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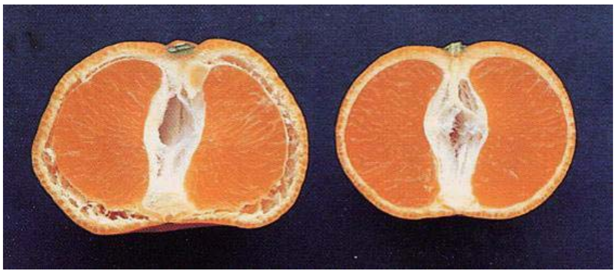
Impact of Global Warming on Agriculture, Forestry and Fisheries and Possible Countermeasures in Japan



MAFF
Ministry of Agriculture,
Forestry and Fisheries

Summary: Impact of Global Warming on Agriculture, Forestry and Fisheries and Possible Countermeasures in Japan

1. Potential Impact of Global Warming on Agriculture, Forestry and Fisheries

1) Based on a scenario where the temperature rises by an average of 3°C by the 2060s:

- The paddy rice yield increases in Hokkaido and decreases in sub-Tohoku region.
- The areas suitable for growing apples gradually move toward the north; the whole of Hokkaido becomes suitable for growing apples, whereas they no longer grow in the sub-Kanto region.
- The areas suitable for growing Satsuma mandarins extend from the southwest coastal region to the southern Tohoku coastal region.
- Chicken production dramatically decreases in western Japan, with some areas showing more than a 15% decrease.

2) Based on a scenario where the temperature rises by an average of 3°C and 5°C by 2081 to 2100, beech habitats decrease 60% and 90%, respectively, from the current level.

3) Saury fishing off the coast of the Nemuro Peninsula, located in eastern Hokkaido, declines; sauries will be scarce in the seas around Japan about 100 years from now due to increased water temperature.

2. Adaptation to Global Warming

1) Paddy rice

- The occurrence of white immature kernels due to high temperatures during the ripening period can be prevented through late planting and direct sowing.
- The Nikomaru variety is recommended because of its good appearance and low occurrence of white immature kernels.

2) Fruit

- Abnormal coloration of grapes due to high temperatures can be prevented by girdling.
- The Ishiji and Tamami varieties are recommended because of the low occurrence of rind puffing, which is caused by high temperatures during the ripening period.

3. Global Warming Mitigation

1) Methane, a global warming gas, originating from paddy fields can be significantly reduced through midseason drainage and alternate wetting and drying irrigation, without reducing the rice yield.

2) Carbon sequestration can be maintained and enhanced through proper forest management including that of multi-storied forests.

Contents

Preface

The Agriculture, Forestry and Fisheries Research Council Secretariat, Ministry of Agriculture, Forestry and Fisheries, Japan (MAFF), prepares and distributes series of the Report on Research and Development in Agriculture, Forestry and Fisheries for public relations.

This report* reviews "Impact of Global Warming on Agriculture, Forestry and Fisheries and Possible Countermeasures in Japan" as particularly high interest to public.

In fact, global warming is becoming a worldwide concern because of the IPCC Fourth Assessment Report**, impact of Al Gore's "Inconvenient Truth" and the scorchingly hot summer of 2007 in Japan. Scientific research program on global warming supported by MAFF have focused on development of mitigation technique designed to reduce (or capture) greenhouse gas emissions originating from agriculture, forestry and fishery sectors. The IPPC Fourth Assessment Report, meanwhile, concludes that global warming is accelerating and most of the warming phenomena observed attributes to human activities. As global warming is now inevitable, efforts should be stepped up to work on development of adaptation technique. MAFF will thus strategically develop both adaptation and mitigation techniques.

This report, therefore, covers assessments of global warming impacts in the past and future, and major results in adaptation and preventive (mitigation) researches in Japan.

*This report was originally published in Japanese in December 2007.

**IPCC is an acronym for "Intergovernmental Panel on Climate Change." (http://www.ipcc.ch/)

1. Status of Global Warming and Potential Impact

(1) IPCC Fourth Assessment Report

The IPCC Fourth Assessment Report, released in 2007, provides the latest findings on the status of global warming and its potential impact. IPCC is an intergovernmental panel jointly established by the World Meteorological Organization (WMO) and the United Nations Environmental Program (UNEP) in 1988, tasked with assessing human-induced climate change and its potential impact and global warming adaptation/ mitigation measures from scientific, technological and socioeconomic viewpoints. The first, second and third reports were released in 1990, 1995 and 2001, respectively. For the fourth report, Working Group 1 produced a report on the physical science basis in February, Working Group 2 on impacts, adaptation and vulnerability in April and Working Group 3 on mitigation of climate change in May, followed by an synthesis report released in November.

(2) Observations of climate change at home and abroad

According to the report of Working Group 1 on the physical science basis, atmospheric CO_2 concentration had increased from approximately 280 ppm in pre-industrial times to 379 ppm in 2005 (a 1.4 times increase

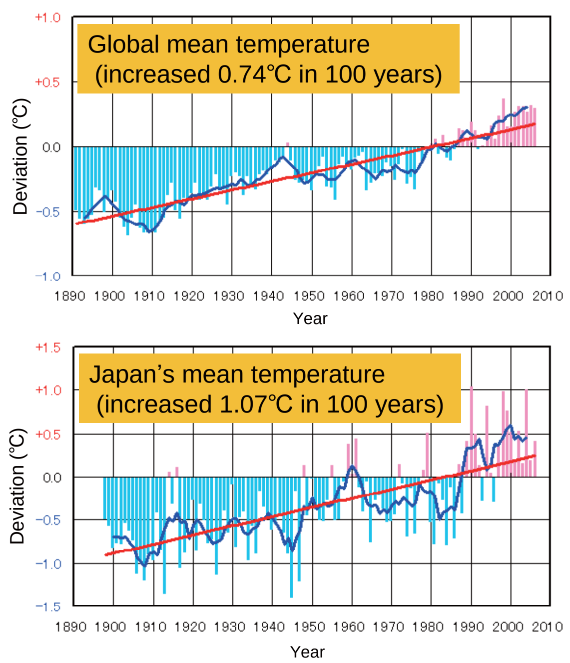


Figure 1 Temperature Increase in the World and Japan
Bar graph: Difference between each year's mean temperature and the normal temperature (i.e., the mean temperature between 1971 and 2000)
Blue line: Five-year moving average of the deviation
Red line: Long-term changes

in about 100 years), resulting in an increase of global mean temperature of 0.74°C (see top of Figure 1). The report also suggests that the second half of the 20th century was likely the warmest 50-year period in the Northern Hemisphere in the last 1300 years, with the mean temperature increasing twice as rapidly as in the last 100 years. Furthermore, the report indicates that global warming is undoubtedly real and almost concludes that global warming gases produced by human activities are to blame. These observations are more affirmative than those in the IPCC Third Assessment Report (2001), which indicated a temperature increase of 0.6°C over the last century, suggesting that global warming gases produced by human activities could be the cause of global warming.

The increase in mean temperature varies from region to region; it is higher in some regions and lower in others. For instance, Japan's mean temperature has increased 1.07°C over the last century, according to the Japan Meteorological Agency, which is higher than the world average of 0.74°C (see bottom of Figure 1). It is also a fact that the weather has been unusually hot since the beginning of the 1990s.

(3) Global climate change in the future

The global mean temperature between 2090 and 2099 is projected to increase by 1.1 to 6.4°C from the 1980 to 1990 levels (see Figure 2), whereas a range of 1.4 to 5.8°C was projected in the previous report (2001). Whatever the case may be, the temperature is likely to increase at a rate much higher than that seen in the last century.

The reason predicted temperatures vary so widely is that they depend a great deal on climate models and societal scenarios (see Figure 3 Greenhouse gas emission scenarios). For instance, the temperature is projected to increase by an average of 1.8°C (1.1 to 2.9°C), according to the scenario for sustainable development society (B1), where environmental conservation and economic development go hand in hand, or by an average of 4.0°C (2.4 to 6.4°C), according to the scenario for fast-growing society, with fossil fuels as the world's primary

Temperature increases in 2100 based on emission scenarios		
Emission scenario	Average	Range
A1FI	4.0	2.4~6.4
A1T	2.4	1.4~3.8
A1B	2.8	1.7~4.4
A2	3.4	2.0~5.4
B1	1.8	1.1~2.9
B2	2.4	1.4~3.8

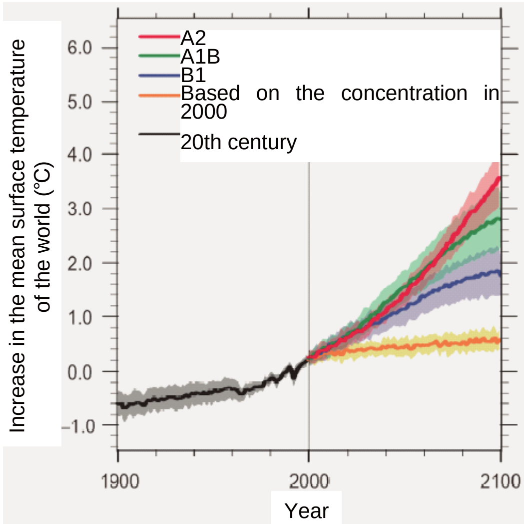


Figure 2 Temperature increase in the future

A1T, A1B, A1FI, A2, B1 and B2 are the scenarios of greenhouse gas emissions (refer to Figure 3 for details). Each solid line refers to the average of predicted temperatures based on multiple models, and each shade, the range of standard deviation. The orange line is based on the assumption that the greenhouse gas concentration is maintained at 2000 levels. All scenarios show that the temperature will increase 0.2°C per decade up to 2030, while the rate varies after 2030.

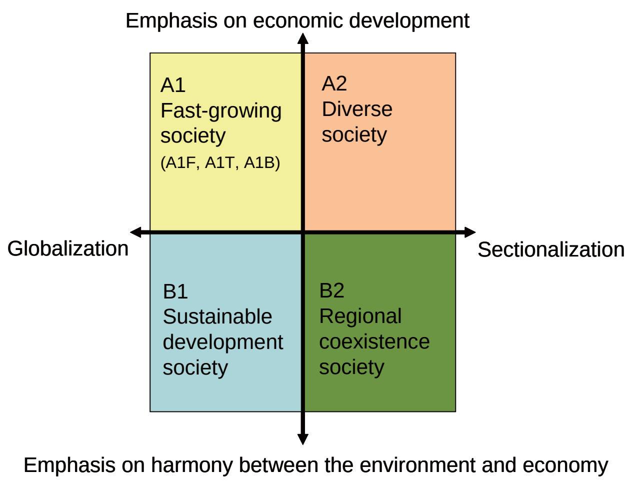


Figure 3 Greenhouse gas emission scenarios

Of the four major scenarios above, the A1 scenario is divided into three sub-scenarios, according to the dependence on fossil fuels: A1F1 (with emphasis on fossil fuel energy), A1T (with emphasis on non-fossil fuel energy) and A1B (with a balanced emphasis on all energy sources).

energy sources. However, all scenarios show that the temperature will increase 0.2°C per decade up to 2030.

2. Impact of Global Warming on Japan's Agriculture, Forestry and Fisheries

The report of Working Group 2 on impacts, adaptation and vulnerability reveals that global warming is having an impact on nature and society around the world, such as the melting of glaciers and frozen tundra, advancement in the springtime phenomenon in animals and plants, and habitat shifts. Global warming is expected to have a serious impact on water resources, ecosystems, food production and other aspects of life.

For agricultural production, low latitudes such as the tropics are more vulnerable than high latitudes to global warming. The IPCC Fourth Assessment Report predicts that grain production will decrease in low latitudes and increase in middle-high latitudes if the global mean temperature increases 2 to 3°C. This means that global warming will have a greater impact on developing countries (most of which are located at low latitudes in Asia and Africa) than on developed countries such as Japan. However, a temperature increase of more than 2 to 3°C will probably result in decreased grain production in both low and high latitudes. The negative impact of global warming will be greater than the positive impact.

While the IPCC reports summarize the potential impact on broad regions like Asia and Africa, they do not refer to those of specific countries. The impact of global warming on Japan's agriculture, forestry and fisheries can be summarized as follows.

(1) Real impact of high temperatures on agriculture, forestry and fisheries

MAFF conducted a nationwide survey in February 2007 to have a clear picture of the impact of high temperatures on agricultural production. High-temperature injury to rice plants, abnormal coloration of fruit and high incidence of pests and diseases were observed.

For instance, white immature kernels occur in many cases, with the daily mean temperature exceeding 27 °C during the ripening period (the period between heading and flowering); all or part of brown rice turns to milky white. This phenomenon is becoming apparent in Kyushu, where the daily mean temperature during the ripening period is on the rise. Another high-temperature injury is cracked rice (see Figure 4), where a mature rice grain cracks due to a rapid change in water content (which causes internal strain). The higher the temperature during the initial ripening period, the more frequently it occurs.

The rind puffing of Satsuma mandarins (see Figure 5) is a phenomenon where the rind separates from the flesh due to high temperatures and heavy rain during the later stages of the ripening period, undermining the quality of fruit and storage. The incidence of sunburned fruit (see Figure 6) is also increasing due to intense sunlight and lack of water during the summer months.

Abnormal coloration of grapes (see Figure 7) is also attributable to high temperatures, which restrain the formation of anthocyanin and undermine grape quality.

The National Agriculture and Food Research Organization (NARO) conducted surveys on fruit in 2003 and on paddy rice, wheat, soybeans, vegetable, flowers and livestock in 2005, with questionnaires sent to public agricultural experiment stations in 47 prefectures, to study the impact of global warming on agriculture. The results were that all prefectures reported the impact on fruit, 90% of them on vegetables and flowers, more than 70% of them on paddy rice and approximately 40% of them wheat, soybeans and livestock (including feed

Figure 4 Cracked rice

A cracked rice grain breaks easily during milling, resulting in poor eating quality.

It is seemingly a whole grain (left), but slight cracks are visible when lighted (right, indicated by the arrows).

crops).

Such phenomena are becoming increasingly widespread, although it remains to be seen if they can be attributed to global warming or considered short-term, sporadic incidents. In fact, while the global mean temperature has increased approximately 1°C over the past century, it is by no means unusual that Japan's mean temperature fluctuates within a range of one degree Celsius from year to year – i.e., natural fluctuations. The relatively wide range of these natural fluctuations makes it difficult to determine the long-term impact of global warming.

Many of the phenomena observed are probably due to high temperatures caused by short-term climate change (natural fluctuations), but the impact of long-term climate change (global warming) is no longer negligible.

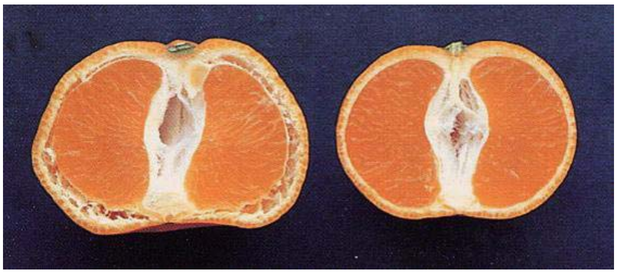


Figure 5 Rind puffing of Satsuma mandarin due to high temperatures and heavy rain (left)

The rind separates from the flesh, undermining the quality of fruit and storage.

Figure 6 Sunburned fruit due to high temperatures and lack of water

Sunburned fruit results in decreased commercial value.

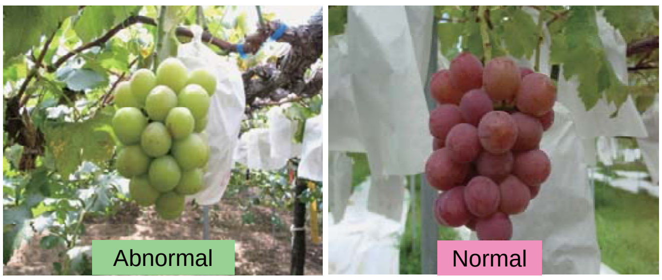


Figure 7 Abnormal coloration of grapes due to high temperatures

Poor coloration results in decreased commercial value.

(2) Potential impact of global warming on agriculture, forestry and fisheries

The results of research conducted on the potential impact of global warming on Japan's agriculture, forestry and fisheries show a decrease in the potential paddy rice yield in some areas, a shift in the areas suitable for growing fruit, a decrease in beech habitats and changes in the distribution and volume of water resources. The progress of global warming will probably have serious impact on Japan's agriculture, forestry and fisheries.

However, there is one factor that should be kept in mind when making predictions: assumptions. Failure to understand such assumptions may cause unnecessary concerns or, worse, negligence that could slow down measures against global warming. The following describes how predictions are made.

Model-based simulations are common tools for predicting the impact of global warming. Specifically, climate chambers are used to simulate the conditions of global warming (high temperatures, high CO_2 concentrations, and other such conditions) under which crops are grown and animals are fed. Data are then collected on the impact of higher temperatures on crops and animals to develop plant (animal) growth models. With data on future climatic conditions fed into these models, they simulate how crops and animals will grow. At the same time, future climatic conditions are calculated, using supercomputers, based on climate models and greenhouse gas emission scenarios.

All models including those for plant growth and climate simulations involve simplifications of complex natural phenomena and hence do not necessarily represent reality. The results of predictions are thus associated with uncertainties. Based on this understanding, it is important to disseminate information to the effect that this or that could happen in the future, judging from the findings available to date. The following are some of the representative studies.

1) Potential impact on agriculture

a) Paddy rice: Predictions of changes in yields

Of studies on the impact of global warming on Japan's agriculture, many have focused on paddy rice. Briefly, yield is expected to increase in the northern region including Hokkaido and decrease in the southern region including Kyushu. Put differently, global warming will have positive effects on regions where it is too cold to grow a given crop, and negative effects on those where it is too hot to grow the crop. This observation coincides with predictions made for the impact of global warming worldwide: positive effects are larger in high altitudes than in low altitudes.

The results of predictions (using statistical analysis of fluctuations based on the relationship between climatic conditions and yields) show that the yield will increase 13% in Hokkaido and decrease 8 to 15% in the sub-Tohoku region in the 2060s, if the mean annual temperature increases by 3°C (see Figure 8). In this particular case, an agroclimatic index (an index based only on temperature and the amount of solar radiation) is used to estimate potential yields. With the assumption that the current atmospheric CO_2 concentration (approximately 350 ppm) will increase 1% annually, four representative global climate models are used to obtain future climate data, the average of which refers to future temperature changes. At the same time, the transplant date is adjusted to maximize the yield, but other factors such as decrease in the yield due to high temperature-induced sterility, soil conditions and the impact of pests and diseases are not taken into account.

According to predictions based on a paddy rice growth model, the yield of the Koshihikari variety will decrease by a maximum of 10% over the next 50 years in the sub-Tohoku region, although the yield can be increased by 5 to 20% over the same period by adjusting the transplant date. The incidence of high temperature-induced sterility, meanwhile, is estimated at less than 5% in all regions for the 2030s, but it is expected to exceed 5% in the Chikushi, Saga, Wakayama and Nobi Plains in the 2090s. (High temperature-induced sterility is a phenomenon where paddy rice is exposed to extremely high temperatures during the flowering period, resulting in poor pollination.)

There is also a need to take into account another impact of global warming: an increase in atmospheric CO_2 concentrations. The results of free air CO_2 enrichment (FACE) studies (see Figure 9) show that an increase of CO_2 concentration by 200 ppm boosts the yield by some 15%. (The free-air CO_2 enrichment

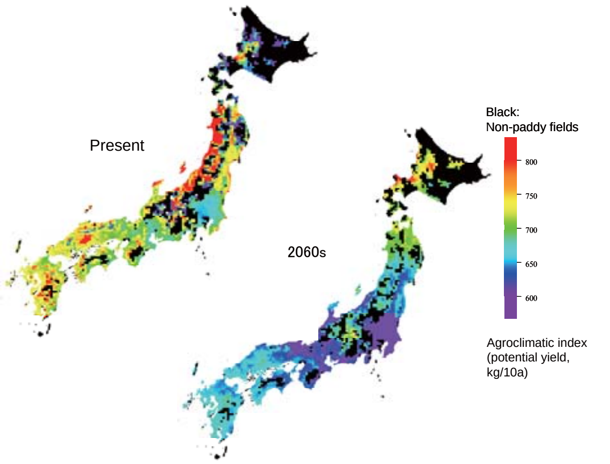


Figure 8 Impact of global warming on paddy rice yields

Prediction results (using statistical analysis of fluctuations based on the relationship between climatic conditions and yields) show that the yield will increase 13% in Hokkaido and decrease 8 to 15% in the sub-Tohoku region in the 2060s, if the mean annual temperature increases by 3°C.

Figure 9 FACE experiment at Shizukuishi-cho (Iwate prefecture) to simulate the impact of high CO_2 concentrations

CO_2 gas is emitted from an octagonal tube according to the direction of the wind to keep the CO_2 concentration (within the area surrounded by the tube) 200 ppm higher than the ambient concentration.

approach involves the artificial emission of CO_2 in paddy fields to simulate the impact of high CO_2 concentrations.) The pores, however, tend to shrink as CO_2 concentrations rise, which could result in increases in the temperature of rice ears and risk of high temperature-induced sterility. Thus, further studies are needed to determine the gross impact of high CO_2 concentrations.

b) Fruit: Predictions of changes in areas suitable for growing fruit

Studies on fruit are also abundant. Adaptation technique against global warming are particularly important for fruit growing because fruit trees are usually not transplantable. A decades-long production with the same tree is required to make fruit growing economically viable and, unlike other crops, the sowing period cannot be adjusted.

Data predicting changes in the mean annual temperature suggest that the areas suitable for growing apples and Satsuma mandarins are moving towards the north. The temperature range suitable for apples is 7 to 13°C; their plantations are widespread, excluding northern/eastern Hokkaido and the southwestern plain. With the temperature increasing by 3°C in the 2060s, however, all of Hokkaido will become suitable for growing apples, whereas they will no longer grow in the sub-Kanto region (see Figure 10).

The temperature range suitable for Satsuma mandarins is 15 to 18°C. Likewise, the areas suitable for growing Satsuma mandarins will extend from the southwest coastal region to the southern Tohoku coastal region in the 2060s.

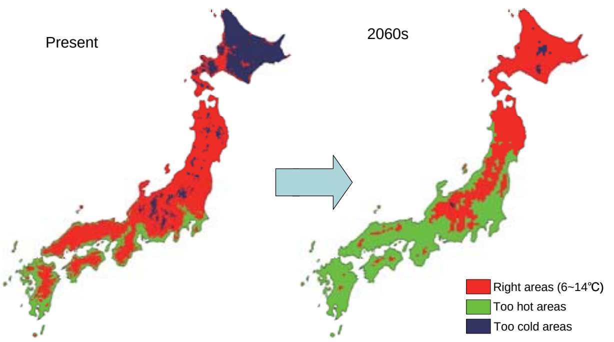


Figure 10 Impact of global warming on apple growing

While apple plantations are widespread, excluding northern/eastern Hokkaido and the southwestern plain, they will move toward the north to include all of Hokkaido in the 2060s, whereas apples will no longer grow in the sub-Kanto region.

Data used for the predictions above are derived from the method used for studies on paddy rice, and these predictions are based on bold assumptions. Only the mean annual temperature is considered to predict a shift in the areas suitable for growing apples and Satsuma mandarins. Thus, a number of uncertainties are involved, which are taken into account to come up with possible scenarios.

c) Predictions of changes in the production of livestock and grass

There have also been studies on the potential impact of high temperatures on livestock and poultry production. For instance, chicken production is projected to decrease, particularly in western Japan, with approximately 10% of the poultry-raising areas experiencing more than a 15% decrease in production in August in the 2060s. Figure 11 shows the rates of decease in Japan's chicken production in August, which are based on the current and predicted mean temperatures (chickens are raised in air-conditioned chambers). Data used for the predictions are derived from the method used for studies on paddy rice.

For grass, an increase of 4°C in the mean annual temperature over the next century is projected to boost production by 50%, as temperate grasses decrease and tropical grasses increase. However, tropical grass is relatively poor in nutrients and the quality of other feed crops could decline. Additional studies are thus required,

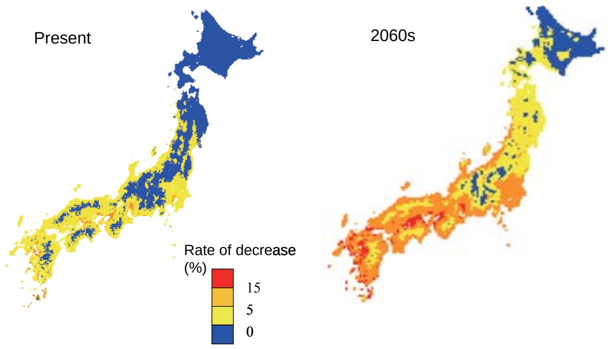


Figure 11 Impact of global warming on chicken production

The rate of decrease in the chicken production in August (at present and in the 2060s), with the standard set at 23°C and the rate estimated at 5% at 27.2°C and 15% at 30.0°C

Chicken production is projected to decrease, particularly in western Japan, with approximately 10% of the chicken-raising areas experiencing more than a 15% decrease in production in August in the 2060s.

Column 1

Higher CO_2 concentrations could boost agricultural production

The positive side of global warming should be considered as well. For example, higher CO_2 concentrations promote photosynthesis of plants. This phenomenon is called the "CO_2 fertilization effect," as it promotes growth and boosts yields. To measure this effect, plants are grown in a climate chamber with high CO_2 concentrations for comparison with those grown under normal conditions. As mentioned earlier, there is also the free-air CO_2 enrichment approach (see Figure 9), which is performed in an open-air environment. Results of experiments show that an increase in CO_2 concentration by 200 ppm boosts the yield of wheat and soybeans by some 15% (see Figure 12).

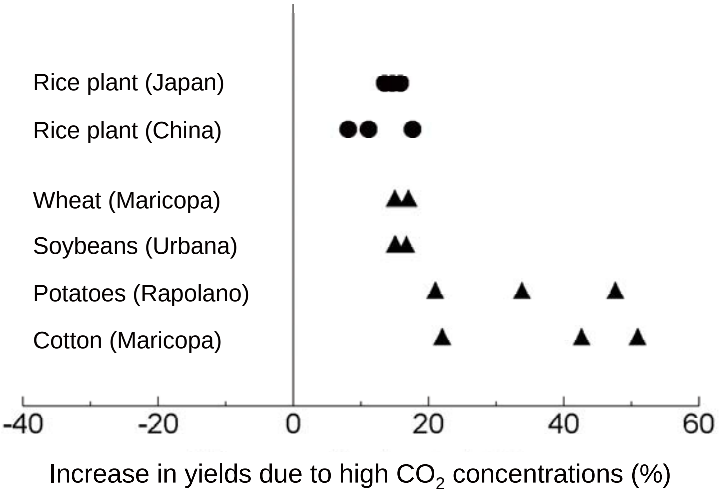


Figure 12 Increase in yield with ambient CO_2 concentrations increased by 200 ppm
Review of Hasegawa et al. (2005) plus data on soybeans by Morgan et al. (2005)

with the quality and nutrient aspects taken into account.

2) Forestry: Predictions of a shift in beech habitats

Predictions have also been made for forestry. While the present distribution of beech species – with climatic, topographic and soil conditions taken into account – suggests conditions suitable for their growth, Figure 13 shows a shift in beech habitats due to global warming. According to a scenario where the mean temperature increases by 4.9°C between 2081 and 2100, the area suitable for the growth of beech species will decrease by 91% (see Figure 13-C). Likewise, according to a scenario where the mean temperature increases by 2.9°C during the same period, the area will decrease by 63% (see Figure 13-D). For cedar species, which are on the decline due to high temperatures and dryness, the results of some studies show that the area unsuitable for their growth will increase, based on analysis of present and future climatic conditions and their present distribution.

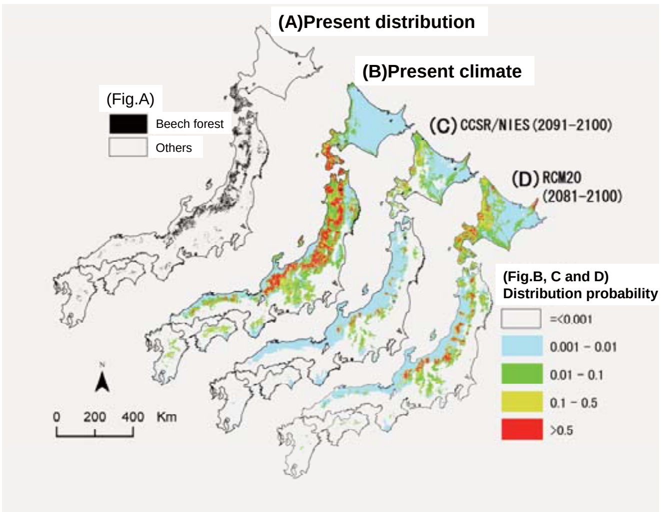


Figure 13 Impact of global warming on the distribution of beech forests

(C): A scenario based on a climate model developed jointly by the Center for Climate System Research, the University of Tokyo, and the National Institute for Environmental Studies

(D): A scenario based on a regional climate model of the Meteorological Research Institute

The area suitable for the growth of beech species will decrease by 91% by the end of the 21st century, with an increase of 5°C in the mean temperature.

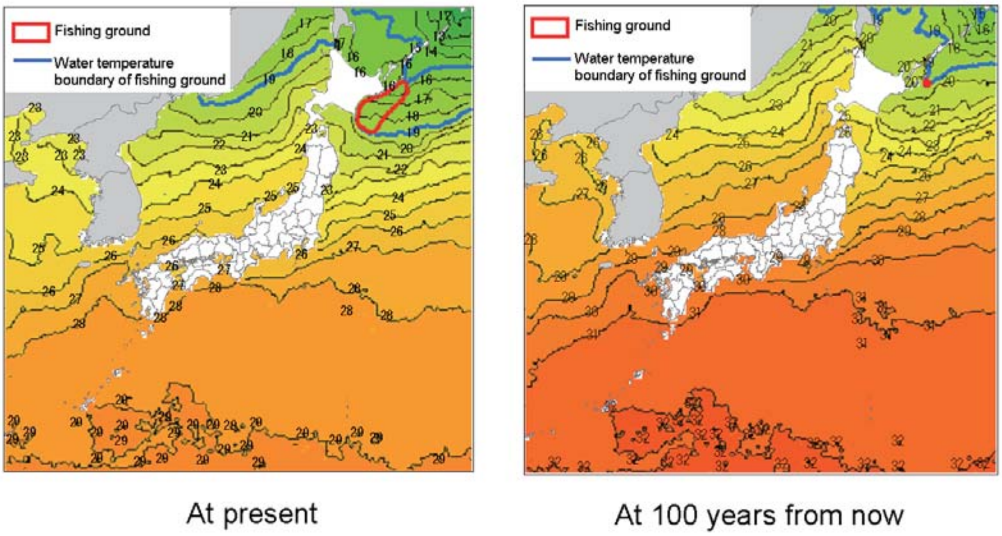


Figure 14 Impact of global warming on saury fishing grounds
Saury fishing grounds are predicted to be dramatically decreased 100 years from now due to an increase in water temperature.

In addition to the predictions for the species mentioned above, a variety of studies have been conducted in the field of forestry, some of which include monitoring and modeling approaches to estimate forest carbon sink.

3) Fisheries: Predictions of changes in Pacific saury fishing grounds

An increase in water temperature could have a significant impact on the habitats of aquatic species. Figure 14 shows expected changes in saury fishing grounds in September, based on the optimum water temperature for sauries. Although saury fishing grounds are located off the coast of the Nemuro Peninsula in eastern Hokkaido (the area circled in red) at present, sauries were predicted to be scarce in the seas around Japan about 100 years from now. Similar studies have been conducted on a number of species, however, it is difficult to precisely predict changes in fishing grounds and seasons as an increase in water temperature causes changes in ocean currents and feeding environments in marine ecosystems. It should thus be noted that these predictions are based on assumptions.

One of the reasons why the impact of global warming on agriculture, forestry and fisheries 50 to 100 years from now should be predicted is that the predictions will enable us to distinguish natural fluctuations from long-term changes due to global warming. Predictions for the next century could hardly give precise images, but comparison between those for the next 50 years and present conditions could provide a clue to what will happen in the near future.

3. Japan’s Adaptation Technique to Global Warming

While the previous paragraphs summarize the existing and potential impact of global warming on agriculture, forestry and fisheries, adaptation techniques to such impact on agriculture can be broadly classified into two categories: development of crop varieties and development of cultivation techniques. For forestry and fisheries, emphasis is placed on predictions of the impact of global warming and analysis of its mechanism. The following sub-paragraphs, therefore, focus on adaptation techniques in agriculture.

(1) Adaptation technique for white immature and cracked rice grain

White immature grain caused by high temperatures during the ripening period (with a mean temperature of 27°C or more) undermine the quality of brown rice. The wihite immature grain can be reduced by avoiding

Figure 15 Comparison of the ratio of perfect grains, white immature grain and the other grain between Nikomaru and Hinohikari in the same heading time. The rate of perfect grain is higher in Nikomaru. (The Nagasaki Agriculture and Forestry Experiment Station, 2005 (high-temperature year)

high temparetures with late planting and direct sowing. Moreover, as an excessive number of grains and shortage of nitrogen during the ripening period could promote the occurrence of white immature grains, there is also a need to optimize the amount and timing of fertilization, and planting density. The new rice variety Nikomaru, breeded in 2005 is recommended because of the low occurrence of white immature kernels, (see Figure 15). In fact, the results of four-year experiments carried out in the western Japan show that grain quality of Nikomaru is generally superior to that of Hinohikari in most of year and regions.

Cracked grain, which breaks easily during milling,, was previously thought to ocuured only by excessive drying of grain with late harvesting. However, recent studies show that cracked grain promoted by high temperature rises during the early ripening period. Preventive techniques include late planting, prevention of early drainage and optimized harvesting.

The occurence of pecky rice, caused by pecky rice bugs, is also on the rise, although its relationship with global warming is yet to be unclear. Studies are thus underway on plant pest forecasting, such as review of pesticides (including new formulations), mowing around paddy field before heading time and insect forecasting through pheromone traps.

(2) Adaptation technique for abnormal coloration of fruit

Of high-temperature injury to fruit, abnormal coloration is one of the most serious problems. For apples, adaptation techniques include a switch to varieties/species with excellent coloring properties and techniques to increase the amount of sunlight through reflective mulches and other techniques. Likewise, there are techniques to enhance the coloration of grapes through girdling (see Figure 16). With the grapevine girdled, sugars photosynthesized in the leaves accumulate in the branches and leaves. As a result, the sugar content increases in the upper part from the girdled portion at the time of harvesting, which in turn promotes the synthesis of anthocyanin and enhances the coloration. Recent studies show that the coloration can be further enhanced with girdling and without bagging. Other coloration enhancement techniques include ABA (abscisic acid, a plant growth regulator) treatment and optimization of the number of fruits per tree.

For citrus, typical adaptation techniques for rind puffing (caused by high temperatures during the ripening period) are improved fruit thinning (control of large fruits through cluster fruiting and other techniques), damage mitigation through plant growth regulator and

Figure 16 Girdling for improvement of coloration (Aki Queen variety)

Sugars photosynthesized in the leaves accumulate in the branches and leaves, thereby promoting the synthesis of anthocyanin and enhancing the coloration.

development of varieties that are resistant to rind puffing (Ishiji, Tamami, among others).

Global warming raises not only summer but also winter temperatures. For instance sleeping disease of greenhouse pears is caused by high temperatures during winter. Too high a temperature during winter retards the flowering and fruiting of pear trees in spring. This phenomenon can be prevented by spraying cyanamide or by starting heating after being exposed adequate low temperature.

(3) Adaptation technique for freezing damage to wheat and drought damage to soybeans

High-temperatures do not pose risk of damage to wheat, as wheat does not grow in high-temperature conditions in summer. However, as winter temperatures increase, the formation of panicles and stalks accelerates, raising the risk of freezing damage. The Iwainodaichi variety* (see Figure 17), even if planted early, is relatively stable during the stalk formation. Global warming could promote its growth, but its stalk formation does not accelerate as quickly as other varieties and hence the risk of freezing damage is minimal. The Iwainodaichi variety, for that matter, is well adapted to high-temperature conditions associated with global warming (see Figure 18).

Soybean production is expected to decrease due to drought. Thus, a system called "FOEAS" is in place to control groundwater levels in upland fields converted from paddy fields. In addition to irrigation, FOEAS is designed for drainage of rainwater.

*Named and registered in 2002, suitable for growing in west of Kanto, up to southern Kyushu.

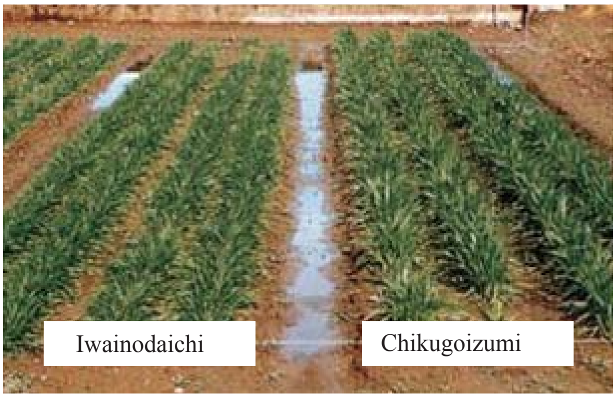


Figure 17 Iwainodaichi variety (left)

The Iwainodaichi variety is relatively resistant to freezing damage, with less stalk formation observed during warm winter periods.

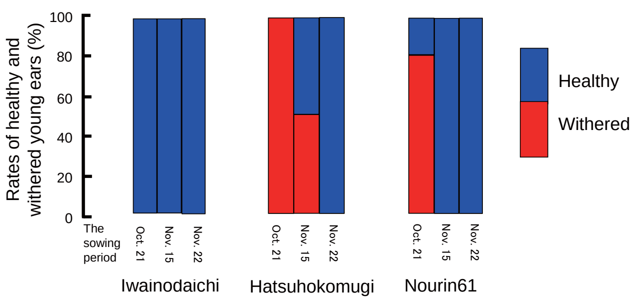


Figure 18 Freezing damage during the sowing season

(4) Adaptation technique for poor fruit set in eggplants and techniques to cool strawberries

Of vegetables, fruit vegetables are vulnerable to high temperatures, resulting in poor fruit set. For instance, high temperatures induce pollen-sterile eggplants (see Figure 19), while parthenocarpic lines* that are highly resistant to high temperatures are under development. Such lines are expected to be the materials for developing new varieties well adapted to global warming.

Effecting cooling techniques, meanwhile, are essential for growing greenhouse vegetables. One such technique is fog cooling, which involves spraying water, although it creates humid conditions conducive to pests and diseases. For this reason, a year-round high-quality cultivation technique is available, adopting partial cooling of the crown of strawberries.

Figure 19 Poor fruit set of an eggplant due to high-temperature-induced pollen sterilization

*Parthenocarpy is the natural or artificially induced production of fruit without fertilization of ovules.

4. Japan's Mitigation Technique to Address Global Warming

Six greenhouse gases covered by the Kyoto protocol include carbon dioxide, methane and nitrous oxide. Of these, carbon dioxide represents the largest share of the world's greenhouse gas emissions. Greenhouse gas emissions are usually associated with the combustion of fossil fuels and, by extension, with automobiles and factories. Meanwhile, agriculture, forestry and fisheries are all human activities that depend on the circulation of nature; they also produce methane and other greenhouse gases. For instance, methane emissions originating from paddy fields and livestock such as cattle account for some 40% of human-induced methane emissions. It is thus imperative that these emissions be reduced through proper management and techniques.

While energy conservation is part of global warming mitigation measures in other sectors such as industry and commerce, taking advantage of the function of nature (e.g., carbon sequestration in ecosystems) is an effective way to reduce greenhouse gas emissions from the agriculture, forestry and fishery sectors. As the term "forest carbon sequestration" suggests, trees and plants absorb carbon dioxide, as does the soil (the very basis of agriculture and forestry), depending on how the soil is managed. What is needed, therefore, is to develop technologies to maintain agricultural productivity and at the same time to mitigate global warming. As mitigation techniques in fisheries center on fuel-efficient fishing boats, the following is focused on those in agriculture and forestry, which involve ecomanagement.

(1)Reduction of greenhouse gas emissions from paddy fields and cattle

In agriculture, croplands and livestock are the primary sources of greenhouse gas emissions. For instance, submerged paddy fields emit methane and drained paddy fields, nitrous oxide, for which adaptation techniques are in place.

The IPCC guidelines (2006) show that 1) methane is emitted from paddy fields, but not from vegetable gardens, 2) methane originating from paddy fields can be reduced through midseason drainage and 3) nitrous oxide is emitted both from paddy fields and from vegetable

Column 2

Enormous amount of carbon is stored in the soil

Part of plant residues decomposes into stable organic matter (humus), which remains in the soil for hundreds to thousands of years, being separated from the carbon cycle and reducing atmospheric CO_2 concentrations. Although a carbon sink is usually associated with forests, soil stores an enormous amount of carbon.

The total amount of organic carbon stored in the soil is estimated at 1.5 trillion tons, approximately double the amount stored in the atmosphere and triple the amount stored in terrestrial plant biomass. Even a slight change in this amount, therefore, has significant impact on atmospheric CO_2 concentrations.

In fact, the amount of organic carbon in the soil, which stood at some 2 trillion tons in the prehistoric age, has decreased to some 1.5 trillion tons. Put differently, as much as 0.5 trillion tons of organic carbon have been released into the atmosphere, with forests converted to croplands, promoting decomposition of soil organic matter. This amount is more than double the increase in atmospheric carbon over the past 140 years (1850 to 1990) due in large part to the combustion of oil and other fossil fuels, which is estimated at 230 billion tons. As these figures show, an enormous amount of carbon dioxide has been released from the soil into the atmosphere.

Soil preparation, which maintains the amount of soil organic matter at relatively high levels, is essential not only for agricultural production but also for global warming mitigation.

gardens, the amount of which increases with the amount of nitrogen fertilizer applied (the former produce less emissions than the latter) (see Table 1).

Specifically, midseason drainage (10 days), followed by alternate wetting and drying irrigation (approximately a month and a half, with a cycle of 3-day inundation and 2-day drainage), coupled with application of nitrogen fertilizer (9kg/10a), inhibits the activity of methane-producing microorganisms in the soil, thereby significantly reducing methane emissions, compared to inundated paddy fields. This practice does not have much of an impact on nitrous oxide emissions or rice yield.

These observations suggest that midseason drainage, a common practice in Japan, is an effective way to reduce greenhouse gas emissions.

Techniques to reduce methane emissions from ruminants such as cattle are also available. In the case of beef cow, for instance, emissions can be reduced by some 10% by increasing the proportion of fat-rich beer cake and raw rice bran in the assorted feed to 12%.

(2) Enhancement of carbon sequestration in forests and wood

The report of Working Group 3 on mitigation of climate change, which is part of the IPCC Fourth Assessment Report, proposes to 1) maintain and increase the forest area, 2) maintain and increase forest carbon sequestration and 3) make use of wood products (enhancement of carbon sequestration and substitution for high-energy materials and fossil fuels).

As Japan has little potential for increasing forest area, it needs to opt for the other two effective measures combined: enhancement of carbon sequestration in forests and in wood as home construction materials. This may come as a surprise, but according to some estimates the carbon stored in home construction materials accounts for some 18% of that stored in forests in Japan. Based on Japan's forest resource database, the Forestry and Forest Products Research Institute developed a model designed to calculate the total amount of carbon sequestration according to a scenario that takes into account both the forest and housing sectors. Simulation results show that proper management of forests (including multi-storied forests) and improvement of the durability of homes are effective in enhancing carbon sequestration. Meanwhile, approximately one third of the global landmass is treeless wasteland, where new afforestation techniques – instead of conventional ones using grass plants and shrubs – are considered effective mitigation measures. Specifically, techniques being developed include a planting method that involves blasting of the hardpan (a layer of hard subsoil or clay) near the surface;

Table 1　Emission coefficients, etc. of methane and nitrous oxide originating from paddy fields and vegetable gardens (IPCC guidelines, 2006)

	Paddy fields		Vegetable gardens
	Inundated paddy fields	Paddy fields with midseason drainage	
Correction coefficients of methane emissions, based on water control (with an inundated paddy field as 1)	1	0.52～0.60	0
Emission coefficients of nitrous oxide (as a percentage of the amount of nitrogen in fertilizer)	0.3	0.3	1.0

- Methane is emitted from paddy fields, but not from vegetable gardens; methane originating from paddy fields can be reduced through midseason drainage.
- Nitrous oxide is emitted both from paddy fields and from vegetable gardens, the amount of which increases with the amount of nitrogen fertilizer applied (the former produce less emissions than the latter).
- With both methane and nitrous oxide taken into account, water control involving midseason drainage, a common practice in Japan, is more effective in reducing greenhouse gas emissions, rather than keeping paddy fields inundated.

Column 3

The ocean has huge potential as a carbon sink

The ocean is vast and hence has huge potential as a carbon sink. According to the IPCC Third Assessment Report (2001), an estimated 6.3 billion tons of carbon is released into the atmosphere every year through human activities, such as combustion of fossil fuels, approximately half of which (3.1 billion tons) is absorbed by Earth. The ocean ecosystem is thought to absorb 1.7 billion tons and the terrestrial ecosystem is thought to absorb 1.4 billion tons. These estimates, however, are associated with many uncertainties such as the processes of absorption and release of carbon – in particular, those in shallow seas involving seaweeds, shellfish and coral reefs. For this reason, MAFF is working on the mechanisms of the carbon cycle in seaweed beds, which represent shallow seas.

selection of salt-tolerant, high-growth trees (natural hybrid species of Eucalyptus for the salt-encrusted soil; and remediation of high-salinity soil near the surface using tubes. At the same time, efforts are underway to convert unused wood biomass such as scrap wood and forest residue into bioethanol.

5. Topics for Future Studies

As global warming is considered inevitable, there is a need to continue studying mitigation measures (techniques to reduce greenhouse gas emissions from agriculture, forestry and fisheries) and, as discussed in this report, adaptation techniques. MAFF, therefore, announced the "Integrated Strategy for Global Warming" on June 21, 2007. The following activities will be emphasized in the "Studies on Global Warming Countermeasures" with focus on mitigation, adaptation and impact assessment.

For mitigation measures, the key is to shed light on the mechanisms of formation and absorption of greenhouse gases such as CO_2 and to develop their models. These basic studies will serve as the basis for developing techniques to manage agroforestry ecosystems designed to minimize greenhouse gas emissions and maximize soil and forest carbon sequestration. In so doing, the carbon balance should be evaluated through life cycle assessment (LCA), thereby developing an integrated system for the management of agricultural techniques and ecosystems to reduce greenhouse gas emissions. At the same time, due consideration should be given to the productivity of agriculture, forestry and fisheries.

Likewise, immediate measures for adaptation should be discussed to deal with crop damage such as high-temperature injury, while developing heat-resistant varieties that meet the needs of growers and techniques that ensure stable agricultural production.

In addition, a more accurate assessment is needed for the nature, degree and period of the impact of global warming on agriculture, forestry and fisheries with the findings presented in this report taken into account. The results of this assessment will then serve as the basis for studying adaptation measures. As part of the basic studies to review drastic adaptation measures including crop switch, it is important to shed light on the physiological mechanisms and hereditary factors that have something to do with the impact of global warming (a deterioration in quality, a decrease in yield, etc.) – a means to accumulate knowledge that contributes to developing new varieties and production techniques. While appropriate adaptation techniques should be systematically developed in each time period from the present to future, any such techniques need to be reviewed from the viewpoint of reducing greenhouse gas emissions. That is, adaptation and mitigation techniques cannot be separated from each other. They should go hand in hand.

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Figure 10: Predictions of a shift in the areas suitable for growing apples and Satsuma mandarins due to global warming (2002), the National Institute of Fruit Tree Science

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