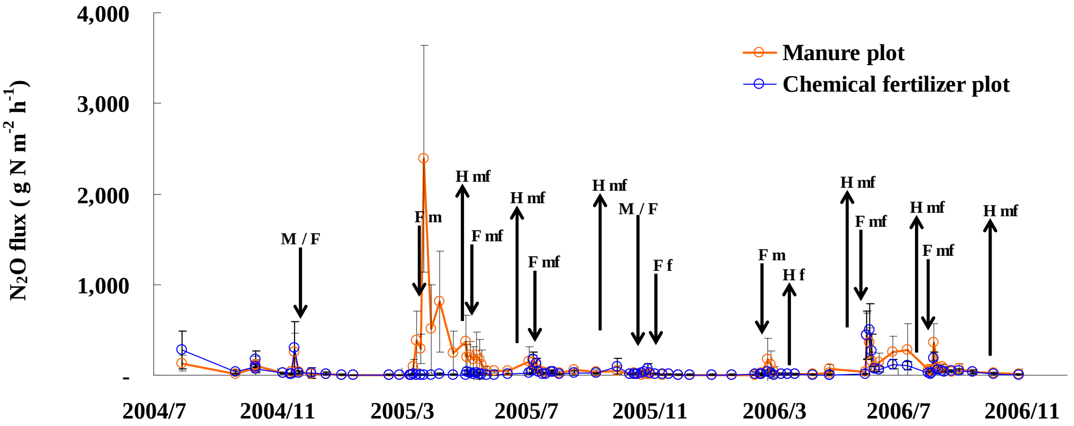

Figure 3.4.8 Seasonal variation in N2O fluxes.
M, Manure application; F, Chemical fertilizer application; H, Harvest
m, Fertilization or harvest in the manure plot; f, Fertilization or harvest in the chemical fertilizer plot

The result of calculating GWP values combined from the results above show that the study site indicated a contribution in the mitigation of global warming. Among these, it appears that CO_2 seemed to be mitigating global warming, N_2O enhancing it, and CH_4 seems to have no influence on global warming. In conclusion, it can be said that these further suggest the importance of fertilizer management in regard to things such as the application of manure on grasslands and the control of the emission of N_2O.

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Chapter 4. General discussion

4.1 Characteristics of the CO_2 budget estimated by an eddy-covariance method

Abstract

Detailed CO_2 budgets (Net Ecosystem Production, NEP) for grasslands were estimated by an eddy-covariance method at four observation sites in Japan, where harvests were carried out periodically. The respective NEP of each site indicated a seasonal variation with plant growth following sprouts and several harvest times.

Among the four sites, CO_2 uptake at the chemical fertilizer plot in Kobayashi during the winter was almost the same as in the summer of other locations. The result of the relationship between NEP and photosynthetically active radiation (PAR) in the daytime during a 10-day period before each harvest showed that the first harvest stage in Nakashibetsu and Shizunai sites had the highest NEP at the same range of PAR in other locations. The relationship also indicated that the atmospheric CO_2 was fixed efficiently in these two grasslands. The NEP at night tended to increase with an increase in air temperature. However, the NEP in the summer (May-September) in Nasushiobara, where the mean temperature at night was 4.7℃ (which was higher than that in Shizunai), was exceptionally lower than the NEP in Shizunai. A temporal variation in the carbon budget for grasslands could be estimated in detail by a continuous measurement of NEP. The stock of carbon in the grasslands increased in the manure plot on each observation site. A long-term observation on the effect of the continuous use of manure should be studied in the future, and the carbon budget, estimated by an eddy-covariance method, should be compared and evaluated by the different methods.

4.1.1 Introduction

In this project, CO_2, CH_4 and N_2O fluxes from manure and chemical fertilizer plots were measured in four locations in Japan for the purpose of clarifying the effect of manure application on the greenhouse gas budget for grassland. As we mentioned in section 4.2, the carbon budget or the net biome production (NBP), which included the yield and the amount of manure applied to the CO_2 budget, strongly affected the global warming potential (GWP) in grasslands. The NBP is the combination of the CO_2 budget (NEP), harvests and manure application. The information on harvest and manure application can be easily obtained from the records of grassland management. However, the NEP can only be obtained from the continuous measurement of CO_2 flux in grasslands.

Recently, a continuous study of NEP in various terrestrial ecosystems (e.g. forest ecosystem) using the eddy-covariance method has been carried out to obtain scientific knowledge and to correspond to the emission regulation of greenhouse gas in each country. However, there are only a few studies on the NEP in grasslands where pasture is regularly harvested. There is only one similar type of study in the experimental fields (double cropping of maize and Italian ryegrass) of the National Agricultural Research Center for Kyushu in the Okinawa Region (Kumamoto Prefecture, Goshi City), National Agriculture and Food Research Organization in Japan (Ohba et al. 2005). The observation data of NEP acquired in this study, can be expected to be important data for quantifying the carbon budget in managed grasslands in the humid and middle latitude regions. This section focuses on summarizing the NEP, the characteristics of the NEP and their differences among the regions mainly focusing on the chemical fertilizer plots on each study site.

In this study, continuous measurement by the eddy-covariance method was carried out, and NEP data taken every 30min was gathered for more than two years. In section 3.1 to 3.4, a change in the daily data of NEP calculated for every 30min is reported. However, the characteristics of the eddy-covariance method are to evaluate the CO_2 budget by a long-term accumulation of the NEP data measured over short intervals of time. In this section, characteristics of the NEP of the short-term (half an hour) measurement in each location is reported.

4.1.2 Seasonal variation in NEP

Figure 4.1.1 shows the seasonal variation in NEP, measured every 30min in the chemical fertilizer plot at four observation sites in the first year of this research. The NEP is the net CO_2 uptake by grasslands from the atmosphere.

NEP in grassland is the sum of: 1) CO_2 uptake by plant photosynthesis (amount of photosynthesis), 2) CO_2 emission by plant respiration, and 3) CO_2 emission by the decomposition of soil organic matter or litter. Generally, the NEP becomes positive in the daytime during the plant growing period because CO_2 uptake by photosynthesis is larger than CO_2 emission by plant respiration and decomposition of soil organic matter or litter. On the other hand, the NEP becomes negative during the night or plant non-growing

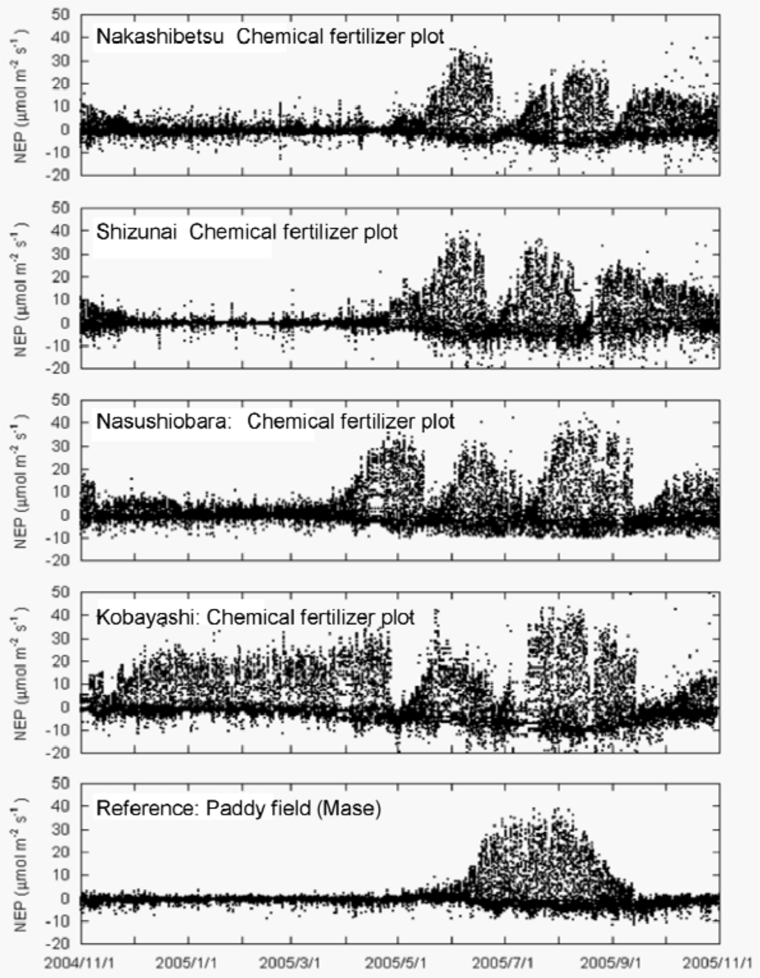

Figure 4.1.1 Seasonal variation in NEP of various study sites.
(November 2004 - October 2005)
(The positive value indicates CO_2 uptake by grassland while the negative value indicates CO_2 emission. For the purpose of comparison, the reference of NEP measured in the same period was taken from a paddy field of Mase, Tsukuba City in Ibaraki Prefecture.)

period because CO_2 is released by plant respiration and decomposition of soil organic matter or litter.

Based on Figure 4.1.1, the following characteristics of NEP in each experimental field can be pointed out. 1) In Shizunai, Nakashibetsu and Nasushiobara, a symmetrical seasonal variation in NEP was observed between growing and non-growing periods. Corresponding to the number of harvests, NEP showed a seasonal variation that possessed three (Nakashibetsu and Shizunai) or four (Nasushiobara) peaks because plants were harvested three or four times during the growing period. On the other hand, the absolute value and variation range of the NEP in winter was small.

2) In Kobayashi, a seasonal variation in NEP was similar to that in Nasushiobara from the spring to autumn. However, the NEP in Kobayashi in winter was different from that of the other three sites, and more than 20μmol m^{-2} s^{-1} of CO_2 uptake was continuously observed from December to April. This CO_2 uptake was consistent with that in the summer of the other three sites.

Based on the detailed analysis of NEP in winter in Shizunai, Nakashibetsu and Nasushiobara, daily variations in NEP in Shizunai and Nakashibetsu, (which were covered by snow in winter), were not observed. On the other hand, a clear and small daily variation in CO_2 uptake in the daytime and emission during the nighttime in winter were observed in Nasushiobara, (which was not covered by snow), suggesting that plant activities continued in the winter.

For comparison, the NEP observed in paddy fields, which is the representative arable land in Japan, is illustrated in Figure 4.1.1. Compared with the NEP in paddy fields, characteristics of NEP in grasslands are as follows:

1) Because of the longer growing period of grasslands than that of paddy fields, the period in which CO_2 was absorbed in grasslands was longer than that in paddy fields. Even in Nakashibetsu where the growing period was the shortest, the NEP in the daytime was positive for seven months of the year.

2) When the maximum NEP uptake and emission in grasslands are compared with those in the paddy fields, the maximum NEP uptake in grasslands was almost the same as in paddy fields (35～40μmicromol m^{-2} s^{-1}). Also, the maximum NEP emission from the grasslands was a little larger than the emissions from the paddy fields.

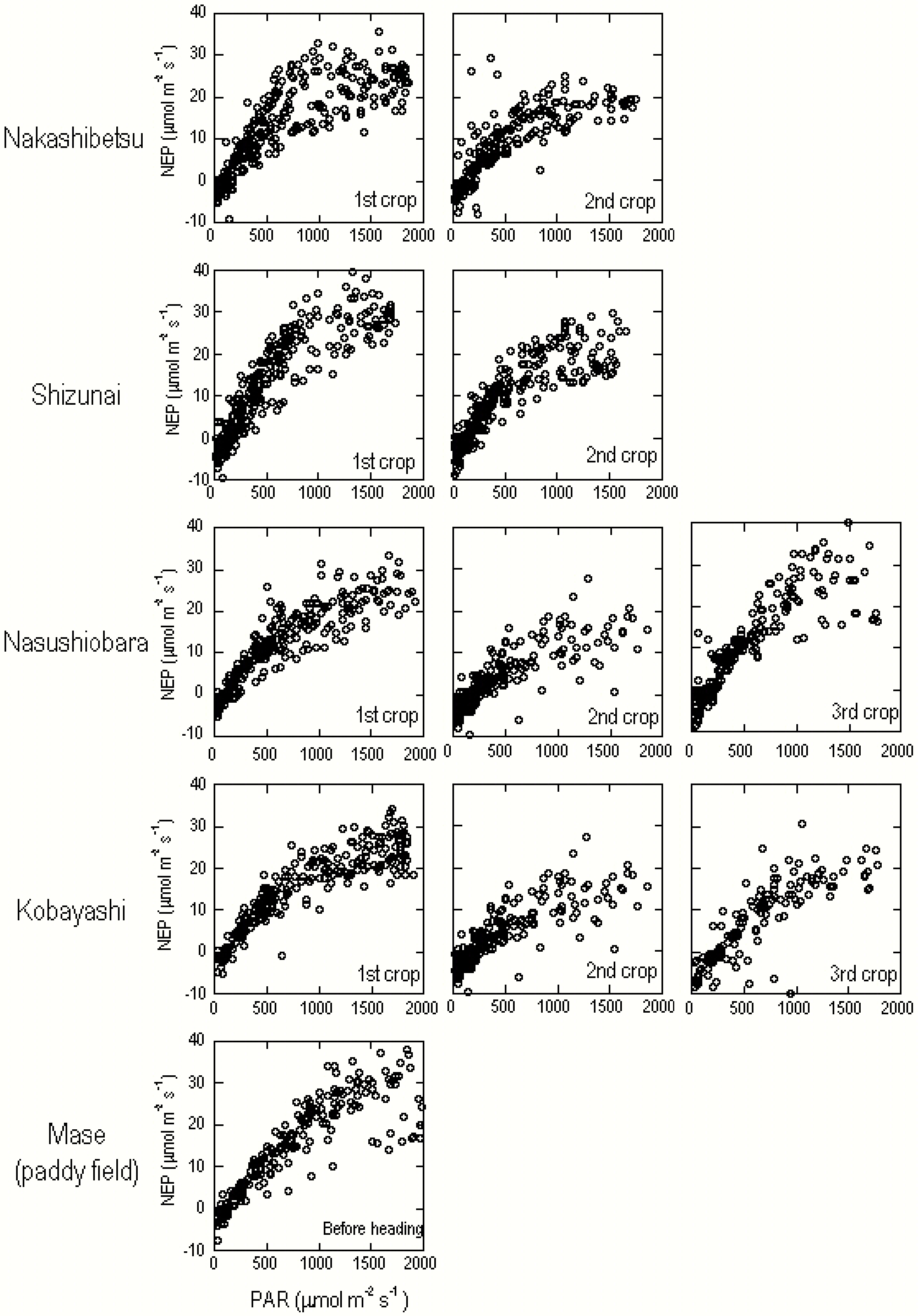

Figure 4.1.2 The relationships between the NEP and incidence photosynthetically active radiation (PAR) in the daytime. (Regarding the chemical fertilizer plot of each study site, the data of ten days before the harvest in 2005 is presented. Here, the condition when the amount of incidence PAR exceeds $20\mu\ m^{-2}\ s^{-1}$ was assumed to be daytime. For comparison, the measured result of 10 days before the formation of threads at the paddy field of Mase, Tsukuba City in Ibaraki Prefecture is shown in the lowest part of the figure.)

4.1.3 NEP in the daytime

As described above, the NEP was strongly affected by the PAR in the daytime during the plant growing season because CO_2 uptake by plant photosynthesis was larger than any other component of NEP. Based on the data on chemical fertilizer plots in 2005, Figure 4.1.2 shows the relationship between PAR and NEP of a 10-day period before the harvest for all sites, excluding the fourth harvesting of Nasushiobara. The reason for selecting the 10-day period before the harvest was that the photosynthesis rate at the time was high and that the variation in dry matter weight was relatively small.

On each observation site, there were rectangular hyperbolic relationships between the photosynthesis of the plant community and PAR for each period, but the shapes of the hyperbola were different depending on the sites and timings of the harvest. Furthermore, the initial slope (the slope of the tangential line of hyperbola at zero of PAR) at the first harvesting was larger than that at the second harvesting, and the initial slopes for Nakashibetsu and Shizunai were larger than in Nasushiobara and Kobayashi. These differences in the initial slope were due to the timing of harvest and the region suggested that the quantum yield of the cool season-type grasses (C_3 plant) decreased with temperature because of influence due to photorespiration. There were differences in the photo-saturated value (asymptotic value on the infinite PAR) according to the timing of harvest or site. However, the phenomenon of photo-saturation was unclear at the time of the third harvesting in Nasushiobara and Kobayashi compared to that of the first harvesting. In Kobayashi, cool season-type grasses (Italian ryegrass) dominated the first harvesting while summer annual weeds (C_4 plant, e.g. crab grass) dominated the third harvesting. These variations in vegetation may have an effect on the relationship between the photosynthesis rate of a plant community and PAR.

From the comparison of a relationship between NEP and PAR in the daytime, seasonal and spatial variations in the amount of CO_2 fixation in a grassland ecosystem became apparent. The relationship between NEP and PAR in the daytime as shown in Figure 4.1.2, includes the effect of ecosystem respiration which changes in accordance with temperature and the seasonal change in dominant species (decribed in the following chapter). However, when we considered the carbon sequestration which includes those effects in grassland ecosystem, CO_2 was efficiently fixed in Nakashibetsu and Shizunai because NEP were high in the same PAR during the period of first harvesting at these sites.

4.1.4 NEP in the night time

The NEP during night is the ecosystem respiration, which is, CO_2 emission due to plant respiration and decomposition in the soil. In addition, these strongly correlate with temperature and dry biomass. Figure 4.1.3 shows the seasonal variation in the mean values of the NEP and temperature at night of the first year in the chemical fertilizer plot on all sites. The NEP at night remained at a low level until May or April in all sites. The NEP then gradually increased, with an increase in temperature and plant growth and reached a maximum in mid August. The range of the seasonal variation was large in Kobayashi, where the temperature was high, but remained almost the same among other sites.

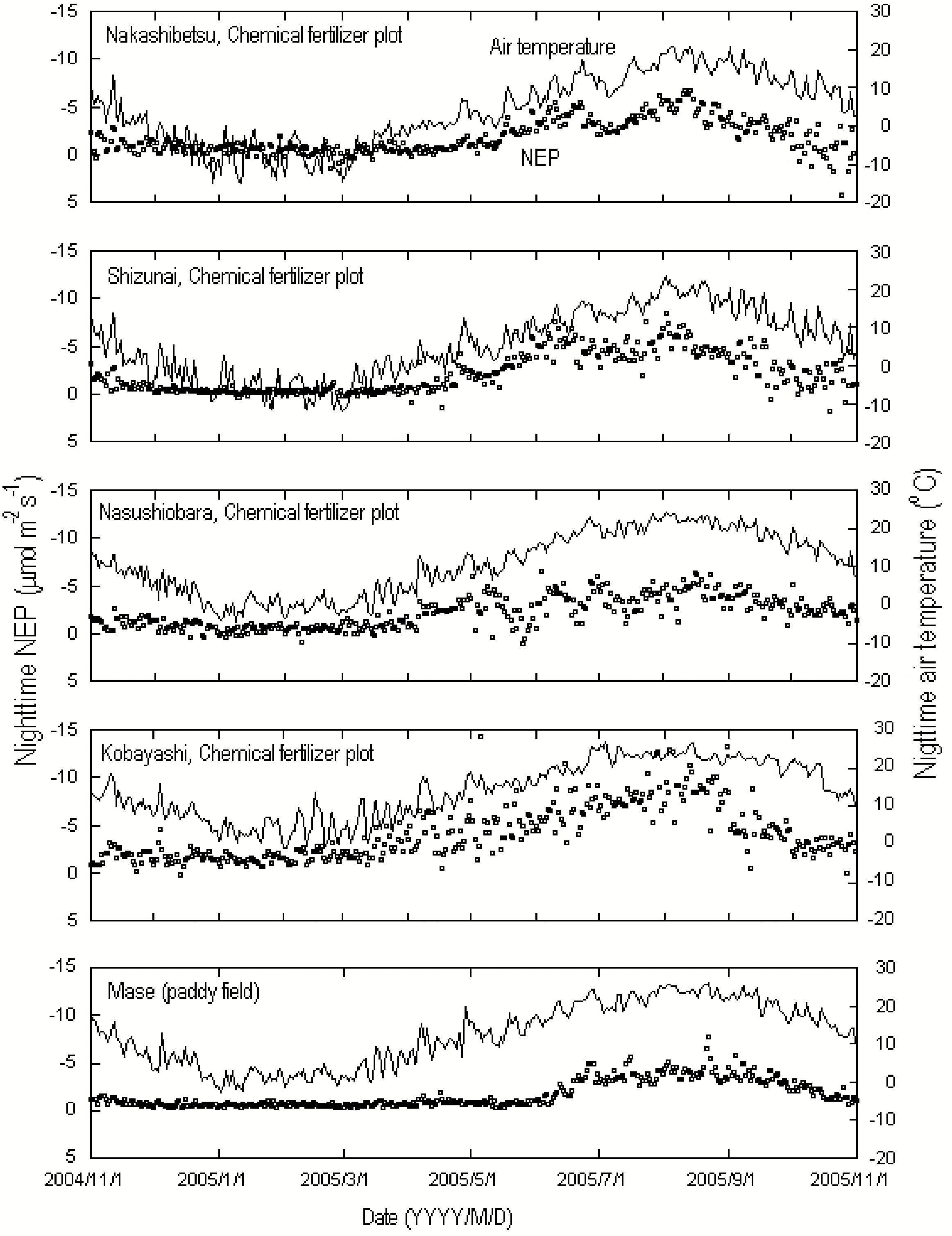

Figure 4.1.3 Seasonal variation in the mean values of NEP and temperature during the night in chemical fertilizer plots (November 2004-December 2005). (For comparison, the result of Mase, Tsukuba is shown in the lowest part of the figure. In this study, the period in which the incidence PAR was of more than 20μmol m^{-2} s^{-1} was regarded as nighttime. The CO_2 values of the upper part of the figure are large because the axis of NEP was reversed.)

The relationship between the mean values of NEP and temperature at night are given in Figure 4.1.4.

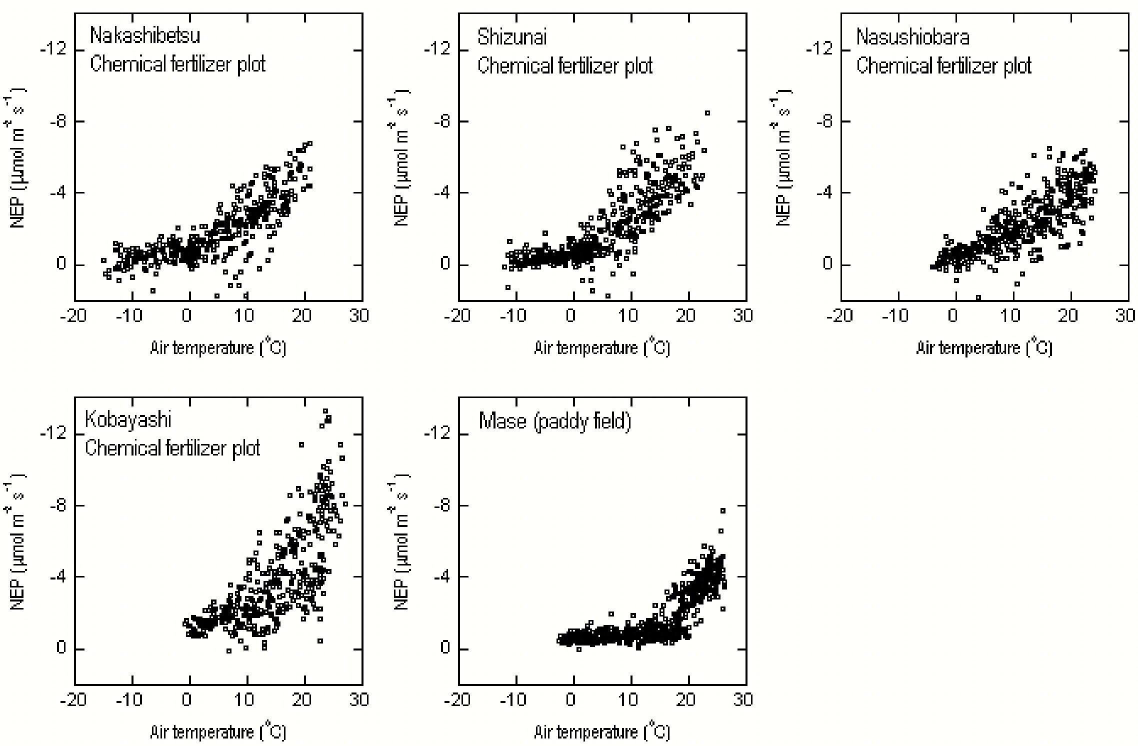

Figure 4.1.4 The relationships between the mean values of NEP and temperature at night in chemical fertilizer plots (November 2004-December 2005). (For comparison, the result of Mase, Tsukuba is shown in the lowest part of the figure.)

There was a trend of an increase in CO_2 emission with temperature in each site. Although the relationships between CO_2 emission and temperature in Kobayashi and Nasushiobara were exponential, as commonly reported in many studies, the relationship in Nakashibetsu and Shizunai was not regular due to the change in the magnitude of increase at a temperature of around 0℃ of intercept. NEP values in the paddy fields were also not consistent, but the range of temperatures were different. The reason for these relations might be due to snowfall in Nakashibetsu and Shizunai and the existence of rice plants in the paddy field. Usually both of them have a strong effect on the amount of ecosystem respiration.

Table 4.1.1 shows the amount of ecosystem respiration at night in a year and in the summer (May-September) in the chemical fertilizer plot in 2005. Ecosystem respiration tended to increase in the areas with a high average temperature at night. However, ecosystem respiration in the summer in Nasushiobara was exceptionally lower than in Shizunai, where the mean temperature during the night was 4.7℃ lower than that in Nasushiobara and therefore ecosystem respiration on both these sites were almost the same. The presence of no clear patterns of the increase in ecosystem respiration beyond 15℃ in Nasushiobara might be due to a decrease in the physiological activities with a summer depression of the cool season-type grasses. However, there are difficult issues in the data analysis of the nighttime NEP, and these issues might have an effect on comparison among the sites. In the future, verification of these hypotheses based on the viewpoint of plant physiology or comparison of the amount of soil respiration obtained from the eddy-covariance or chamber methods is required.

Figure 4.1.1 clearly shows that the amounts of ecosystem respiration in all observation sites were larger than that in the paddy fields. One of the reasons for this could be that the large amounts of CO_2 were emitted due to the large amount of soil organic matter and litter and the high amount of emission was due to their higher decomposition in grasslands compared to that in the paddy fields. The other reasons could be that the CO_2 released from subsurface soil could have been inhibited due to the flooded condition of the paddy field.

Table 4.1.1 Amount of ecosystem breath in chemical fertilizer district at nighttime and normal temperature at nighttime

Investigation spot	Year 2004.11.1～2005.10.31		Summer 2005.5.1～2005.9.30	
	Amount of ecosystem respiration at nighttime (Mg C ha^{-1} y^{-1})	Mean values of temperature at night(℃)	Amount of ecosystem respiration at nighttime (Mg C ha^{-1} period^{-1})	Mean values of temperature at night (℃)
Nakashibetsu	3.24	3.1	2.39	12.2
Shizunai	3.91	4.5	2.94	13.6
Nasushiobara	4.02	10.1	2.55	18.3
Kobayashi	8.45	13.6	5.74	21.0
Reference : Paddy field（Mase）	3.09	11.7	2.09	20.0

4.1.5 Variation in the amount of carbon stock in grasslands estimated by NEP

Figure 4.1.5 shows the long-term variations in cumulative NEP since the beginning of a steady measurement by the eddy-covariance method, assuming the 1st of November 2004 to be a starting date. The variation in cumulative NEP, which includes the increased amount by manure application and the decreased amount by harvest, shows the variation in carbon stock in the grasslands that consisted of plant and soil. Although these data were from only two years of measurement, carbon stock in the chemical fertilizer plot tended to decrease a little in Nakashibetsu, to be stable in Shizunai, and to increase in Nasushiobara and Kobayashi. On the other hand, carbon stock in the manure plot in the grasslands increased because of the effect of manure application. How this tendency changes with the continuous application of manure, would be a further issue of interest that would have to be studied.

From this study of the continuous measurement of NEP by the eddy-covariance method, temporal variation in carbon stock in grasslands could be estimated in detail. However, it is necessary to investigate the temporal variations in organic carbon in soil and plant including the root for the verification of that result. Development of a simple method for verification is thus expected. In addition, comparison with the model of an ecosystem of a carbon budget is effective in improving the reliability of data obtained from the multiple sites. When NEP is measured by the eddy-covariance method, there are some problems that should be considered. These are, for example, detecting the unusual value resulting from the event of rainfall and its supplement, data analysis during times of low wind velocity at night, and the heat generation problem of the gas analyzer that takes part in the revision of atmospheric density on the open-pass eddy-covariance method.

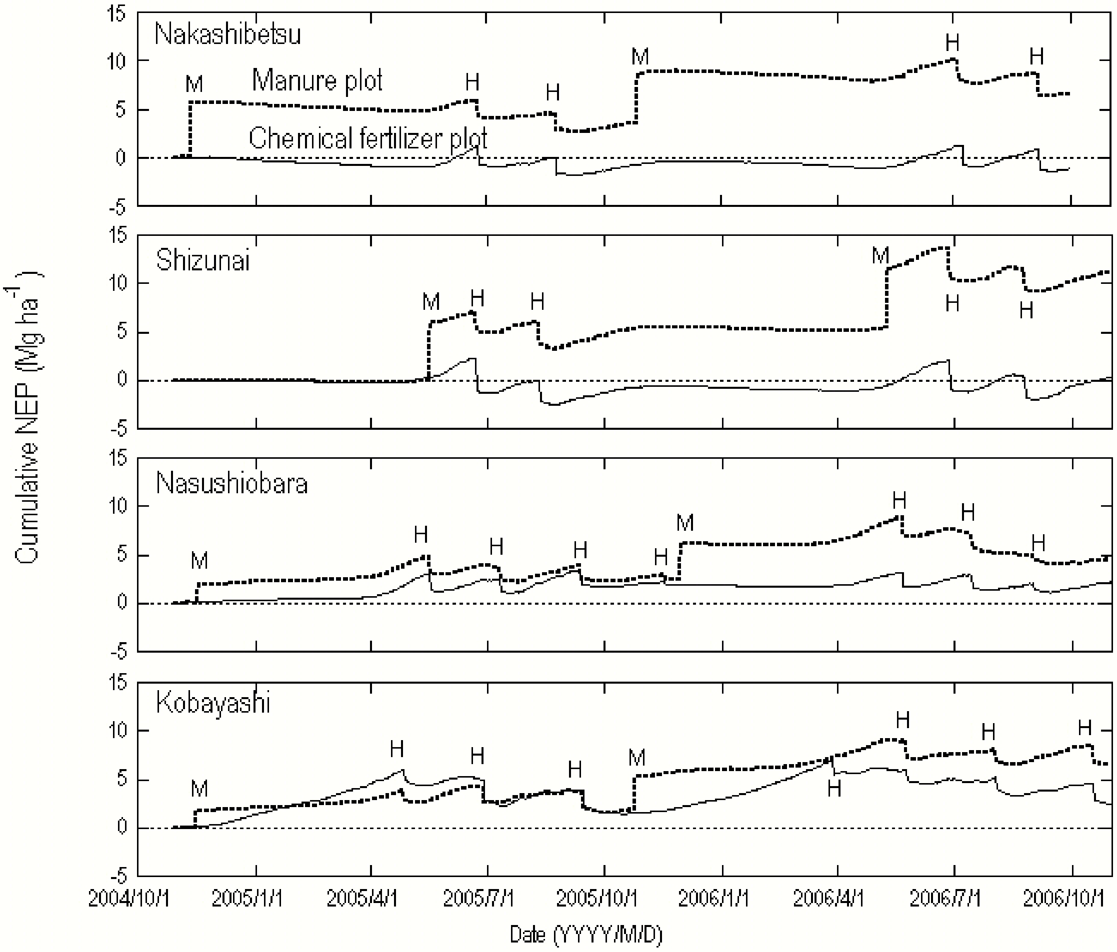

Figure 4.1.5 Long-term variation in cumulative NEP beginning from 1st November 2004. (The dotted lines represent the manure plot while the solid lines represent the chemical fertilizer plot. Variation in cumulative NEP that includes the increased amount due to manure application (M) and the decreased amount due to harvest (H), indicating the variation in carbon stock in grassland)

Reference

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4.2 Effect of manure application on the greenhouse gas budget

Abstract

Net biome production (NBP), measurements of CH_4 and N_2O emissions, and the effect of manure application to GWP was investigated during two years in the grasslands of four different climatic locations ranging from Hokkaido to Miyazaki in Japan. In the grasslands that were not applied with manure, GWP was affected by the annual mean temperature and duration of sunshine during the growing period. In addition, the GWP became positive and contributed to global warming when the duration of sunshine and the annual mean temperature were below 1000h and 10℃, respectively. Due to the application of manure, the GWP became negative in all observation sites, and it indicated a contribution to the mitigation of global warming. The contribution of NBP to the GWP was the largest, that of N_2O emissions were medium and those of CH_4 emissions were small. Based on the analysis of NBP components (NEP, the amount of harvested carbon and the amount of manure application), NEP and the amount of harvested carbon increased with an increase in the applied amount of N, and the effect increased with an increase in the annual mean temperature (up to 28℃).

In the regions where the annual mean temperature and the duration of sunshine during the growing period were below 10℃ and a 1000h, respectively, the NBP usually became negative when manure was not applied because the decomposition of organic matter continued after the harvest. Therefore, the application of manure is indispensable for maintaining carbon in the agricultural soil of cold districts. When GWP in this study was compared to that in the study on paddy fields or on upland in Hokkaido, the GWP was negative and global warming was mitigated only in the grasslands where manure was applied. In the paddy field, CO_2 was fixed but CH_4 was emitted. On the other hand, global warming was accelerated because of CO_2 and N_2O emission in the upland. Although manure application is the technique used for controlling global warming in cold districts, reduction in N_2O emission should be considered in the future.

4.2.1 The carbon budget

Table 4.2.1 shows the NBP and its components in manure and chemical fertilizer plots at the four observation sites. In all sites, NBP in the manure plot was positive, and was larger than that in the chemical fertilizer plot.

Table 4.2.1 Net biome production (NBP) and its components in manure and chemical fertilizer plots in four regions

Region	Year	Net biome production（Mg C ha^{-1} y^{-1}）							
		Manure plot					Chemical fertilizer plot		
		NEP	H	M	NEP-H	NBP	NEP	H	NBP
Nakashibetsu	2005	1.27	3.29	5.59	-2.02	3.57	2.67	3.57	-0.90
	2006	2.91	4.46	5.08	-1.5	3.53	4.22	4.11	0.02
Shizunai	2005	3.31	3.96	5.83	-0.65	5.18	4.69	5.42	-0.73
	2006	4.63	4.98	5.96	-0.35	5.60	5.84	5.13	0.71
Nasushiobara	2005	5.27	4.78	1.85	0.50	2.35	6.36	4.53	1.83
	2006	2.03	3.98	3.79	-1.95	1.83	3.60	3.82	-0.23
Kobayashi	2005	3.81	3.91	1.87	-0.10	1.77	5.98	4.50	1.49
	2006	6.14	4.50	3.19	1.64	4.83	6.84	5.53	1.30

One year was assumed as the period from 1st October to 30th September of the following year in Nakashibetsu and Shizunai. In Nasushiobara, the period from 8th November 2004 to 15th November was regarded as 2005, and from 16th November 2005 to 7th November 2006 was regarded as 2006.

That is, the carbon in grasslands was increased due to the application of manure. NBP is calculated by the differences between the input that are due to manure application (M) and carbon fixation by plants (NPP), and the output that are harvested carbon (H) and organic matter decomposition (RH) in soil and manure, as follows:

$$NBP = M + NPP - H - RH$$

NPP-RH means the NEP, and it was directly calculated using the eddy-covariance method in this study. Due to this, NBP was calculated by the equation: $NBP = M + NEP - H$. Based on these results, differences between the manure and chemical fertilizer plots or among the locations will be clarified in this chapter. After that, the relationship between the differences and climatic conditions will be analyzed.

First, to confirm whether there was a significant difference among the treatments and among the sites, a two-way ANOVA corresponding to one factor (treating this as a replication to make the values in each year corresponding to each site) was analyzed and its results are given in Table 4.2.2. There was a significant difference in NBP among the treatments at a 1% level, but not among the sites. This was because the NBP in the manure plot was larger than that in the chemical fertilizer plot, and the application of manure apparently contributed to the carbon fixation. The important parts of the result are as follow. There were no differences in the amount of harvested carbon (H) among the sites or treatment. On the other hand, there was a significant difference in NEP among the treatments at a 1% level but not among the sites. Furthermore, NEP in the chemical fertilizer plot was larger than that in the manure plot. NEP was calculated by the difference between the net primary production (NPP) of herbage plant, and organic matter decomposition (RH) of soil and manure. There is a high possibility of no variation in NPP among the treatments because the amount of harvested carbon between the chemical fertilizer and manure plots were similar. Therefore, the variation in NEP between the treatments might be due to the fact that organic matter decomposition of soil and manure (RH) in the manure plot was larger than that in the chemical fertilizer plot. NEP-H means the difference between the reproduction of herbage plant, and organic matter decomposition of soil and manure. The NEP-H in the chemical fertilizer plot was larger than that in the manure plot at a 5% level, but there was no difference among the sites. NBP in the manure plot was larger than that in the chemical fertilizer plot due to the large contribution of carbon application by manure.

Table 4.2.2 Result of a two-way ANOVA corresponding to one factor with respect to net biome production (NBP) and its components

(a) Amount of harvested carbon (H)

	Degree of freedom	Sum of squares	Mean squares	F value	P value
Region	3	2.20	0.73	1.33	0.381
Treatment	1	0.49	0.49	3.49	0.135
Region×Treatment	3	0.87	0.29	2.06	0.249
Error	4	0.56	0.14		
Total	15	6.32			

(b) NEP

	Degree of freedom	Sum of squares	Mean squares	F value	P value
Region	3	17.50	5.83	1.49	0.344
Treatment	1	7.36	7.36	48.25	0.002
Region×Treatment	3	0.01	0.00	0.02	0.994
Error	4	0.61	0.15		
Total	15	41.10			

(c) NEP－Amount of harvested carbon (NEP-H)

	Degree of freedom	Sum of squares	Mean squares	F value	P value
Region	3	9.84	3.28	1.92	0.268
Treatment	1	4.05	4.05	12.09	0.025
Region×Treatment	3	0.83	0.28	0.83	0.544
Error	4	1.34	0.33		
Total	15	22.90			

(d) NBP

	Degree of freedom	Sum of squares	Mean squares	F value	P value
Region	3	4.45	1.48	1.25	0.403
Treatment	1	39.43	39.43	42.15	0.003
Region×Treatment	3	10.87	3.62	3.87	0.112
Error	4	3.74	0.94		
Total	15	63.24			

4.2.2 Effect of climatic factors and N application to the carbon budget

The result of a two-way ANOVA showed that there were differences in components of the carbon budget (NEP, H and NEP－H), except for H, between the chemical fertilizer and manure plots, but not amongst the sites. Generally, it is known that the NPP of plant and organic matter decomposition (RH), which are components of the NEP, are affected by temperature, moisture and fertilization. Due to this, the relationship between the climatic factors (annual mean temperature, annual precipitation and duration of sunshine during the growing period) and the amount of inorganic N supply (application rate of chemical N fertilizer + release rate of manure N (estimated value from Uchida's model, Agriculture, Forestry and Fisheries Research Council Secretariat, 1985)) were investigated.

1) The amount of harvested carbon (H)

Figure 4.2.1 shows the relationships between the amounts of harvested carbon (H), the annual mean temperature (a) and the amount of inorganic N supply (b).

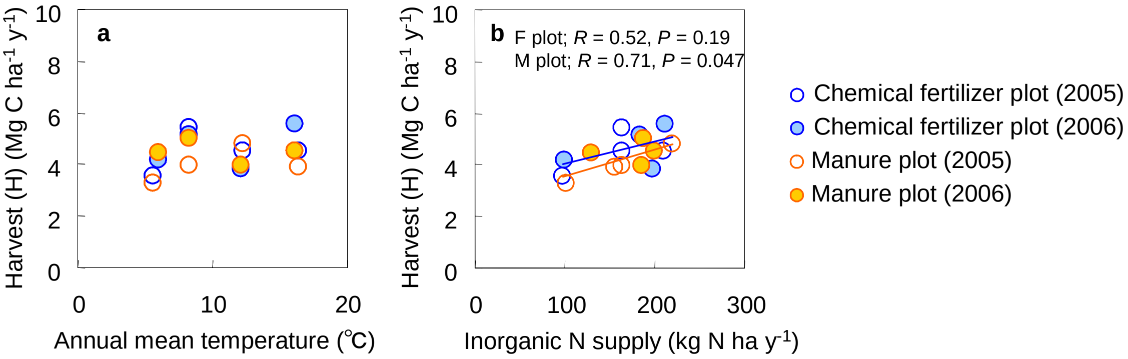

Figure 4.2.1 The relationships between the amounts of harvested carbon (H) and annual mean temperature (a), the amount of inorganic N supply (b)

There was no significant correlation between the amount of harvested carbon and the annual mean temperature. However, the yield tended to decrease with a decrease in temperature (chemical fertilizer plot: $\mathrm{R}=0.33$, $p=0.43$; manure plot: $R=0.16$, $p=0.70$). Also, the amount of harvested carbon (H) tended to increase with an increase in the inorganic N supply. In the chemical fertilizer plot, the relationships between the amount of harvested carbon and inorganic N supply were not significant ($\mathrm{R}=0.52$, $p=0.19$), but the relationship was significant ($R=0.71$, $p<0.05$) in the manure plot. The production of herbage plants were strongly affected however, by the application of N.

2) Net ecosystem production (NEP)

Figure 4.2.2 shows the relationships between NEP and the annual mean temperature or inorganic N supply. The NEP tended to increase with an increase in annual mean temperature (chemical fertilizer plot: $R=0.69$, $p=0.060$; manure plot: $R=0.59$, $p=0.13$). The NEP increased with an increase in inorganic N supply, and there was a significant correlation between them in the manure plot ($R=0.77$, $p<0.05$). Figure 4.2.3 shows not only the relationships between the NEP and the annual mean temperature in this study, but also the relationships of the measured values of the previous studies that were calculated by the micrometeorological method. Comparing the NEP of this study to those from the previous studies, the NEP of this study tended to be large. This was because there were both fertilized and unfertilized grasslands in the documented values, these were separated, and the relationship between NEP and annual mean temperature were evaluated. In the unfertilized grassland, NEP tended to be zero or negative with an increasing annual mean temperature, and was significantly correlated with the annual mean temperature by the quadratic function ($\mathrm{y}=-0.032\ \mathrm{x}^2+0.61\ \mathrm{x}-1.6$, $R^2 = 0.22$, $p<0.01$). From this regression, the NEP turned out to have a maximum annual mean temperature at 9.5℃, and the positive NEP, which is the carbon fixation, was between 3℃ and 16℃ of the annual mean temperature. Even in the fertilized grassland, the NEP was correlated with the annual mean temperature using the quadratic function ($\mathrm{y}=-0.028\ \mathrm{x}^2+0.80\ \mathrm{x}$

-1.0, $R^2=0.12$, $p=0.32$, not significant), and turned out to have a maximum at 14.6℃ and to be positive between 1℃ and 28℃. These results indicate that the effect of fertilization on the NEP was large, especially in warm districts and also that fertilization could be very effective in carbon fixation.

Generally, cool season-type grasses start to grow at a temperature above 5℃. Figure 4.2.4 shows the relationships between the NEP and the duration of sunshine during the growing period in which the daily mean temperature was 5℃ and above. The result also showed that there was a significant positive correlation between them ($R=0.81$, $p<0.05$) in the chemical fertilizer plot. Although, there was no significant correlation between them in the manure plot, a trend of a positive relation between them was observed ($R=0.63$, $p=0.060$). There was a large temporal variation in NEP in Nasushiobara, and NEP was small in 2006. This was because the duration of sunshine in 2006 (877h) was smaller than in 2005 (1110h), and the scarcity of sunshine duration might have suppressed the growth of herbage plants. Growth of the herbage plant could have been more suppressed because the vegetation changed from 2005 to 2006 and deterioration of grassland was continuing in Nasushiobara. These results basically showed that NEP was strongly affected by the production of herbage plants that were influenced by the climatic conditions and the amount of N application.

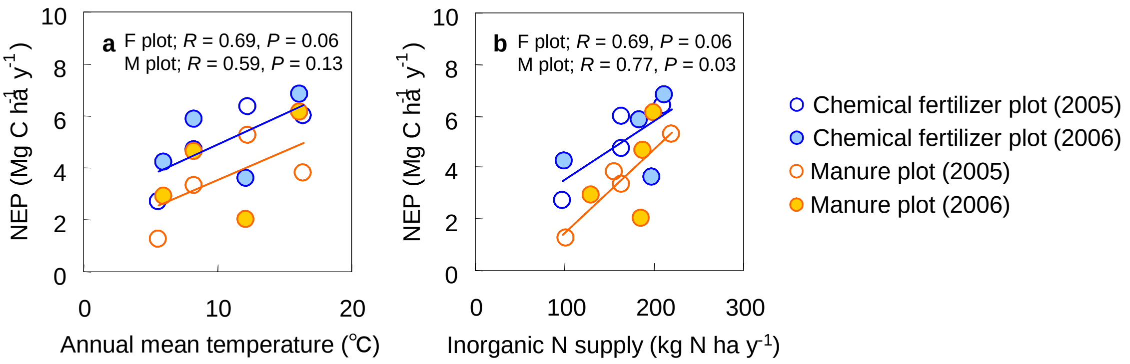

Figure 4.2.2 The relationship between the net ecosystem production (NEP), the annual mean temperature (a) and the amount of inorganic N supply (b).

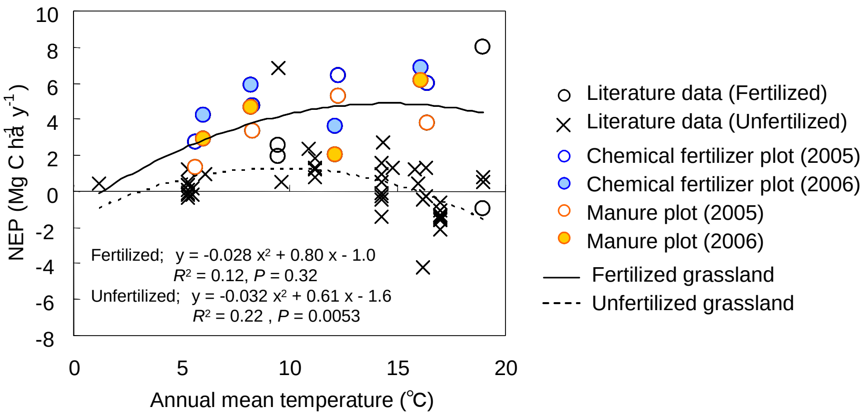

Figure 4.2.3 The relationship between the annual mean temperature and net ecosystem production. (The reference values are the NEP of grasslands measured by the micrometeorological method.)

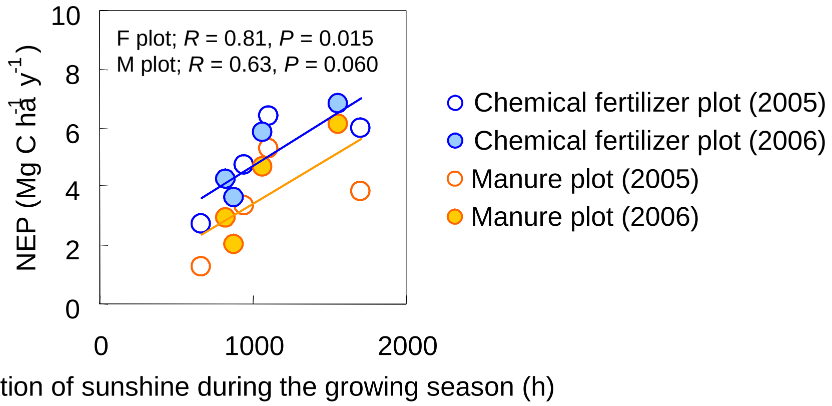

Figure 4.2.4 The relationship between the duration of sunshine during the growing period and net ecosystem production. (The plant growing period was assumed to be the period of time where it had a temperature above 5℃.)

3) The carbon budget (NEP-H) of residue and re-production of herbage plant and organic matter decomposition

Carbon budgets (NEP-H) with respect to the herbage plant residue, re-production of herbage plant and organic matter decomposition were negative in Nakashibetsu and Shizunai in Hokkaido. Figure 4.2.5 shows the relationship between NEP-H and the annual mean temperature. NEP-H was positively correlated with the annual mean temperature, and there was a significant positive correlation between them in the chemical fertilizer plot ($y = 0.18x - 1.5$, $R^2 = 0.54$, $p < 0.05$). From the regression analysis between them in the chemical fertilizer plot when the annual mean temperature was below 8.2℃, the NEP-H were negative, therefore organic matter decomposition exceeded the re-production and residue of the herbage plant. That is, organic matter decomposition was larger than the re-production and residue of herbage plant in the cold region like Hokkaido which is classified as a cool temperate and sub-polar zone. We tried to analyze this using the data in Shizunai where organic matter decomposition was measured throughout the year.

Figure 4.2.6 shows the relationship between organic matter decomposition and soil temperature at a 5cm depth in Shizunai. This relationship indicated that organic matter decomposition increased with an increase in soil temperature, and also showed that organic matter decomposition occurred even at a temperature of 0℃. As described in the results chapter, NEP was negative during the snow-covered condition in Nakashibetsu and Shizunai, and CO_2 was emitted from both of the sites. In the cold district where the growing period is short, re-production and the amount of herbage plant residue was small. In addition, organic matter decomposition occurred not only in the summer season, but also in the seasons of low temperature. This was one of the reasons for a negative NEP-H. As a result of this, it is thought that carbon loss from the agricultural land in cold districts could have been large. However, in Nasushiobara where the annual mean temperature was 12℃, the NEP-H was negative when the duration of sunshine during the growing period was short in 2006.

Figure 4.2.7 shows the relationship between NEP-H and the duration of sunshine during the growing period. In chemical fertilizer and manure plots, significant positive correlations between them were observed (chemical fertilizer plot: R=0.78, $p < 0.05$; manure plot: R=0.78, $p < 0.05$). This relationship indicated that when the duration of sunshine during the growing season fell below 1000h, the carbon budget became negative. Thus, the duration of sunshine also greatly influenced the carbon budget.

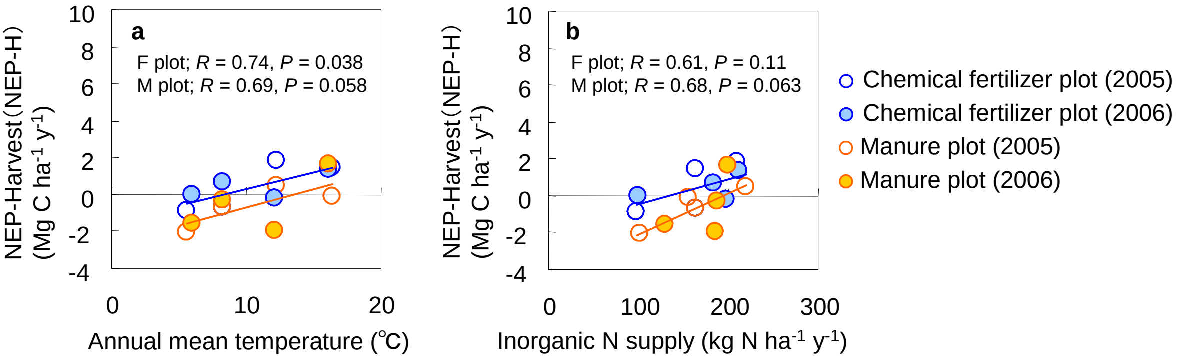

Figure 4.2.5 The relationships between the harvested carbon subtracted from the net ecosystem production (NEP-H) and the annual mean temperature (a), amount of inorganic N supply (b).

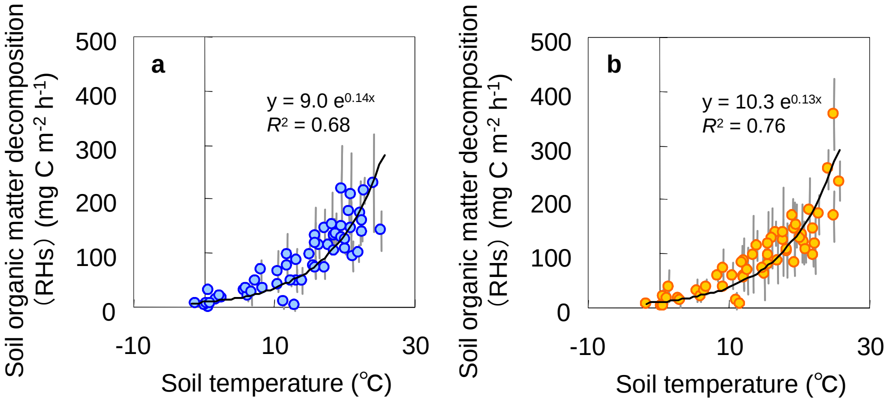

Figure 4.2.6 The relationships between soil temperature at a 5cm depth and soil organic matter decomposition (RHs) in the chemical fertilizer plot (a) and the manure plot (b) in Shizunai.

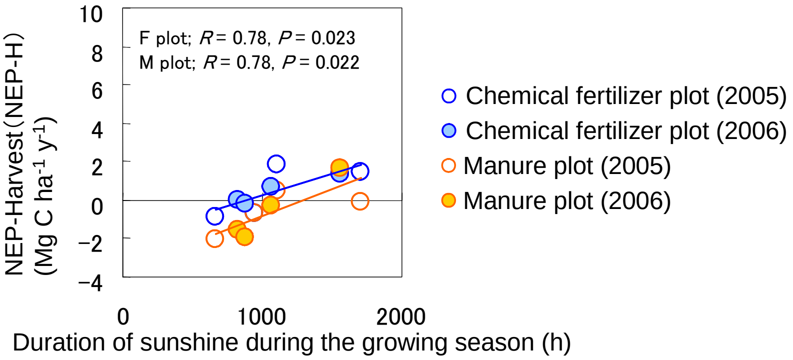

Figure 4.2.7 The relationship between the harvested carbon subtracted from the net ecosystem production (NEP) and the duration of sunshine during the growing period.

4) The carbon budget in grasslands (net biome production, NBP)

It was recognized that NEP-H would become negative in cold districts or during the year when there wasn't enough hours of sunshine during the growing period. In such a case, application of manure would be effective. Figure 4.2.8 shows the relationships between the net biome production (NBP, carbon budget in which manure (M) was added, NBP= NEP－H ＋M) and the annual mean temperature. In the chemical fertilizer plot, NBP equaled the NEP-H because the manure application was zero, and the result was similar to that of figure 4.2.5a.

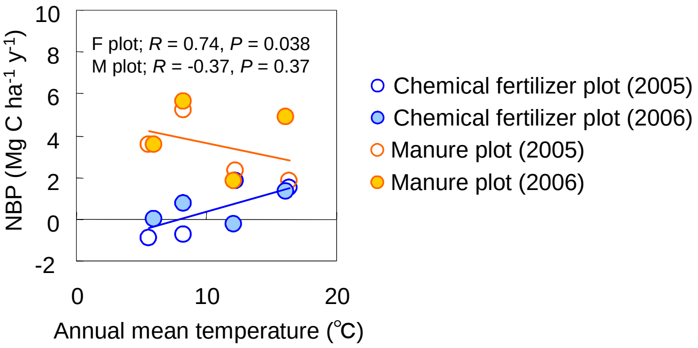

Figure 4.2.8 The relationship between the net biome production (NBP) and annual mean temperature.

In the manure plot, all values of NBP were positive. However, the NBP tended to decrease with an increase in annual mean temperatures, and this relation was not significant (R＝－0.37, p＝0.37). The reason for this is that the amount of manure applied was smaller in the warm districts like Nasushiobara and Kobayashi, than that in the cold regions. In the warm district, the factor of this restriction is due to the high potassium content in manure.

5) Effect of manure application to the soil organic matter decomposition

Generally, an increase in soil organic matter by the application of manure is considered to be effective. IPCC (2003) pointed out that the effect of manure application on the increase in soil organic matter could be recognized in the temperate and tropical districts. In the case of green manure, the increasing rates of soil organic matter, (which existed in up to the 30cm depth of soil when manure was applied), were 4% in the dry district and 11% in the wet district. In addition, the rates in the case of animal manure were 37% in the dry district and 44% in the wet district. However, the effects in the cold districts were not mentioned in the IPCC report (IPCC 2003). In this study, the amounts of soil organic carbon at a 30cm depth (average of chemical fertilizer and manure plots) in Nakashibetsu, Shizunai, Nasushiobara and Kobayashi were 120, 76.3, 138 and 157 Mg C ha^{-1}, respectively. The increasing rate was the ratio of the amount of carbon increase due to the application of manure (difference in NBP between the manure and chemical fertilizer plots) and the amount of soil organic carbon. Accordingly, averages of the increasing rate during the two years in Nakashibetsu, Shizunai, Nasushiobara and Kobayashi were 3.31, 7.08, 0.92 and 1.21%, respectively.

These increasing rates were small compared to the IPCC's data. But these effects were observed in all sites including the cold district. However, this effect was calculated from the carbon budget of the year when manure was applied. This is because manure that is added to the soil decomposes year after year, and the pattern of how the effect continues to maintain a positive carbon budget should be considered. This point was assessed as follows.

In Shizunai, the amount of harvested carbon (H) was larger than the NEP, except for what was in the chemical fertilizer plot in 2006. Annual amounts of organic matter decomposition measured in Shizunai in 2005 and 2006 were 1.8 and 1.6 Mg C ha^{-1} y^{-1}, respectively. Therefore, the decomposition rates of organic matter in 2005 and 2006 were calculated as 34% and 30%, respectively, since the applied amounts of manure carbon were 5.8 and 6.0 Mg C ha^{-1} y^{-1}. On the other hand, the rates of decomposition of soil organic matter was estimated to be 5.6-7.0% because the decomposition amounts of soil organic matter in 2005 and 2006 in the chemical fertilizer and manure plots ranged from 4.4 to 5.2 Mg C ha^{-1} y^{-1}. Based on the results using Uchida's model in Figure 4.2.9, the decomposition rate of manure after five and eight years would be below 5% and 3%, respectively, and 50-70% of the applied amount of carbon would be lost after ten years**.** From this viewpoint, the decomposing condition of the manure applied would be equal to that of soil organic matter in the fifth year and 2-3 Mg C ha^{-1} y^{-1} of the applied manure would remain even in the tenth year. This value would be larger than the NBP in the chemical fertilizer plot (-0.7-0.7 Mg C ha^{-1} y^{-1}). This means that an application of manure could maintain the positive carbon budget for at least ten years in Shizunai. Furthermore, the remaining amounts of manure were larger than the NBP in the chemical fertilizer plot in Nakashibetsu.

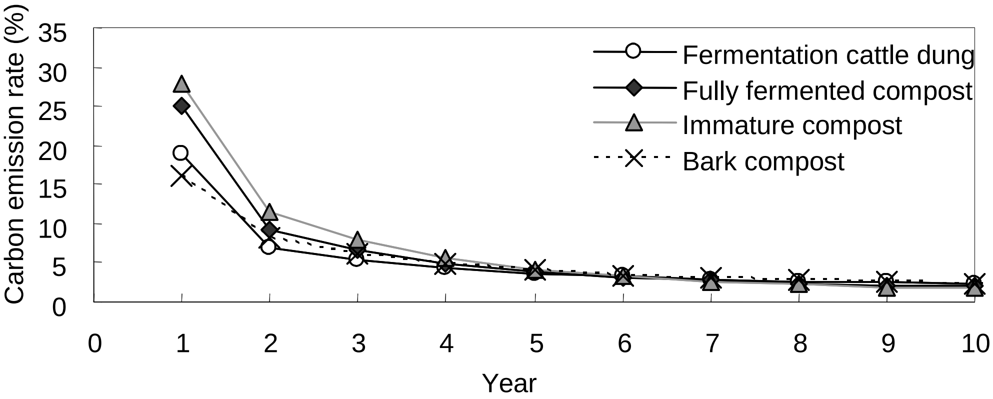

Figure 4.2.9 Variation in the carbon emission rate of various types of manure according to Uchida's model (Agriculture, Forestry and Fisheries Research Council Secretariat, 1985).

Although the amount of decomposition of organic matter was not measured in Nakashibetsu, more of the effects of manure application than in Shizunai can be expected. This is since decomposition of organic matter might be smaller than in Shizunai due to a lower temperature, and also since the NBP in the manure plot was larger in Nakashibetsu than in Shizunai. On the other hand, in the warm districts of Nasushiobara and Kobayashi, the grassland itself had an effect in making the carbon budget positive because the NBP in the chemical fertilizer plot was positive at least in Kobayashi, excluding Nasushiobara in 2006 when the duration of sunshine was low. The grasslands which have manure applied can be regarded as effective carbon stock. In the future, clarification of the changes in the annual decomposition rate of manure and understanding of the differences in decomposition rates of soil organic matter are expected.

4.2.3 CH_4 flux

The result of a two-way ANOVA showed that there were no relationships between CH_4 emission either in the sites or treatments (Table 4.2.3). CH_4 was absorbed in Nasushiobara and Kobayashi in both years, but the emission and uptake of CH_4 occurred in both years in Nakashibetsu and Shizunai, situated in the cold district. However, there were no relationships between CH_4 emission and the amount of N application, annual precipitation or annual mean temperature (Table 4.2.4).

Because CH_4 oxidizer is suffocated due to NH_4, N application by fertilization could have caused a decrease in the CH_4 uptake (Jensen et al., 1998). In Shizunai, CH_4 emission from an unfertilized plot was almost the same as in manure and chemical fertilizer plots, and the effect of fertilization on CH_4 uptake and emission was not clear. However, a decrease in CH_4 uptake might occur due to the application of fertilizer, because Mori et al. (2005) reported that 1.8-2.4 kg C ha^{-1} y^{-1} CH_4 was absorbed in unfertilized grasslands in Nasushiobara. On the other hand, the maximum activity of CH_4 oxidization in soil occurs on the surface mineral layer, and it doesn't depend on the vegetation (Czepiel et al., 1995). On the O layer in forest soil, CH_4 oxidization might be lower in the organic layer because CH_4 was emitted in anaerobic conditions (Bender and Conrad, 1994). Grasslands in Shizunai have been maintained for a long time since grasslands were established after regeneration. Also, the below-ground parts grew well and formed the root mats, which could have possibly helped result in a small CH_4 uptake.

Table 4.2.3 CH_4 emission from each region

Region	Year	Period	CH_4 emission			
			Treatment			
			Manure plot		Chemical fertilizer plot	
Nakashibetsu	2005	2004/10/1-2005/9/30	-0.23	(0.83)	-0.55	(1.04)
	2006	2005/10/1-2006/9/30	0.03	(0.55)	0.41	(0.54)
Shizunai	2005	2004/10/1-2005/9/30	0.44	(0.37)	0.20	(0.60)
	2006	2005/10/1-2006/9/30	-0.16	(0.33)	-0.12	(0.36)
Nasushiobara	2005	2004/11/9-2005/11/21	-0.75	(0.33)	-0.86	(0.30)
	2006	2005/11/22-2006/11/9	-0.15	(0.51)	-0.50	(0.23)
Kobayashi	2005	2004/10/21-2005/10/20	-0.26	(0.42)	-0.23	(0.28)
	2006	2005/10/21-200610/20	-0.21	(0.35)	-0.23	(0.77)

	Result of a two-way ANOVA corresponding to one factor				
Factor	Degree of freedom	Sum of squares	Mean squares	F value	P value
Region	0.92	3	0.31	1.50	0.343
Treatment	0.02	1	0.02	0.59	0.486
Region×Treatment	0.04	3	0.01	0.34	0.799
Error	0.16	4	0.04		
Total	1.97	15			

Standard deviations are shown in parentheses.

Table 4.2.4 Correlations between CH_4 emission, environmental factors and soil chemical and physical properties

Factor	Correlation coefficient	
	Manure plot	Chemical fertilizer plot
Amount of the applied N	0.36	-0.42
Amount of inorganic N supply	-0.41	-0.42
Annual mean temperature	-0.39	-0.33
Annual precipitation	-0.22	-0.11
pH in surface soil	-0.35	0.16
C content in surface soil	0.07	-0.02
N content in surface soil	0.24	0.32
C:N ratio in surface soil	-0.54	-0.67

**, 1% significance level; *, 5% significance level

4.2.4 N_2O flux

The result of a two-way ANOVA indicated that there were significant differences (at 5% level) in N_2O emission among the treatments, but no differences among the sites (Table 4.2.5). However, the amount of N_2O emission tended to increase with an increase in annual mean temperature, and as Table 4.2.6 shows, there was a significant correlation among them at a 1% level especially in the manure plot.

Table 4.2.5 N_2O emission from each region

Region	Year	Period	N_2O emission (kg N ha^{-1} y^{-1})	
			Treatment	
			Manure plot	Chemical fertilizer plot
Nakashibetsu	2005	2004/10/1-2005/9/30	0.6 (0.2)	0.3 (0.1)
	2006	2005/10/1-2006/9/30	1.9 (0.6)	0.5 (0.1)
Shizunai	2005	2004/10/1-2005/9/30	3.8 (1.2)	2.8 (0.7)
	2006	2005/10/1-2006/9/30	4.9 (2.8)	2.9 (0.7)
Nasushiobara	2005	2004/11/9-2005/11/21	7.1 (2.8)	4.8 (1.0)
	2006	2005/11/22-2006/11/9	10.9 (3.6)	9.1 (2.2)
Kobayashi	2005	2004/10/21-2005/10/20	11.3 (3.0)	1.9 (0.6)
	2006	2005/10/21-200610/20	5.3 (2.0)	3.1 (0.6)

Factor	Result of a two-way ANOVA corresponding to one factor				
	Degree of freedom	Sum of squares	Mean squares	F value	P value
Region	108.3	3	36.1	6.13	0.056
Treatment	26.3	1	26.3	7.70	0.050
Region×Treatment	14.8	3	4.9	1.45	0.354
Error	13.7	4	3.4		
Total	185.3	15			

Standard deviations are shown in parentheses.

Table 4.2.6 Correlations between N_2O emission, environmental factors and soil chemical and physical properties

	Correlation coefficient	
	Manure plot	Chemical fertilizer plot
Amount of the applied N	-0.21	0.71
Amount of inorganic N supply	0.53	0.71
Annual mean temperature	0.78 *	0.38
Annual precipitation	0.40	0.10
pH in surface soil	0.18	-0.59
C content in surface soil	-0.52	-0.45
N content in surface soil	-0.64	-0.77 *
C:N ratio in surface soil	0.18	0.61

**, 1% significance level; *, 5% significance level

Although the relationships between N_2O emission and applied N fertilizer in the chemical fertilizer plot and between N_2O emission and inorganic N supply in the manure plot were not significant, both these correlations were positive (Table 4.2.6). In Nasushiobara, N_2O emission was 9.1 kg N ha^{-1} y^{-1} in the chemical fertilizer plot. This can be regarded as an outlier at a 5% level on the Smirnov-Grubbs test. Based on this result, when the value of Nasushiobara in 2006 was excluded, a significant positive correlation between N_2O emission and the applied amount of N fertilizer was observed ($y = 0.031x - 2.72$, $R^2 = 0.86$, $p < 0.01$). Furthermore, in the manure plot, large N_2O emissions such as 11.2 kg N ha^{-1} y^{-1} in Kobayashi in 2005 and 10.9 kg N ha^{-1} y^{-1} in Nasushiobara in 2006 were observed. Although these values were not outliers, there was a significant positive correlation between N_2O emission and the amount of inorganic N supply ($y = 0.052x - 4.79$, $R^2 = 0.99$, $p < 0.01$) when excluding these values from the regression analysis**.** The NEP values in Kobayashi in 2005 and Nasushiobara in 2006, (where N_2O emission values were excluded from those regressions), were low due to insufficient sunshine or due to the deterioration of grassland (Figure 4.2.2). Those grasslands were actually sites that were already regenerated or sites that were planned to be regenerated.

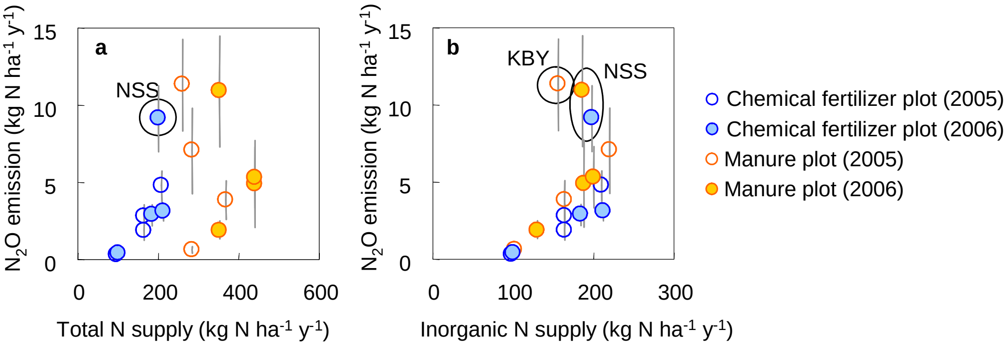

Figure 4.2.10 The relationships between N_2O emission and the applied amount of N (a), amount of inorganic N supply (b).

From these results, it was thought that the decrease in production of herbage plants might have reduced the amount of N uptake, and N_2O emission might have been accelerated. However, based on the results of Figure 4.2.10, there is a high possibility that N_2O emission depended on the amount of inorganic N supply. However, as Figure 4.2.11 indicates, the proportion of N_2O emission with respect to the amount of inorganic N supply significantly correlated (at a 5% level) with the mean annual temperature in the manure plot. Furthermore, the amount of N_2O emission from the manure plot was significantly larger than that from the chemical fertilizer plot (Table 4.2.5). Therefore, the N_2O emission increased because the use of labile organic carbon by microbes might have accelerated these activities, and such activities might have accelerated nitrification and denitrification (Jones et al., 2005).

The applied amount of N and the amount of N_2O emission in our study tended to have similar patterns with previously reported values (Figure 4.2.12). Furthermore, the proportion of N_2O

emission with respect to the amount of applied N tended to increase, with an increase in annual mean temperature (Figure 4.2.13). However, variability in this relation was large, and this could have possibly been influenced by the moisture content.

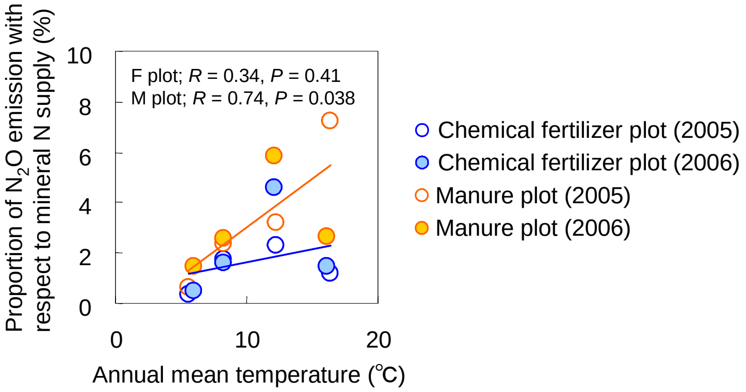

Figure 4.2.11 The relationship between the annual mean temperature and the proportion of N_2O emission with respect to the applied amount of inorganic N.

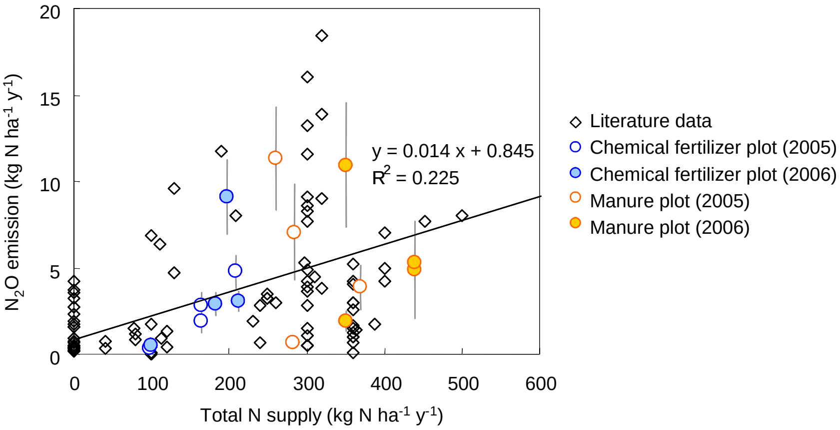

Figure 4.2.12 The relationship between N_2O emission and the amount of applied N

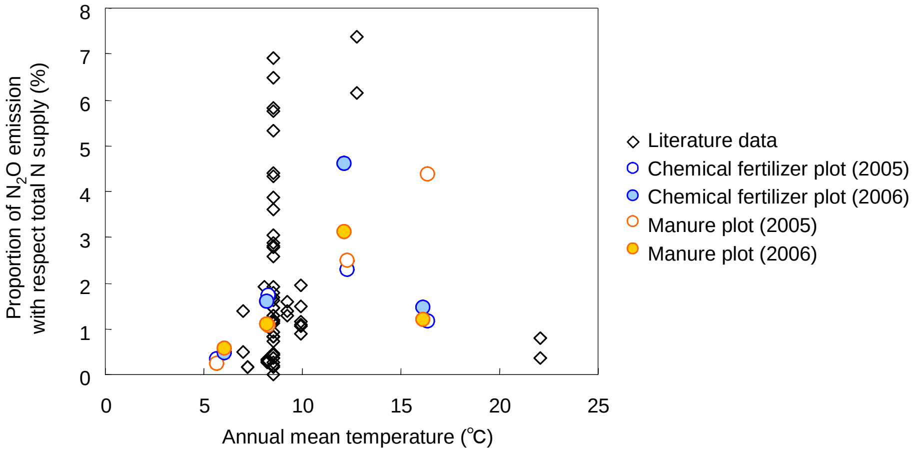

Figure 4.2.13 The relationship between the annual mean temperature and the proportion of N_2O emission with respect to the applied amount of N (Documented values were from grasslands of mineral soils).

4.2.5 The global warming potential (GWP)

The result of a two-way ANOVA showed that the GWP was significantly different between the treatments, but not between the observation sites (Table 4.2.6). The carbon budget (NBP) had the most effect on the GWP and next was N_2O (Figure 4.1.14), while the effect of CH_4 on the GWP was small. The relationship between GWP and the annual mean temperature indicated that the GWP tended to be positive under 10℃ in the chemical fertilizer plot (Figure 4.2.15).

Table 4.2.7 Global warming potential (GWP) in each region

Region	Year	GWP (Mg CO_2eq ha^{-1} y^{-1})							
		Manure plot				Chemical fertilizer plot			
		GWP components			GWP	GWP components			GWP
		CO_2	CH_4	N_2O		CO_2	CH_4	N_2O	
Nakashibetsu	2005	-13.1	- 0.01	0.3	-12.8	3.3	- 0.02	0.1	3.4
	2006	-12.9	0.00	0.9	-12.0	- 0.4	0.01	0.2	- 0.2
Shizunai	2005	-19.0	0.01	1.8	-17.2	2.7	0.01	1.3	4.0
	2006	-20.6	0.00	2.3	-18.3	- 2.6	0.00	1.3	- 1.3
Nasushiobara	2005	-8.6	- 0.02	3.3	-5.4	- 6.7	- 0.03	2.2	- 4.5
	2006	-6.7	0.00	5.1	-1.6	0.8	- 0.02	4.2	5.1
Kobayashi	2005	-6.5	- 0.01	5.3	-1.2	- 5.5	- 0.01	0.9	- 4.6
	2006	-17.7	- 0.01	2.5	-15.3	- 4.8	- 0.01	1.4	- 3.4

Factor	Result of a two-way ANOVA corresponding to one factor				
	Degree of freedom	Sum of squares	Mean squares	F value	P value
Region	90.8	3	30.3	1.3	0.400
Treatment	425.8	1	425.8	22.5	0.009
Region×Treatment	173.0	3	57.7	3.0	0.155
Error	75.6	4	18.9		
Total	861.2	15			

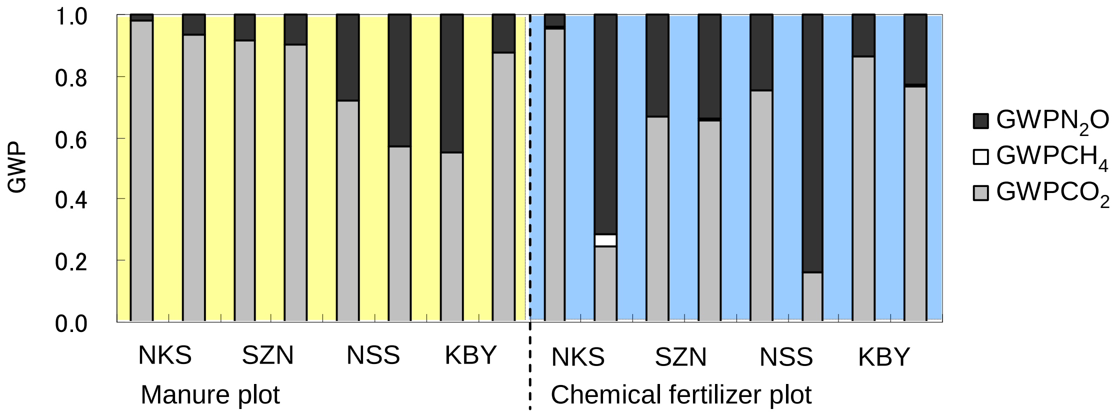

Figure 4.2.14 The ratios of $GWPCO_2$, $GWPCH_4$ and $GWPN_2O$ in the absolute values of $GWPCO_2$, $GWPCH_4$ and $GWPN_2O$.

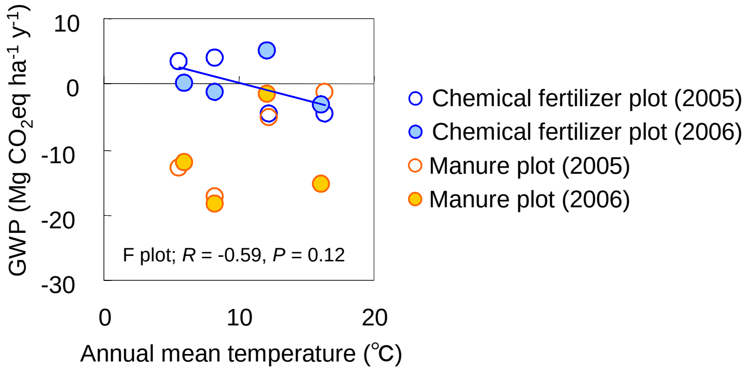

Figure 4.2.15 The relationship between the annual mean temperature and global warming potential.

In the manure plot, the GWP was negative in 2005 and 2006 in all sites, indicating that the application of manure was effective in mitigating global warming. In Nasushiobara and Kobayashi, the GWP was negative in the chemical fertilizer plot when excluding the value for 2005 in Nasushiobara. This suggested that grasslands in the warm district contributed to the mitigation of global warming. However, the GWP was positive in Nasushiobara when the production of herbage plants decreased due to insufficient sunshine and deterioration of grasslands in 2006. Therefore, grasslands in the warm districts could have possibly contributed to the enhancement of global warming, when the production of herbage plants lowered.

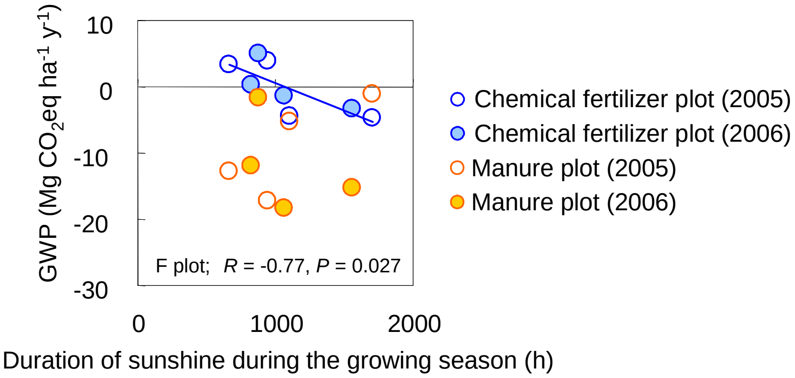

Figure 4.2.16 The relationship between the duration of sunshine during the growing period and the global warming potential (The growing period was regarded as the period when daily mean temperature was above 5℃).

There was a significant negative correlation (R＝-0.77、$p<0.05$) between the GWP and the duration of sunshine in the chemical fertilizer plot (Figure 4.2.16). Based on this relation, if manure had not been applied, the GWP would have become positive in durations of sunshine below a 1000h. The application of manure thus showed a comparatively large effect on the mitigation of global warming in the years of low temperature and insufficient durations of sunshine.

Figure 4.2.17 shows the GWP that was measured in several agricultural fields in Hokkaido (Mu et al. 2006, Naser et al., 2007). In each upland field, the GWP was positive due to CO_2 (NBP) and

N_2O, and these fields contributed to global warming. In the paddy field, CO_2 made the GWP negative but there were also some sites where the GWP budget became positive due to CH_4 emission in several fields. CH_4 emission is generally induced by the application of rice straw. The GWP in Mikasa was a little larger than that in Nakashibetsu and Shizunai. This study showed a possibility of mitigating global warming by the application of manure. It also provides an important grassland management system for the mitigation of global warming and enhancement of agriculture in cold districts. However, suppression of N_2O emission should be considered because the application of manure enhances N_2O emission.

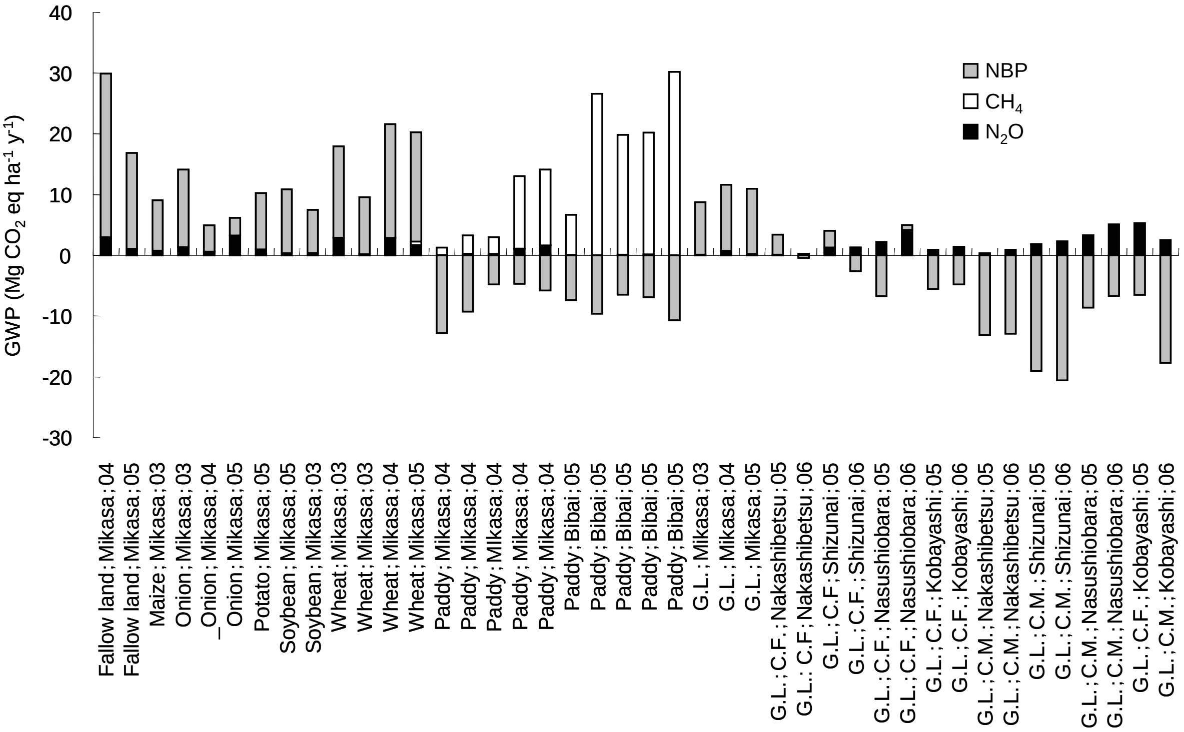

Figure 4.2.17 Comparison among documented and measured values of this study, concerning the GWP for various land uses in Hokkaido. NBP of the documented value was measured by an ecological technique. Note: C.F., C.M. and G.L. stand for chemical fertilizer, manure and grassland, respectively.

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Appendix 1. Meteorological data of each observation site

1. Shizunai site

Appendix 1.1 Monthly precipitation in the Shizunai site

	Precipitation（mm）			
	2004	2005	2006	Average year
January	56	63	12	42
February	84	16	66	30
March	49	36	121	67
April	91	126	82	110
May	239	96	195	153
June	97	68	171	93
July	122	165	52	136
August	133	93	96	213
September	135	158	46	202
October	23	138	110	102
November	102	96	137	127
December	53	58	25	67

Appendix 1.2 Monthly duration of sunshine in the Shizunai site

	Duration of sunshine（h）			
	2004	2005	2006	Average year
January	129	125	159	117
February	155	138	110	148
March	176	182	147	168
April	162	170	146	160
May	153	145	221	165
June	153	156	134	126
July	163	89	139	95
August	157	136	160	115
September	108	136	167	112
October	121	127	187	135
November	108	117	118	101
December	101	131	128	98

Appendix 1.3 Monthly average, maximum and minimum temperature in the Shizunai site

	Average temperature（℃）				Maximum temperature（℃）				Minimum temperature（℃）			
	20	2005	2006	Average	2004	2005	2006	Average	2004	2005	2006	Average
Janu	-2.	-3.2	-4.3	-3.9	4.4	6.8	4.0	0.0	-11.4	-14.0	-13.3	-8.1
Febr	-1.	-4.2	-3.0	-3.5	10.6	4.9	7.1	0.4	-10.0	-13.7	-15.6	-8.1
Marc	0.	0.1	1.9	0.2	11.6	10.5	14.8	3.7	-10.8	-12.9	-6.7	-3.7
April	5.	5.7	4.8	5.6	19.0	16.4	16.3	9.4	-3.6	-3.3	-4.2	1.4
May	11	8.9	10.5	10.3	20.8	20.4	21.9	14.1	1.3	1.0	0.3	6.4
June	15	15.0	13.9	14.3	26.4	27.7	24.8	17.5	8.3	7.9	5.3	11.1
July	19	17.8	18.1	18.3	30.1	28.0	25.3	21.1	10.1	11.2	12.9	15.8
Aug	20	22.1	22.8	20.7	29.9	31.3	29.5	23.6	10.7	14.3	15.6	17.8
Sept	17	17.9	17.9	17.2	25.3	27.2	25.5	20.9	10.2	9.3	8.5	13.3
Octo	11	12.5	11.6	11.2	21.7	21.2	23.8	15.5	-1.5	2.4	-0.1	6.6
Nove	7.	5.8	6.8	4.8	20.2	18.5	18.4	8.9	-7.7	-3.2	-2.1	0.6
Dece	-0.	-2.7	0.0	-0.5	11.5	7.2	9.6	3.1	-10.4	-13.7	-8.7	-4.2

Appendix 1.4　Monthly average soil temperature at 5cm and 10cm depth in the Shizunai site

	Manure plot						Chemical fertilizer plot					
	5cm soil temperature			10cm soil temperature			10cm soil temperature			10cm soil temperature		
	2004	2005	2006	2004	2005	2006	2004	2005	2006	2004	2005	2006
January		0.1	1.2		0.6	1.4		0.2	1.4		0.8	1.8
February		0.3	1.0		0.6	1.1		0.1	1.0		0.8	1.4
March		0.6	1.2		0.6	1.2		0.5	1.3		0.7	1.5
April		4.9	5.0		4.5	4.8		4.6	4.3		4.1	4.2
May		10.9	12.2		10.6	11.8		10.3	11.0		10.0	10.7
June		16.2	13.7		15.8	13.5		16.9	14.1		16.3	13.7
July		18.7	18.7		18.4	18.4		18.8	18.7		18.5	18.3
August		22.3	20.5		22.0	20.1		22.5	20.6		22.0	20.2
Septemb		18.0	17.3		17.9	17.2		17.8	17.5		17.9	17.5
October	10.2	12.0	11.7	11.8	12.2	11.8	11.1	12.2	11.7	12.3	12.6	12.1
Novembe	6.2	5.3		7.2	5.5		7.0	5.3		7.9	6.1	
Decembe	0.7	0.7		1.1	1.0		1.1	1.0		1.6	1.6	

2. Nakashibetsu site

Appendix 2.1 Monthly average temperature in the Nakashibetsu site

	Average temperature (℃)				Maximum temperature (℃)				Minimum temperature (℃)			
	2004	2005	2006	Average*	2004	2005	2006	Average *	2004	2005	2006	Average*
January	-5.8	-6.8	-7.1	-7.3	-1.0	-1.7	-2.6	-2.4	-12.9	-13.7	-13.2	-13.8
February	-5.2	-7.3	-6.0	-7.3	-0.3	-3.1	-1.0	-2.3	-11.7	-13.2	-12.9	-13.9
March	-2.6	-3.1	-0.8	-3.0	1.7	1.8	3.0	1.2	-8.0	-9.0	-5.5	-8.5
April	2.8	2.9	1.9	3.2	7.4	7.5	5.7	8.1	-1.9	-1.2	-2.0	-1.4
May	9.8	6.3	9.4	8.3	15.3	10.8	15.9	14.1	4.7	2.6	3.3	3.2
June	14.5	13.9	11.8	11.8	20.5	20.0	15.6	16.6	9.2	9.0	8.9	7.8
July	17.4	14.7	15.6	15.7	22.2	18.4	19.8	20.0	13.8	11.7	12.4	12.3
August	18.8	20.0	20.8	18.0	23.6	24.4	25.2	22.2	14.5	16.2	17.2	14.5
September	15.9	16.3	15.9	15.0	20.4	21.1	20.3	19.4	11.6	11.5	11.4	10.5
October	10.0	10.6	9.4	9.2	15.4	15.8	14.4	14.4	5.0	5.4	4.1	3.7
November	4.6	3.7	4.4	2.5	9.4	8.5	9.2	7.3	-0.5	-2.8	-0.4	-2.6
December	-4.6	-3.5	-3.6	-3.4	0.4	0.5	0.8	1.0	-11.3	-8.9	-9.1	-8.5
Annual average	6.2	5.6	6.0	5.6	11.3	10.3	10.5	10.0	1.0	0.6	1.2	0.3
5-10 Monthly average	14.4	13.6	13.8	13.0	19.6	18.4	18.5	17.8	9.8	9.4	9.6	8.7

*:1971 ～2000 Mean annual value

Appendix 2.2 Monthly average soil temperature at 5cm and 10cm depth in the Nakashibetsu site

	5cm soil (℃)			10cm soil (℃)		
	2004	2005	2006	2004	2005	2006
January		0.2	0.3		0.5	0.5
February		0.1	0.2		0.3	0.4
March		0.0	0.2		0.3	0.3
April		1.5	1.4		1.4	1.1
May		8.0	9.8		7.8	9.4
June		14.4	12.6		13.9	12.2
July		17.3	17.5		16.9	17.3
September		20.6	20.9		20.2	20.4
August		18.6	17.6		18.6	17.7
October		12.4	11.0		12.6	11.0
November	5.2	4.7		5.9	5.3	
December	0.8	0.4		1.2	0.7	
Annual average		8.2			8.2	
5-10 Monthly average		15.2	14.9		15.0	14.7

Appendix 2.3 Precipitation and monthly duration of sunshine in the Nakashibetsu site

	Precipitation (mm)				Duration of sunshine (h)			
	2004	2005	2006	Average year *	2004	2005	2006	Average year *
January	120	20	21	51	137	128	163	149
February	75	26	30	34	163	155	153	166
March	34	86	67	64	179	210	139	179
April	48	124	124	85	176	181	142	149
May	95	83	185	105	133	93	212	143
June	40	49	175	103	140	156	72	100
July	24	141	22	131	122	42	88	81
August	156	91	115	143	152	112	119	92
September	145	190	153	176	139	138	139	113
October	23	62	278	125	109	157	151	149
November	96	65	104	86	136	150	129	139
December	101	55	59	58	142	136	164	143
Total/year	955	989	1,331	1,160	1,728	1,657	1,670	1,604
Total (from May to・Oct)	482	615	927	782	795	698	780	679

*:1971 ～2000 Mean annual value

3. Nasushiobara site

Appendix 3.1 Monthly precipitation in the Nasushiobara site

	Precipitation (mm)			
	2004	2005	2006	Average year
January	15.0	17.0	―*	31.3
February	56.5	46.0	―*	51.7
March	58.0	50.0	―*	83.4
April	55.0	138.0	90.5	123.6
May	70.0	186.0	171.0	150.0
June	88.5	146.0	198.0	194.9
July	425.0	225.5	375.0	209.2
August	457.3	103.5	118.0	233.4
September	126.0	153.5	234.0	254.7
October	89.0	542.5	239.5	126.2
November	58.5	86.0	138.0	75.7
December	17.5	70.0	147.5	27.0
Annual average	1516.3	1764.0	―	1561.0

Meteorological observation data inside the Research Station; Annual average values are the average of 1971～2000.

*Values of January-March, 2006 are the referred data due to the bad condition of the observation system. Values of March, 2006 are the calculated values of 1st -14th of March.

Appendix 3.2 Monthly duration of sunshine in the Nasushiobara site

	Duration of sunshine (h)			
	2004	2005	2006	Average year
January	148.6	181.9	181.9*	200.0
February	181.7	199.2	123.3*	193.7
March	194.1	209.0	―*	215.6
April	205.2	233.0	173.9	216.9
May	189.4	125.3	116.9	213.4
June	129.1	134.0	53.8	148.0
July	108.5	145.1	47.3	155.2
August	138.3	126.9	138.5	184.6
September	137.3	88.3	128.0	146.7
October	95.1	134.7	151.2	175.4
November	175.6	141.4	161.3	179.6
December	173.0	172.2	151.9	195.7
Annual average	1875.9	1891.0	―	2224.8

Footnote of Appendix 3.2

Meteorological observation data inside the Research Station.

Annual average values are the average of 1981～2000.

*Values of January-March, 2006 are the referred data due to the bad condition of observation system. Values of March, 2006 are the calculated values of 1st -14th of March.

Appendix 3.3 Monthly average, maximum and minimum temperature in the Nasushiobara site

	Average temperature (℃)				Maximum temperature (℃)				Minimum temperature (℃)			
	2004	2005	2006	Average year	2004	2005	2006	Average year	2004	2005	2006	Average year
January	0.7	0.6	0.1*	1.2	11.3	9.6	――*	5.8	−7.3	−8.3	−4.3*	−3.5
February	2.5	0.8	2.6*	1.6	18.5	12.8	――*	6.2	−8.0	−7.6	−2.3*	−3.1
March	4.5	3.4	3.6*	4.7	21.0	15.0	――*	9.6	−6.9	−7.6	−1.7*	−0.5
April	11.2	10.2	9.4	10.3	27.5	27.2	20.7	15.8	−0.8	−3.3	−1.4	4.8
May	15.9	13.8	15.4	15.0	29.9	24.5	27.0	20.5	3.4	1.5	3.2	9.6
June	19.9	20.6	19.3	18.6	31.1	32.4	29.4	23.0	7.2	9.7	9.2	14.7
July	23.9	22.3	22.1	22.3	33.6	32.2	33.2	26.0	12.6	15.9	15.4	18.1
August	22.7	24.4	24.5	23.7	33.0	34.1	34.2	28.3	13.4	17.0	15.5	19.9
September	20.7	20.8	19.9	20.0	30.3	31.3	31.2	24.0	12.1	10.2	9.4	16.2
October	13.4	15.2	15.5	14.3	26.2	28.3	25.8	19.0	0.0	4.4	6.8	9.8
November	10.6	7.9	9.3	8.6	19.6	19.7	21.4	13.7	−1.2	−2.9	−3.4	3.6
December	4.4	0.5	4.5	3.7	20.9	11.0	14.2	8.7	−7.4	−7.6	−4.5	−1.4
Annual average	12.5	11.8	――	12.0	17.8	16.7	――	16.7	7.5	7.2	――	7.4

Meteorological observation data inside the Research Station. Annual average values are the average of 1985～2000. *Values of January-March, 2006 are the referred data due to the bad condition of observation system. Values of March, 2006 are the calculated values of 1st -14th of March.

Appendix 3.4 Monthly average soil temperature at 5cm and 10cm depths in the Nasushiobara site

	Manure plot						Chemical fertilizer plot					
	5cm Soil temperature (℃)			10cm Soil Temperature (℃)			5cm Soil temperature (℃)			10cm Soil temperature (℃)		
	2004	2005	2006	2004	2005	2006	2004	2005	2006	2004	2005	2006
January		1.8	1.7		2.8			1.8	1.4		2.3	1.9
February		2.5	3.5		3.2			2.8	3.0		3.2	3.4
March		5.0	6.2		5.2			5.6	5.2		5.8	6.0
April		11.3	10.1		10.6			11.1			11.0	10.1
May		15.0	15.3		14.7			15.4			15.0	15.7
June		21.0	19.4		20.2			21.4			20.8	19.4
July		23.6	23.2		23.2			23.6			23.3	22.9
August		25.0	25.6		25.5			24.8			24.8	25.6
September		22.4	21.9					22.3			22.5	
October	15.0	17.5	17.0	15.5			14.7	17.4		15.2	17.8	
November	11.2	9.9	11.2	11.9			9.8	9.7		10.7	10.3	
December	5.2	3.1	6.2	6.5			4.9	2.7		5.7	3.6	
Annual average		13.2	13.4					13.2			13.4	

Observation data of the study field

4. Kobayashi site

Appendix 4.1 Monthly precipitation in the Kobayashi site

	Precipitation (mm)			
	2004	2005	2006	Average year
January	50	68	115	78
February	47	228	206	106
March	185	112	133	184
April	166	83	266	206
May	265	163	331	218
June	156	241	506	503
July	141	328	1009	389
August	419	152	230	299
September	740	450	154	272
October	367	83	11	115
November	84	85	127	74
December	178	39	154	66

Appendix 4.2 Monthly duration of sunshine in the Kobayashi site

	Duration of sunshine (h)			
	2004	2005	2006	Average year
January	189.4	138.5	148.3	147.6
February	185.6	131.9	128.0	146.8
March	185.7	200.7	202.2	160.4
April	217.6	221.8	168.3	160.9
May	123.9	183.3	80.5	125.5
June	129.7	107.5	69.0	87.5
July	253.1	111.1	123.3	137.4
August	157.0	154.5	170.6	154.7
September	110.8	167.8	119.4	136.8
October	194.9	144.3	236.1	165.4
November	209.2	177.4	143.6	145.0
December	172.9	168.5	153.2	150.0

Appendix 4.3 Monthly average, maximum and minimum temperature in the Kobayashi site

	Average temperature				Maximum temperature				Minimum temperature			
	2004	2005	2006	Average year	2004	2005	2006	Average year	2004	2005	2006	Average year
January	5.0	4.8	6.1	5.2	16.4	13.4	20.4	15.6	-3.9	-2.5	-2.7	-3.0
February	7.7	5.9	8.0	6.6	21.3	18.6	20.0	17.7	-1.5	-3.4	-2.4	-2.4
March	10.4	8.4	9.1	9.3	22.0	20.7	21.3	20.5	-1.9	-1.3	-2.2	-0.8
April	15.7	15.7	14.2	14.1	30.0	28.5	26.1	24.9	0.9	3.5	2.7	2.9
May	19.5	19.1	19.3	17.7	31.2	28.7	29.1	27.5	10.6	10.4	12.2	9.4
June	22.8	22.7	22.3	20.3	32.4	31.8	32.3	29.1	13.6	12.1	15.2	12.5
July	27.0	26.2	26.5	23.7	35.5	34.9	35.4	31.6	19.4	19.9	20.6	17.7
August	26.3	26.1	26.9	23.9	33.8	34.0	36.3	31.4	20.9	18.8	21.1	17.9
September	23.5	24.5	23.1	21.3	31.0	32.8	31.4	29.6	15.9	15.4	14.1	13.1
October	18.1	19.0	20.1	17.0	27.7	30.4	28.6	26.3	5.8	7.9	11.4	7.4
November	13.7	12.9	13.8	12.0	24.3	25.1	24.4	21.7	4.3	1.2	4.8	1.9
December	9.7	4.6	8.7	7.2	21.5	16.7	20.7	17.2	0.8	-4.0	-3.5	-2.1

(Average annual values are the past 20-year-average from AMeDAS data)

Appendix 4.4 Monthly soil temperature at 5cm and 10cm depths in the Kobayashi site

	Manure plot						Chemical fertilizer plot					
	5cm			10cm			5cm			10cm		
	2004	2005	2006	2004	2005	2006	2004	2005	2006	2004	2005	2006
January		5.4	7.0		5.9	7.5		5.4	7.0		5.9	7.5
February		6.9	8.9		7.2	9.6		6.9	8.9		7.2	9.6
March		9.4	9.8		9.3	10.0		9.4	9.8		9.3	10.0
April		14.9	13.5		14.4	13.5		14.9	13.5		14.4	13.5
May		20.3	18.5		19.7	18.2		20.3	18.5		19.7	18.2
June		22.3	22.9		21.7	22.6		22.3	22.9		21.7	22.6
July		25.9	26.1		25.7	25.8		25.9	26.1		25.7	25.8
August		25.5	28.2		25.4	27.9		25.5	28.2		25.4	27.9
September		24.9	24.3		24.9	24.6		24.9	24.3		24.9	24.6
October	19.3	21.0	20.4	19.7	21.6	20.8	19.3	21.0	20.4	19.7	21.6	20.8
November	14.2	13.9		14.6	14.7		14.2	13.9		14.6	14.7	
December	9.7	6.5		10.4	7.6		9.7	6.5		10.4	7.6	

Appendix 2. Explanation of terminology

Terminology	Abbreviation	Japanese translation	Explanation of terminology
Global Warming Potential	GWP	地球温暖化指数	It is a coefficient to mutually compare the influences on global warming that varies according to the gas type based on CO_2. Assuming the global warming effect of CO_2 equivalents to 1, CH_4 and N_2O become 23 and 296 times when thinking about the cumulative effect of next 100 years according to the report of IPCC 2001.
Gross Primary Production	GPP	総一次生産	Amount of CO_2 uptake due to plant photosynthesis
Net Primary Production	NPP	純一次生産	NPP = GPP - RA
Net Ecosystem Production	NEP	純生態系生産	Amount of net CO_2 respiration by ecosystem NEP = GPP - RE = NPP - RH
Ecosystem Respiration	RE	生態系呼吸	Amount of CO_2 emission due to plant and soil respiration RE = RA + RH
Autotrophic Respiration	RA	植物呼吸	RA = RP + RR
Aboveground Autotrophic Respiration	RP	植物地上部の呼吸	Amount of above-ground plant respiration
Root respiration	RR	根呼吸	Amount of plant root respiration
Heterotrophic Respiration	RH	微生物呼吸	Amount of decomposition of soil organic matter
Soil respiration	RS	土壌呼吸	RS = RR + RH
Net Biome Production	NBP	純生物相生産	Carbon budget of ecosystem that contains input and output by an abiotic process such as transportation of yield, application of organic fertilizer, leaching of dissolved organic matter, and burning etc.
Net Ecosystem CO_2 Exchange	NEE	純生態系CO_2交換	Amount of CO_2 exchange between ecosystem and the atmosphere per unit of time and land area NEE = -NEP
Green House Gas	GHG	温室効果ガス	Although carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), chlorofluorocarbon (CFC), etc. are almost completely passed the insolated energy from the sun similar to the greenhouse glass, they prevent emitting the heat outside the earth by taking up the radiated heat (infrared rays) from the earth surface. Although the normal temperature of the earth is kept about 15℃ due to the greenhouse gases, if these gases do not exist, temperature will decrease to -18℃.
Carbon dioxide	CO_2	二酸化炭素	It becomes colorless and scentless in normal temperature and pressure, becomes carbonic acid when dissolving into water and show weak acidity. This is generated by the combustion of fossil fuel comprising of carbon such as coal, oil, natural gas and wood. Although the concentration was about 280ppm in the atmosphere before the Industrial Revolution, it is increasing every year because of combustion of fossil fuels and a decrease in forest that was the absorption source since the industrial revolution, and it rose up to 367ppm in year 2000. It accounts for 60% of the global warming.
Methane	CH_4	メタン	It is a colorless combustible gas in the normal temperature and pressure. It is a chief ingredient of the natural gas, and is produced when organic matter is decomposed or fermented in anaerobic condition. It is produced from the anaerobic decomposition process at the final processing center of the disposed organic waste, bottom of the marshes, livestock excreta, and sewage sludge. Although the concentration was about 0.7 ppm in the atmosphere before the Industrial Revolution, it rose up to 1.784 ppm in 2000. Greenhouse effect per unit of amount is 23 times stronger than that of carbon dioxide. It accounts for 20% of the cause of global warming.
Nitrous oxide	N_2O	亜酸化窒素	It is a colorless gas in the normal temperature normal pressure. This is an narcotic, and it is called the laughing gas. Although it is stable and not decomposed in the troposphere, it damages the ozone layer reacting with the stratosphere zone. This is one of the representative greenhouse gases such as carbon dioxide, methane and chlorofluorocarbon (CFC). When the strength of greenhouse effect of carbon dioxide is assumed to be 1, it will become 296 times. It is said that the combustion of organic matter and the fertilization with N fertilizers are causes of its emission.The density was 0.270 ppm in the atmosphere before the Industrial Revolution but it rose up to 0.316ppm in 2000.
Intergovernmental Panel for Climate Change	IPCC	気候変動に関する政府間パネル	This Panel was formed by the co-sponsoring of United Nations Environment Program (UNEP) and World Meteorological Organization (WMO) in November, 1988 as an official platform that discusses the global warming problem. Each country participates as per the qualification of the government. This is examining three problems such as ① evaluation of scientific finding with respect to global warming, ② evaluation of the impact of global warming with prospect of environmental and social economy, and ③ ideal way of measures in the future.
Kyoto Protocol		京都議定書	This is a protocol to the United Nations Framework Convention on Climate Change with the objective of reducing greenhouse gases that cause climate change. It was adopted in December 1997 by the 3rd Conference of the Parties, which met in Kyoto. It obligates developed countries for 5.2% (6% in Japan, 7% in America, 8% in EU and so on) reduction in the emission of greenhouse gases compared to 1990 during the first commitment period (2008-12). To achieve the numerical reduction target, the Kyoto mechanism (flexibility measures) was introduced. As a requirement for coming into effect, the total amount of greenhouse gas emission (CO_2 conversion) in 1990 that was concluded and ratified by the countries as mentioned in Annex I (including developed countries) is prescribed to be more than 55% of the total amount of emission in 1990 of all the countries of Annex I. It took into effect on 16th February 2005.

Appendix 2 Flux measurement methods and units (continued-2)

Measurement methods		Flux	Cumulative value of flux
NEP	Eddy-covariance	$g\ C\ m^{-2}\ d^{-1}$	$kg\ C\ ha^{-1}$
CO_2	Chamber	$mg\ C\ m^{-2}\ h^{-1}$	$kg\ C\ ha^{-1}$
CH_4	Chamber	$\mu g\ C\ m^{-2}\ h^{-1}$	$kg\ C\ ha^{-1}$
N_2O	Chamber	$\mu g\ N\ m^{-2}\ h^{-1}$	$kg\ N\ ha^{-1}$

Appendix 3. Name list of the Environment Conservation Promoting Committee and the Environment Conservation Working Committee of the Research Project

	Name	Affiliation	Position	P.O. Box	Address
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