Impacts of Global Warming on Agricultural Production and Adaptations in Response

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Abstract

Measures in response to global warming can be divided into two strategies: mitigation, which reduces climate change itself by the reduction of greenhouse gases, and adaptation, which reduces the impacts of climate change. Interest in the adaptation approach, in particular, has recently been rising both in Japan and internationally. Agricultural production is expected to be greatly impacted by future climate change, and enhanced knowledge through research on adaptation will be required in order to reduce these impacts. Against such a background, this paper summarizes the concept of adaptation and describes some existing studies on the impacts of global warming on agricultural production and studies on adaptation. With this as a basis, the paper discusses the crucial issue of studies concerning adaptation in the agricultural sector and presents suggestions. From a policy standpoint, the significances of studies differ between those that quantitatively estimate the impacts of global warming, taking adaptation measures into consideration and using climate scenarios as assumptions on the one hand, and studies aimed at selecting, promoting and implementing adaptation measures suitable for reducing impact damage on the other. While proceeding with these two types of studies in a balanced manner, it is necessary to promote close cooperation between both research communities. An important task with regard to the former type of study is further refinement of methods for assessing impacts on agricultural production taking extreme weather phenomena such as typhoons, continuous dry periods, etc., into consideration. For the latter type, important tasks include estimation of adaptation costs, clarification of factors that inhibit implementation of individual adaptations, and accordingly, grasping of the limitations that can be expected with regard to future adaptations.

Key words: adaptation, agricultural impact, climate change, global warming, vulnerability

1. Introduction

1.1 Adaptation to global warming

The Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) cites projections of an increase in globally averaged surface temperature of 1.4°C to 5.8°C over the period 1990 to 2100 (IPCC, 2001b). Pointing out that global warming has already become evident, the report states that it is very likely that the 1990s was the warmest decade in the instrumental record (1861 to 2000). In view of the high possibility that global warming will cause large-scale, irreversible changes in global systems, response measures are of great importance.

Measures in response to global warming can be categorized into mitigation, in which emissions of greenhouse gases (GHGs), considered to be the cause of global warming, are reduced; and adaptation, in which the adverse impacts of global warming are reduced by bringing about adjustment in natural eco-systems and socio-economic systems to climate change. Policy analysis and assessment studies initially focused on mitigation. However, now that the enormous costs of mitigation have become clear, coupled with the realization that global warming is already progressing and that severe climate change cannot be avoided even if all mitigation measures are fully implemented, greater attention is being paid to adaptation. The United Nations Framework Convention on Climate Change stipulates that adaptation should be studied as part of each country's domestic measures.

1.2 Global warming and agricultural production

When temperatures rise due to global warming, changes take place in the amount of solar radiation, precipitation, etc., and yields of cereal crops per unit area also change. As a result, there may be cases in which existing agricultural areas become unsuitable for agriculture, and vice versa. Changes in crop yield due to global warming can also be expected to affect prices, production, consumption and trading of cereal crops on the global market. For example, when cereal crop yields decrease in major producing countries, not only will there be an adverse economic impact on the exporting countries, but also on the importing counties due to higher market prices and the difficulty of securing supplies.

1.3 The objectives and structure of this paper

Agricultural production is expected to be greatly impacted by future climate change. Enhanced knowledge through research on adaptation is required in order to reduce these impacts. The objectives of this paper are to provide an outline of the concept of adaptation and describe some existing studies on the impacts of global warming on agricultural production and studies on adaptation. With this as a basis, the crucial issue of studies concerning adaptation in the agricultural sector is discussed and suggestions are presented. First, Section 2 provides a summary of the concept of adaptation and describes adaptation measures that could be adopted in the agricultural sector. An overview of existing agricultural impact assessment studies is then provided in Section 3. Lastly, Section 4 classifies studies on adaptation according to type, discussing research tasks concerning adaptation in the agricultural sector, and presenting some suggestions.

2. Adaptation in the Agricultural Sector

2.1 What is adaptation?

The Third Assessment Report of IPCC Working Group II defines adaptation as "adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities" (IPCC, 2001a). In other words, adaptation takes place when living things, including both human individuals and groups, reduce adverse impacts of climate change by modifying their biological responses, patterns of behavior, systems, facilities, etc., or when they successfully amplify beneficial impacts of climate change.

Adaptation encompasses both those implemented to reduce directly damage due to climate change, and those that contribute to indirect reduction of damage due to climate change by enhancing future adaptive capacity. For example, in an area where cultivation of wheat has become difficult due to increasing temperatures, a shift by farmers to cultivation of heat-tolerant crops would belong to the former category, whereas development of an information system for farmers to enable them to learn which crops would be suitable for cultivation under a changed climate would belong to the latter. Both types of measures can be considered adaptations.

The Third Assessment Report also describes the classification of sectors and systems, intentionality and timing of implementation as the main criteria for classifying adaptations. Systems can be broadly classified into natural systems and human systems. The movement of animals and plants to suitable habitats would fall under the former type. Intentionality can be classified into autonomous adaptation, in which the intervention of public organizations is unnecessary, and planned adaptation. Timing of implementation can be classified into reactive adaptation, which is implemented after the manifestation of an impact, and proactive (or anticipatory) adaptation, which is implemented in anticipation of an impact prior to its manifestation. The adaptation of natural systems is basically autonomous and reactive.

Table 1 shows an example of the classification of adaptations by Klein *et al.* (1999). The entity implementing adaptation could be a private individual or a public entity such as a country or a corporation. Note, however, that an adaptation implemented by one entity is not independent of adaptations implemented by other entities. One example is that an adaptation by an individual is implemented within the framework of laws and regulations of the country concerned.

2.2 What is adaptive capacity?

Adaptive capacity means the ability of a system to adjust to climate change (including climate variability and extremes) in order to moderate potential damage, or to take advantage of opportunities or to cope with the consequences. Namely, it is the ability to plan and implement effective adaptations and to respond to increasing risk and stress so as to reduce the frequency and degree of harmful results due to impacts of climate

Table 1 Example of classification of adaptations.

		Anticipatory	Reactive
Natural Systems			Changes in length of growing season. Changes in ecosystem composition. Wetland migration.
Human Systems	Private	Purchase of insurance. Construction of houses on stilts. Redesigning of oil-rigs.	Changes in farming practices. Changes in insurance premiums. Purchase of air-conditioning.
	Public	Early-warning systems. New building codes, design standards. Incentives for relocation.	Compensatory payments, subsidies. Enforcement of building codes. Beach nourishment.

change.

For the implementation of adaptations, various conditions related to wealth, scientific and technical knowledge, information, skills, infrastructure, institutions, equity, etc., must be satisfied. These can be referred to as component factors of adaptive capacity. It may be possible to realize some adaptation measures at little or no cost. However, a certain level of cost is generally involved when implementing the majority of effective adaptation measures. As a precondition for implementing a particular type of adaptation, the relevant technology must exist and be available for use. Moreover, for the effective implementation of an adaptation, people must first recognize the need for some form of adaptation. In addition, knowledge concerning available adaptation measures is necessary, together with the ability to assess measures for selection and implement those judged to be most suitable. In the case of undertaking adaptation as a group, it is necessary to obtain the consensus of the group members, so transparency of the decision-making system is also necessary.

Adaptive capacity is acquired through a combination of these component factors. However, the relative importance of each factor will differ according to the circumstances in which adaptation is implemented, the nature of the disaster being faced and so on. Individual component factors are neither independent nor exclusive, but have close mutual relationships. In an international framework, when studying the provision of adaptation assistance to developing countries, which are especially vulnerable to global warming, it will be important to identify the cause of any lowering of adaptive capacity and to give assistance for the improvement and reinforcement of such capacity so that the countries can efficiently and effectively implement adaptations to reduce the adverse impacts of anticipated climate change and climate variability.

2.3 Increasing attention to adaptation

Measures in response to global warming fall into two categories: mitigation (also referred to as emissions reduction), in which carbon dioxide and other GHGs are reduced to prevent global warming from progressing; and adaptation, in which natural and social systems are adjusted to climatic conditions where global warming is in progress. Throughout the world, including Japan, mitigation measures against global warming were first considered. One reason that can be cited for this is that, while mitigation simultaneously reduces the effects on all systems susceptible to climate impact, adaptation affects only limited systems. In other words, in the event of drastic global warming, impacts are projected to manifest on diverse fields including agriculture, water resources, health and natural vegetation in various places worldwide. When the progress of global warming is suppressed by mitigation, each of the impacts on these multiple fields and regions will be reduced simultaneously. On the other hand, adaptation measures are basically implemented by specifying a certain field and region, such as construction of a reservoir in a region that is expected to become susceptible to drought due to global warming, or switching agricultural crops to heat-tolerant varieties in a region where crop growth is deteriorating due to heat stress, so their effect is limited to the field and region targeted by the measures. Another reason for the initial focus on mitigation is that from the beginning, there was an understanding that overcoming global warming by adaptation alone was impossible. If GHGs were emitted without restraint and global warming rapidly progressed, although the impacts on some fields and regions could be sufficiently alleviated by adaptation, there would be others in which unacceptable adverse impacts remained even if the maximum possible adaptation measures were implemented. For example, suitable habitats for animals and plants are expected to change due to global warming. If global warming progresses drastically, however, even when all realistic adaptation measures are adopted, the impacts cannot be completely avoided and extinctions may occur among animals and plants that lose suitable habitats. Therefore, since it is impossible to avoid all of the impacts of global warming by adaptation alone, it plays a complementary role among the entire range of global warming measures.

Although efforts in the sphere of adaptation have consequently lagged behind in comparison with mitigation, recently there has been a rapid increase in recognition of its importance. One of the reasons behind this trend is that studies have shown that climate change cannot be completely suppressed even with maximum emission reduction efforts, so the occurrence of some impacts cannot be avoided. In particular, such impacts are manifesting at an early stage in developing countries, whose adaptive capacity is low, and many policymakers have begun to understand that improvement of the adaptive capacity of developing countries is an urgent task. Moreover, there are cases in which, by conducting planned adaptations in advance, the total of the amount of damage and the cost of measures can be suppressed compared with the implementation of reactive adaptations only (*e.g.* Ebi *et al*. (2004)). People are also beginning to recognize that there are many cases in which the risk of disasters (i.e., disasters from extreme weather events) due to current climate variability can be reduced as a side effect of anticipatory adaptation with long-term climate change in view (IPCC, 2001a). These are also factors in the recent increase in attention to adaptation.

2.4 Adaptation in the agricultural sector

Examples of adaptation in the agricultural sector include technical, administrative and policy measures, as well as those that can be implemented at the farm level or that should be undertaken at the community or governmental level, as summarized in Table 2.

Table 2 Examples of adaptation in the agricultural sector. (created from Kurukulasuriya & Rosenthal (2003))

	Adaptation options		Adaptation options
Short-term	Crop insurance	Long-term	Changing crop mix
	Private/public programs.		Adopting new crops.
	Formal/informal schemes.		Planting in different parts of farm.
	Portfolio (Crop/Livestock) diversification		Converting land use.
	Replacement of plant types, cultivars, hybrids and animal breeds with new varieties.		Irrigation
	Alternative production techniques (adjustment of capital and labor inputs).		Modernization of farm operations
	Multi-cropping.		Research and development.
	Mixed farming systems of crops and livestock.		Adoption of technology (*e.g.* use of sprinklers).
	Adjusting timing of farm operations		Permanent migration
	Adjusting cropping sequence.		Defining landuse and tenure rights
	Adjusting timing of irrigation.		Efficient water use
	Changing cropping intensity		Improving water distribution.
	Adjusting fertilizer and other inputs.		Promoting irrigation efficiency.
	Changing land use practices.		Changing crop and irrigation schedules.
	Changing location of crop/livestock production.		Water recycling and the conjunctive use of groundwater.
	Rotating or shifting production between crops and livestock.		Rehabilitation and modernization.
	Abandonment of land.	Both short and long-term	Investment promotion
	Changing the timing of activities (sowing, planting, spraying and harvesting).		Developing market efficiency
	Changing the timing of irrigation.		Pricing reform.
	Livestock management		Developing open markets.
	Change in biological diversity, species.		Reforming agricultural markets.
	Altering breeding management programs (i.e., changing composition, or species distribution).		Adoption of technological and other adaptation measures
	Change in grazing management (timing, duration and location).		Promoting trade
	Changing the location of watering points.		Developing extension services
	Changes in rangeland management practices.		Improving forecasting mechanisms
	Modifying operation production strategies.		Institutional strenthening and developing decision-making structures
	Changing market strategies.		
	Implementing feed conservation techniques/varying supplemental feeding.		
	Changes in tillage practices (conservation tillage)		
	Land contouring and terracing.		
	Maintaining crop residues.		
	Fallow and tillage practices.		
	Planting of hedges.		
	Alternative drainage method.		
	Construction of diversions, reservoirs and water storage.		
	Irrigation.		
	Reducing water use in land preparation.		
	Temporary migration		
	Short-term forecasts		
	Food reserves and storage		

3. Existing Agricultural Impact Studies Taking Adaptation into Consideration

3.1 Global-scale crop productivity estimation

Existing studies assessing the agricultural impacts of global warming on a global scale include those by Takahashi *et al*. (1997) and Fischer *et al*. (2002) using a potential crop productivity model that was developed based on a method for evaluating the suitability of climate and soil resources for cultivating crops formulated by the Food and Agriculture Organization (FAO). Here, potential crop productivity means the achievable yield of a crop per unit area assuming a certain level of input. By biologically modeling the growth of cereal crops using data on temperature, precipitation, potential evapotranspiration, photosynthetically active radiation, soil quality, topography, etc., as input information, Takahashi *et al*. (1997) quantitatively assessed potential productivity at the global level of twelve types of crops, namely, rice, winter and spring wheat, maize (tropical and temperate cultivation), sorghum (tropical and temperate cultivation), pearl millet, cassava, sweet potato, white potato and soybean, while Fischer *et al*. (2002) made similar quantitative assessments in greater detail for 154 types of crops.

Murai *et al*. (2005) improved on the methods of Takahashi *et al*. (1997) by conducting potential productivity impact assessments, taking changes in crop species and planting dates due to climate change into consideration. In that study, cultivated rice was categorized into four species and wheat into five species, the growth characteristics of each were converted into parameters, simulations were conducted under the current climate to estimate potential productivity for all crop species, and the crop species that obtained the highest potential productivity were selected. For simulations under a future climate, in the case of crop species changing from the present state (i.e., the case of adaptation by changing crop species), estimations were performed for all species and those that obtained the highest potential productivity were selected, in a process similar to that used for simulations under the current climate. On the other hand, in the case of no species change (i.e., the case of no adaptation by changing of crop species), simulations were performed on the assumption that the optimum species under the current climate would be continuously cultivated in the future as well. Concerning the climate conditions, the monthly climate values of the Climate Research Unit at East Anglia University (CRU) in normal years during the 30-year period from 1961 to 1990 for a grid of 0.5° × 0.5° latitude and longitude were used as the baseline (current) climate, and the future climate scenario was prepared by adding climate change data (average values from the baseline period to the period from 2036 to 2065) obtained from the output results of SRES-A1B (IPCC, 2000) emission scenario[1)] simulations by the CCSR/NIES (Center for Climate System Research at the University of Tokyo / National Institute for Environmental Studies) model to the baseline climate data.

Figure 1 shows the impact of climate change on the potential productivity of wheat in 2050. Potential productivity was simulated for different adaptation conditions and the results were compared in order to study the effects of adaptation. Developing countries have potential capacity to improve their production through irrigation and mechanization, so the adverse impacts of future anticipated climate change can be expected to be offset by implementation of adaptations such as changing the crop species cultivated and cultivation periods, which can be executed comparatively easily at the farm level (adaptation case). In parts of Canada, Europe and Russia that are currently unsuitable for production because of low temperatures acting as an inhibiting factor, it is projected that areas of possible cultivation will newly appear. However, in the central and eastern United States and other areas that currently have good conditions for cultivation, even in the case of adaptation a decrease in production is still expected. On the other hand, when appropriate adaptation measures are not taken (case of no adaptation), a serious lowering of productivity due to climate change becomes evident. Especially in the United States and South America, a significant decrease is projected in areas in which production is possible. As regards productivity, increases in the rate of irrigation and invested labor can be expected in Africa, South America, and elsewhere, and the extent of decrease will be smaller compared with the industrialized countries.

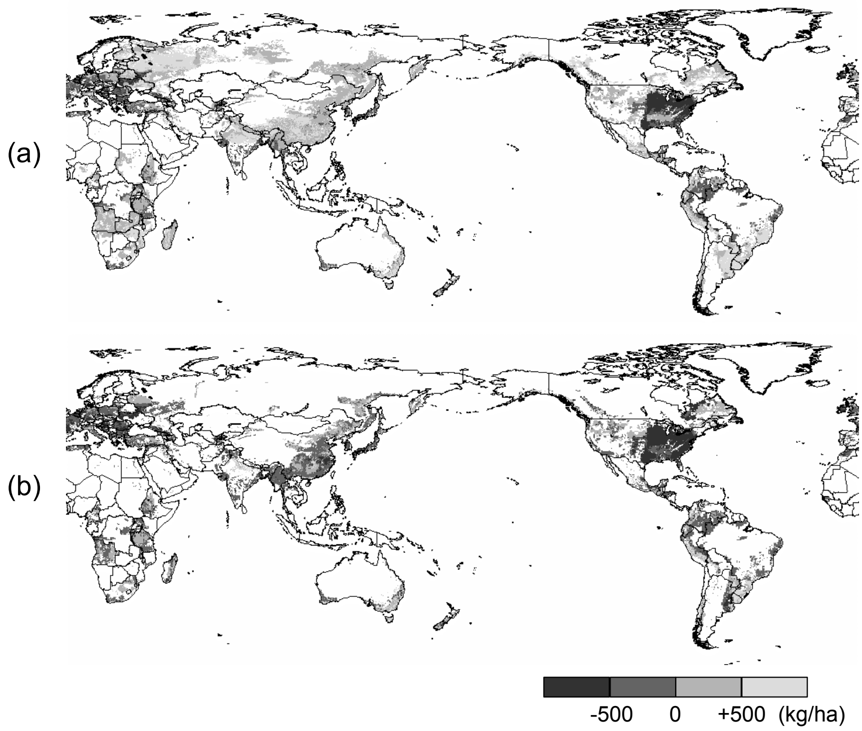

Fig. 1 Projected changes in wheat productivity due to global warming from the present condition to 2050. (Murai *et al.*, 2005)
(a) Adaptation case (It is assumed that farmers can adapt to climate change by changing wheat varieties and planting dates)
(b) Case of no adaptation

An overview of the results of impact studies on crop production shows that, without taking into consideration the CO_2 fertilization effect due to the increase in atmospheric carbon dioxide concentration, crop yields are projected to increase in many mid-latitude regions if the temperature rise is 2°C to 3°C or less, and to decrease if the temperature rise is higher than that (Takahashi, 2005). In tropical regions, for some crops such as rice, the temperature is close to the upper limit of the suitable growing temperature, and the main form of agriculture in practice depends on rainwater, so it is possible that even a small temperature rise may result in a decrease in productivity.

3.2 Estimation of economic impacts and population at risk

In the event of a temperature rise of 2°C to 3°C or more, increases in food prices are projected due to such factors as interruptions in food supplies on a global scale. Global warming is also projected to cause a decrease in the incomes of poor people in developing countries and an increase in the number of people at risk of hunger, as well as greater difficulty in securing food due to increased incidence of extreme events. On the other hand, the results of estimations that take the CO_2 fertilization effect into consideration tend to describe a more optimistic future image (Takahashi, 2005).

In Japan, the relative profitability of the agricultural sector has declined compared with that of other production sectors since the period of high economic growth. The volume of food imports has rapidly increased, and food self-sufficiency in terms of caloric value has fallen to about 40%. Although the country is almost self-sufficient in rice, its staple food, it depends on imports for most forage crops such as wheat and maize. As a result, there are concerns that adverse impacts on crop yields in exporting countries due to climate change will also affect Japan's food situation through steep increases in international market prices. A number of research groups including the Japan International Research Center for Agricultural Sciences (JIRCAS), the National Institute for Environmental Studies (NIES), and the Research Institute of Innovative Technology for the Earth (RITE) are conducting studies to estimate economic impacts, populations at risk of hunger, etc., using an international trade model that takes changes in global cereal crop productivity into account. For example, according to an analysis by Takahashi *et al.* (1999), when the CO_2 fertilization effect is not taken into consideration, the productivity of rice, wheat and other crops tends to decrease conspicuously, especially in low-latitude regions. Moreover, many developing countries – in which people use a high ratio of their overall personal expenditures to buy crops as food – are located in the low-latitude regions, so these countries are susceptible to the impact of price increases due to declining productivity.

Parry *et al.* (2004) performed simulations of international trade and adjustment of production and consumption by means of an agroeconomic model, using the results of crop productivity estimations from climate model outputs, with SRES scenarios as assumptions together with the population and economic growth projections of the SRES scenarios, and thereby estimated the populations exposed to hunger risk. Figure 2 shows the impacts of climate change on the population at risk of hunger under the SRES scenarios (change from the reference case, which assumes no climate change and no change in atmospheric CO_2 concentration), with the CO_2 fertilization effect due to the increase in atmospheric CO_2 concentration taken into account in the left-hand graph and not taken into account in the right-hand graph. Estimations were made based on the assumptions of four SRES scenarios (however, with regard to the A2 and B2 scenarios, the A2a, A2b, A2c, B2a, and B2b scenarios obtained by general circulation model [GCM] ensemble simulation, which have different initial conditions as assumptions, were used). Under the A2 scenario, when the CO_2 fertilization effect is not taken into account there is a decrease in crop productivity due to the occurrence of significant climate change, while at the same time the

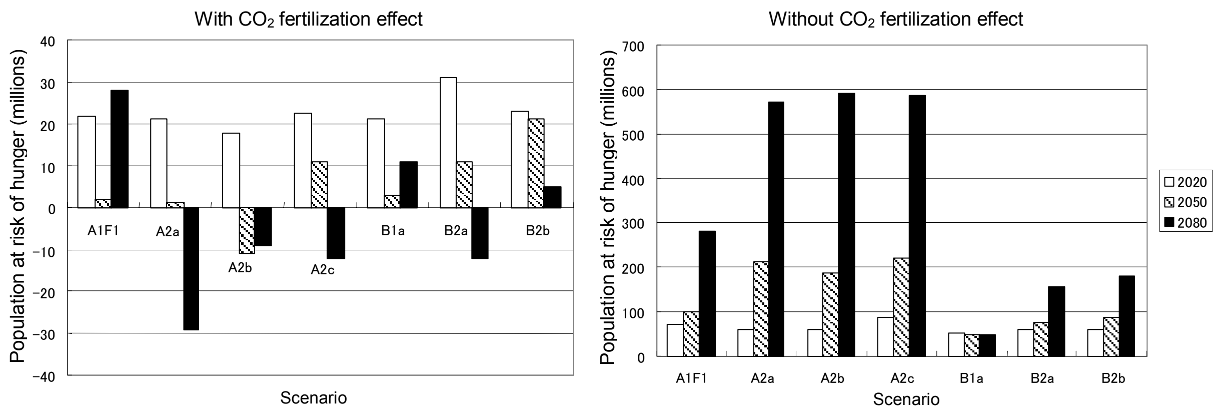

Fig. 2 Impacts of climate change on the population at risk of hunger under SRES scenarios. (Parry *et al.*, 2004)
Additional population at risk relative to the reference case which assumes no change in either climate or atmospheric CO_2 concentration

population parameter shows a large increase. Therefore, the additional population at risk of hunger due to climate change is largest (500 to 600 million people) in this case. When the CO_2 fertilization effect is taken into account, on the other hand, the CO_2 fertilization effect exceeds the adverse impacts of climate change, reflecting the high atmospheric CO_2 concentration, and the risk population is expected to decrease. Hence, there are great disparities in the results of estimations of the population at risk of hunger depending on whether or not the CO_2 fertilization effect is taken into account. It is known that the magnitude of the CO_2 fertilization effect is affected by such factors as soil moisture and nutrients, competition with weeds, and the sunlight and temperature environment. However, the magnitude of the CO_2 fertilization effect that can be expected in actual agricultural fields has not yet been elucidated.

3.3 Studies concerning the selection, promotion, and implementation of adaptation measures

At the initial stage, studies on the agricultural impacts of climate change focused almost exclusively on estimating crop productivity expected in the case of climate change occurring over a long duration. As described in connection with the examples mentioned in subsection 3.1 above, certain types of adaptation have been adopted as assumptions in such studies, and increases or decreases in production are estimated after taking these assumed adaptations into consideration. However, the early implementation of adaptations has become necessary in vulnerable regions where climate change is gradually manifesting. This is prompting increased attention to studies concerning the selection, promotion and implementation of adaptation measures (hereafter referred as "studies on implementation of adaptation"). Although productivity estimations have generally been made using agricultural and engineering methodologies exclusively, social science methodologies are playing an increasingly important role in studies on implementation of adaptation.

Bryant *et al*. (2000) conducted an overall survey of existing studies on the impacts of climate change on agriculture and agricultural adaptation taking Canada as the target region, and examined the importance of decision-making by farmers in adaptation to climatic variability and change in the agricultural sector. They found that the methods used in studies on farmers' decision-making regarding adaptation to environmental change encompassed questionnaire surveys, interviews, focus groups[2)] which included farmers, and surveys and analyses of measures actually taken by farmers against variability of climate conditions in the past. When these methods are applied, the results of model estimations concerning future productivity changes are often used as reference information given to farmers at the time of surveys. Bryant *et al*. (2000) noted in their report that many farmers were skeptical about the reality of climate change, and that even among farmers who perceived such change, a significant ratio made no consistent efforts to adapt to it. Hence, they found that formers' perception of changes in climatic conditions does not necessarily guarantee they will make conscious adaptation efforts. Moreover, the survey results showed that rather than overall climate change, many farmers placed more importance on potentially fatal changes in conditions such as precipitation in the growing season, the incidence of early and late frosts, and the frequency of droughts.

According to Bryant *et al*. (2000), although farmers in the province of Quebec expressed a high level of confidence in their ability to respond to climatic variability and hence, from their point of view, to climatic change because of their experience of coping with interannual climate variability in the past, their possession of various technological and management response measures, and so on, in reality economic losses associated with climatic conditions frequently occur, and they have needed public relief and compensation. In other words, farmers have not necessarily been able to adapt efficiently to interannual variability of climatic conditions heretofore. The report also mentions that crop insurance programs may reduce the sensitivity of producers in adjusting to changing conditions.

3.4 Vulnerability assessment

From the viewpoint of studies on measures and their practical application, the vulnerability of agriculture in each region needs to be estimated not only in terms of vulnerability to climate stressors such as climate change and climate variability, but from an overall perspective including vulnerability to various other stressors in the natural and social environments. Thus far, however, global warming impact assessment studies have generally studied vulnerability by focusing only on climate stress, and have often not taken other stressors specifically into consideration. There is growing recognition recently that in order to identify practical solutions, measures should be investigated taking multiple stressors simultaneously into consideration, and concrete studies have begun.

For example, O'Brien, *et al*. (2004) studied agriculture in India taking into account biophysical factors including soil conditions and moisture; socio-economic factors including literacy rates, degree of gender equity, percentage of the workforce employed in agriculture and distance to major ports; and technological factors including productivity, availability of irrigation and quality of infrastructure. Using this information, they mapped both the capacity to adapt to increasing dryness and variability of the Indian monsoon, as well as the capacity to adapt to competition from imports and export opportunities accompanying the liberalization of agricultural trade. Districts with low adaptive capacity from both perspectives were thus shown to have a high vulnerability to multiple stressors. As a result, many districts with a high vulnerability to climate change and market opening (globalization) were identified in the states of Rajasthan, Gujarat and Madhya Pradesh, as well as southern Bihar and western Maharashtra.

4. Necessary Adaptation Studies for Policy Support

4.1 Classification of studies dealing with adaptation

The number of studies dealing with adaptation has been increasing in response to the growing attention being paid to this subject. Such studies can be broadly classified into two types according to their objectives, with each type of study playing a different role in investigations into a future framework (Burton *et al*., 2002). The first type of study has the objective of answering the question: "To what extent can adaptation reduce impacts of climate change?" Simulation analysis using computing models has been the principle method used to answer this question. There are various types of models, ranging from biophysical process models to statistical models and general equilibrium models for welfare analysis. However, a common characteristic of these models is that they use future climate scenarios projected by climate models as input assumptions, and estimate future impacts of global warming while taking the effects of adaptation into consideration. As regards the number and types of available adaptation measures, in many cases assumptions are used as preconditions. Major climate change that has serious impacts even when adaptations are implemented has to be avoided. Knowledge obtained by this type of study is used for investigating the upper limits of permissible climate change when discussing GHG mitigation policies.

The objective of the second type of study is to answer the question: "What adaptation policies are needed, and how can they best be developed, applied, and funded?" Such studies serve as a basis for the selection, promotion and implementation of adaptations suitable for reducing the impact in a targeted region or field. Appropriate adaptations are estimated according to criteria such as the magnitude of the impact reduction effect, economic efficiency, and equity. However, since a detailed understanding of the conditions of the region is a fundamental requirement in this type of study, limited availability of data often makes quantitative assessments difficult. Other factors must also be considered such as relationships with existing policies of a higher priority (targeted at issues other than global warming), secondary impacts arising from the implementation of adaptations, and so on, making it difficult to generalize assessment methods. Even an adaptation with a significant impact reduction effect cannot be considered appropriate if the cost of its implementation is extremely high compared with the magnitude of impact damage if the adaptation were not implemented. Nor can an adaptation that is advantageous to a country overall be considered to be appropriate if it creates a serious division between people who benefit and people who lose when the details are examined. Moreover, adaptations that are incompatible with existing higher priority policies addressing poverty reduction, disaster countermeasures, industrial development, etc., will be difficult to adopt. Appropriate adaptations must therefore be selected, promoted and implemented in light of the actual conditions in each region concerned.

In this second type of study dealing with adaptation, it is important to understand which factors have hindered or promoted the implementation of effective adaptations to reduce vulnerability from past and present disaster cases, that is, to gain an understanding of past and present adaptive capacities. By grasping the present adaptive capacity situation, it becomes possible to study what types of efforts are necessary in order to reduce vulnerability under the environment of a changed future climate. Moreover, since information convenient for quantification, such as statistical data, may be unavailable in many cases, an anthropogeographic approach is often used based on descriptive reference materials and surveys of local residents.

4.2 Research tasks

Adaptation studies can be broadly classified into two types as described above. In order to solve the global warming issue, these two types of adaptation studies need to be advanced in a balanced manner with the close cooperation of study communities in Japan and overseas. Each type of study has a certain complementarity with the other type. For example, the results of quantitative estimations of impacts taking adaptation into consideration provide an outlook for future climate change impacts, which can then serve as a basis for judgments related to adaptations in studies on the implementation of adaptations in individual regions. Conversely, a deeper understanding of factors that hinder or promote the implementation of adaptations in individual regions as well as knowledge on various other conditions gained through studies on adaptation implementation can be reflected in assumptions on adaptations when performing impact assessment simulations using models, and this, in turn, will also support refinement of the models themselves (by incorporating social and other factors into the model). However, it would appear that study communities have not always cooperated effectively with each other up to now, especially in Japan.

As mentioned in subsection 3.3 in connection with the study by Bryant *et al*. (2000), farmers respond more sensitively to the occurrence of potentially fatal phenomena as a nucleus for adaptation behavior than to a gradually increasing impact on productivity due to general climate change. Hence, for studies dealing with the quantitative estimation of impacts taking adaptation into consideration, namely, what changes can be expected from now on due to extreme weather events, such as typhoons, continuous dry periods and heat waves, and what impacts these will have on agricultural production, there is a strong need for further enhancement of the methods used so that more refined estimations can be made. An important task when refining estimation methods will be to improve and expand them so as to enable as many adaptation options as possible to be investigated and to allow adaptations to be expressed more realistically.

A high degree of uncertainty is inevitable in each of the processes involved in quantitative estimation of global warming impacts, such as the projection of future socio-economic conditions and GHG gas emissions, the projection of carbon circulation and climate changes, the projection of impacts, and so on. The value of the results of impact projections when applied to policy studies is greatly enhanced when such uncertainties are specifically addressed. For example, expressing the results of future impact projections in probability distribution form holds promise as a method, although this approach has rarely been adopted so far.

When assuming the conditions for investigating the upper limits of permissible climate change in discussions on GHG mitigation policies, it is necessary to get an overview of the impact projection results from various fields and regions in both a comprehensive and aggregate manner. For this purpose, it is important to promote the use of common units in impact assessment (primarily the monetary assessment of impacts), and to develop communication tools and a database of knowledge from impact studies so as to enable specific information on impact assessment options to be efficiently provided to policymakers.

In the case of studies on the implementation of adaptation, on the other hand, various areas exist in which adequate scientific knowledge has not yet been obtained, even though they represent important research tasks from the viewpoint of policy study support. These include estimating the cost of adaptations; elucidating factors that hinder the implementation of individual adaptations, and clarifying what future limits on adaptations can be expected based on that knowledge; elucidating the changes that take place in the characteristics of adaptations over time (effects of experience, learning, etc.); elucidating stress factors other than climate change; and so on. Subsection 3.3 introduced the case of studies conducted in Canada. However, in order to answer the question, "What adaptation policies are needed, and how can they best be developed, applied, and funded?" as mentioned in subsection 4.1, bottom-up type studies are necessary, and original studies focusing on Japan as the targeted region are eagerly awaited. When the situation of studies in Japan is examined, although more substantial studies are appearing which estimate potential yield change due to global warming, it seems that there is a gap in the number of concrete studies related to adaptation (particularly studies on the implementation of adaptation) compared with the situation in Western countries that are advanced in the field of global warming studies. There is an urgent need, therefore, to expand and improve such studies so as to promote investigations into future climate change policy in Japan and to enable Japan to take the initiative in discussions on an international framework.

Achnowledgement

This paper is based on the results of studies entitled "Impact Assessment of Future Climate Change Using High-Resolution Climate Change Scenarios Including Extreme Events (B-12)" and "Comprehensive Assessment of Climate Change Impacts to Determine the Dangerous Level of Global Warming and to Determine the Appropriate Stabilization Target for Atmospheric GHG Concentration (S-4)," which are research topics of the Global Environmental Research Fund (GERF).

Notes

[1)] Future socio-economic/greenhouse gas emissions outlook released by IPCC in 2000 (IPCC, 2000). A family of six scenarios was prepared – A1B, A1F1, A1T, A2, B1, and B2 – each with different assumptions concerning future developments in population, society, economy, technology and the environment.

[2)] A survey method in which approximately ten people who have certain common denominators are gathered together, asked questions as a group and encouraged to engage in discussions, which the surveyor observes. This method is used when there is a need to understand the perceptions of specific types of people.

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