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Impacts of Climate Change on Korean Agriculture and Its Counterstrategies

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Preface

Climate change is a megatrend that will lead to future changes in our society. Its impacts area now clearly recognized worldwide. For Korea, the average temperature has risen by 1.5℃ over the past 100 years, an increase far higher than the average global temperature rise, bringing about serious impacts on Korean agriculture, such as the change in locations suitable for crop cultivation and the increase in crop damage by blights and pests. Even though mitigation measures such as greenhouse gas reduction and absorption have come into effect both nationally and internationally in order to cope with the climate change, the evidence suggests the inevitability that global warming will continue for a considerable period of time. Agriculture, in particular, is very sensitive to climate change, so that countermeasures against climate change should be prepared urgently. Proper countermeasures against climate change will provide important tools for the future agriculture to plan agricultural policies and mid/long-term agricultural development plans and for the farm households to plan their farming.

This report is an English edition of the final result of two-year study project on the impacts of climate change on the agricultural sector of Korea and the countermeasures against it. It analyzes the actual conditions and prospects of climate change, its impacts on Korean agriculture and the farmers' responses to climate change. It then presents the Korean agricultural sector's countermeasures against climate change and a master plan for adaptation to climate change. I hope that this report will serve as a basic data for understanding the impacts of climate change on Korean agriculture and establishing countermeasures against it.

I would like to acknowledge all the people who have contributed to completing this Report, especially Prof. Tae-Kyun Kim (Kyungpook

National University) who analyzed the impacts of meteorological disasters on Korean agriculture, and Prof. Young-Sung Cho (Korea University) and Deputy Director Hyun-Kyung Jang (Ministry for Food, Agriculture, Forestry and Fisheries) who helped as advisors for the research. In addition, I would like to thank Professor Ian Gordon (Chungang University) and James Banfill (KREI Visiting Researcher) for their editorial comments on the English version of this report.

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President Se-Ik Oh
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ABSTRACT

Impacts of Climate Change on Korean Agriculture and Its Countermeasures

The average temperature in Korea has increased by 1.5℃ over the last 100 years, the winter season has become shorter with a longer summer season, and the time for the blooming of spring flowers has become earlier due to global warning. As a result of these changes, agricultural productivity has decreased, the cultivation regions for crops have moved northward, and damages from winter pests has increased. Scientific diagnosis and evaluation of climate change is very important in setting a vision for future farming and the direction for agricultural policy. It will provide useful information for the establishment of countermeasures such as long-term regional agricultural development plans and farm household planning.

This study was implemented in order to make recommendations for systematic and step-by-step countermeasures to climate change through in-depth analysis of climatic changes and their impacts on the agricultural sector. In order to accomplish the purpose of the study, this project was planned as a two-year task, and in 2008, the first year of the task, the study covered current status analysis and forecast of climate change; diagnosis of agricultural production pursuant to climate change; a review of cases for impact analysis in agricultural sector in major countries; and the ripple effect of climate change on the agricultural economy. In 2009, the general ripple effect of climate change was analyzed while suggesting a master plan to cope with climate change in the agricultural sector. This master plan was based on evaluations by analysts and experts. who prioritized various countermeasures to climate change both for major crop production regions and for individual farm household.

This report consists of a general overview of the first and second year

study. Chapter one presents the needs of the study, a summary of preceding studies, and methodology. Chapter two describes the current state and outlook for climate change at home and abroad. Chapter three covers basic concepts and theoretical approaches to cope with climate change in the agricultural sector. Chapter four reviews general impacts of climate change on the agricultural ecosystem, including the influence of climate factors, shifts in major production areas of crops, and economic impacts. Chapter five describes farmers' awareness of climate change, their attitudes to coping with climate change, and their decision-making regimes under risk and uncertainty. Chapter six presents impacts of climate change on the agricultural sector of major countries (Japan, the European Union, the United Kingdom, China, and Australia), and countermeasures in these respective countries. In Chapter seven, a basic direction of countermeasures to climate change is discussed along with the master plan for adaptation and related core tasks. Lastly in Chapter eight, a summary and conclusion are presented.

The major findings of this study are summarized as follows :

First, the National Institute of Meteorological Research (NIMR) forecasted that the average temperature will increase by 1.5℃ by 2020, 3.0℃ by 2050 and 5.0℃ by 2080 from the 30-year average between 1971~2000. They also forecasted that precipitation will increase by five percent by 2020, seven percent by 2050 and fifteen percent by 2080.

Second, due to increases in temperature by global warming, the appropriate region for cultivation of certain crops is shifting and new kinds of pests are emerging, which are expected to result in changes to cultivated crop species and an increase in the area of crops damaged by these pests. In particular, apples, peaches, grapes and beans are expected to suffer more damage due to brown grasshoppers, and the areas susceptible to rice stripe virus (RSV) will move northward, expanding to a nationwide level.

Third, the result of an analysis on climate variables by the kind of disaster which causes damage to crops shows that damages by typhoon, strong wind-blast, and snow have increased due to increases in annual average temperature, while damages by seismic wave, strong wind blast, storm and snow have increased due to an increase in pole temperature difference. The analysis also showed that as precipitation increased, the damage from heavy rain increased, whereas the damage from hail, lightning and strong wind-blast decreased. In addition, damage by heavy rain and typhoon has increased as the intensity of precipitation has increased.

Fourth, the result of an analysis on the factors that have contributed to stagnant yield of rice in the periods of 2002~2003 and 2006~2007 showed that the 'weather' factor had a larger impact on the yield than the 'technology' factor. In the period of 2002~2003, weather had a contributing factor of 76.4 percent, whereas technology had a contributing factor of 23.6 percent. In the period of 2006~2007, weather had a contributing factor of 66.5 percent whereas technology had a contributing factor of 33.5 percent. In both periods, weather had a significantly bigger impact than technology.

Fifth, a crop simulation analysis was used to check the influence of adaptation means to climate change, and the result of the analysis showed that as global warming progressed, the quantity of rice decreased when cultivation timing was fixed, regardless of the ecotype of rice plant, the quantity of nitrogenous fertilization, and irrigation condition. When cultivation timing was adjusted, the quantity of rice increased. This result implies that, at least in the case of agricultural sector, developing production technologies adapted to climate change can minimize potential risks.

Sixth, the shifting of major production regions due to climate change was observed. In the case of apples, peaches, grapes and the 'Hallabong' citrus fruit, the cultivated regions moved northward while the cultivated regions for apple and grape expanded nationwide. And in the case of tropical crops, some of which are cultivated on Jeju Island, it was analyzed that it will be possible to cultivate a considerable number of tropical fruit items within a number of years.

Seventh, for the analysis of climate change's effect on agricultural productivity, a Kernel regression was applied to four crops: rice, cabbage, radish and apple. The result of the regression analysis showed that, in the case of rice, the rise of temperature by 1℃ increased the production quantity by approximately 24.4kg per 10a when the average temperature during cultivation period is lower than 19℃ due to climate factors. When the average temperature is higher than 20℃, the production quantity fell by approximately 6.2kg per 10a. In the case of cabbage, radish and apple, the influence of climate factors to productivity varied by item and region.

Eighth, for the analysis of climate change's influence on farming assets, a Ricardian model was applied, and according to the analysis, the price of farmland per ha decreased by 14.55~19.24 million won when annual average temperature (12.4℃) increased by 1℃. An analysis was conducted to identify climate change's influence on gross agricultural income by applying a Ricardian model, and the result of the analysis showed that the increase of temperature by 1℃ reduced gross agricultural income by 2.6~4 million won per ha, which is larger than the influence on farmland price.

Ninth, the result of a survey showed that farmers' awareness of climate change appeared to be high and they felt unusual changes in weather and an increase in diseases and harmful insects. The survey result also showed that farmers had a keen interest in the countermeasures to climate change. They showed a high willingness to participate in the adaptation plan at the farmhouse level in the future, but there were bottlenecks such as lack of techniques and knowledge, insufficient information, and shortage of labor.

Tenth, an Expectation Utility Model was used to analyze the benefits of adopting means for adapting to climate change for the period of 2011~2040. The difference of expected income depending on the application or non-application of means of adaptation was found, and the analysis showed that there will be an income difference of approximately 790 thousand won in Gwangju, 1.2 million won in Milyang and 1.4 million in Jeonju. The probability of farmers applying means of adaptation was indirectly calculated based on the model. According to the calculation, it is anticipated that approximately 65 pcrcent of farmers would adopt means of adaption. What this shows is that farmers are keenly interested in adapting to climate change and that their capability to accommodate appropriate technology is high.

Lastly, the result of an evaluation on the priority of means of adaptation in agricultural sector revealed that development of technology and management of agricultural infrastructure are the most important. It showed improvement of plant breeding to be the first priority, management of water supply for agriculture as the second priority, and development of production technology as the third priority in all cases of short, medium and long-term planning.

Up to now, the main focus of countermeasures to climate change in agricultural sector was given to the measures to mitigate greenhouse gas, but in consideration of the inevitability of global warming, and especially the weather-dependent characteristics of agriculture, more interest and policy-based support will have to be given to the measures for adaptation to climate change. Countermeasures to climate change in the agricultural sector are especially required to actively change perceptions on climate change and expand common understanding in order to minimize risk and utilize climate change risks as an opportunity. In order to accomplish this, appropriate education and training programs will have to be developed and operated for farmers, government officials, and people in charge of relevant organizations.

In order to effectively implement the adaptation strategy in the agricultural sector, it is important to have roles appropriately assigned to the subjects concerned, such as government officials, farmers, research professionals and people in charge of relevant organizations, as well as establish an integrated administration system to comprehensively plan and drive countermeasures to climate change.

In order to perform a systematic study of climate change's impact on agriculture and prepare countermeasures, it will be important to organize joint research among relevant sciences, including: agricultural science, ecology, agricultural engineering, hydrology, meteorology and agricultural economics. To ensure higher reliability of the analysis, an integrated simulation model, which connects the scenario-based forecast with the characteristics of agriculture and socio-economic factors, has to be developed continuously. On top of that, future study will have to perform more concrete and systematic analysis of economic and policy effects expected from utilizing different means of adaptation in the agricultural sector.

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Introduction

Chapter 1

1. Need for the Study

Climate change refers to changes beyond the average atmospheric condition that are caused both by natural factors such as the orbit of earth's revolution, volcanic activities and tectonic movements and by artificial factors such as the increase in concentration of greenhouse gases and aerosol. Climate change caused by global warming, which refers to the average increase in global temperature, has become a megatrend that will lead to significant changes in future society. Regarding its impacts, The UN Intergovernmental Panel on Climate Change (IPCC) presented considerable scientific evidences in its fourth report on climate change (2007) and the effects have become clearly recognizable worldwide. In addition, people have become more aware of the fact that global warming can not be avoided due to the continued increase in greenhouse gas emissions and the changes in the climate system. The Club of Rome Report 1972 officially raised global warming as an international issue and, in 1985, World Meteorological Organization (WMO) and United Nations Environment Programme (UNEP) officially declared carbon dioxide as the principal cause of global warming. In order to effectively cope with the global warming issue, Intergovernmental Panel on Climate Change (IPCC) was organized in 1988 and has carried out systematic research and in-depth studies on climate change.

According to the fourth report of UN IPCC (2007) on climate change, it is indisputable that global warming has serious impacts on the earth and it is very likely that the increase in greenhouse gas emission by anthropogenic activities has caused global warming since the mid-21st century. Most especially, this report warns us is, that if mankind continues lead a life that depends on fossil fuels such as oil and coal, the average temperature of the earth will rise by up to 6.4℃ by the end of the 21st century (2090~2099) and the sea level will rise by 59㎝. In comparison, it was analyzed that the average temperature of the earth has risen 0.74℃ over the past 100 years (1906~2005).

Global warming not only causes a change in average temperature and precipitation but also increases the frequency of floods, droughts and heat waves and the intensity of typhoons and hurricanes, which follow the change in temperature and precipitation patterns. The impacts of climate change are also shown in various other forms throughout the world, including a rise in sea level, melting glaciers, the northward movement of plant habitats, changes in animal habitats, a rise in ocean temperature, shortened winters and the early arrival of spring.

According to the outlook of climate change in Korean Peninsular by National Institute of Meteorological Research (2009), the average temperature of Korea is expected to rise 4℃ and the sea level 1m by the end of the 21st century (2071 ~ 2100) on the assumption that the uses of all energy sources are balanced during the 21st century. It is analyzed that due to global warming the average temperature of Korea for the past 100 has already risen 1.5℃ (1.9℃ in winter and 0.3℃ in summer), with an ever shortening winter, a lengthened summer and early blooming in the spring. As a result, the locations suitable for crop cultivation have changed and the crop damages by blights and pests have increased, in turn leading to reduced agricultural productivity. This can be seen in the apple-farming area, which has shifted north even to Yangu, Gangwon Province from Daegu, Gyeongbook Province.

As the acceleration of global warming affects not only the ecological system but also the human life, it has become an important issue both nationally and internationally. Approaches to deal with the issue of global warming are divided largely into mitigation measures, which focus on reduction and absorption of greenhouse gases, the causative factors, and into adaptation measures to minimize the damages by climate change. So far, the global warming issue has been dealt with the focus on mitigation of greenhouse gases based on the international environmental conventions such as IPCC and Kyoto Protocol. For agriculture, however, the focus has been increasingly shifting to adaptation and adaptability based on the assessment of impacts of climate change and vulnerability to it. The IPCC emphasizes that it is very important for the agricultural sector to adapt itself to climate change. This is due to the fact that global warming will continue for the next several decades because of the previously emitted greenhouse gases. This will continue even after the emissions of greenhouse gases, the causative materials of climate change, have been significantly reduced due to active mitigation measures.

It takes at least 5 to 10 years to assess the impacts of climate change and the vulnerability to it and prepare proper countermeasures against it. For Korea, climate change is proceeding at a faster rate than the global average rate. Agriculture is especially climate-dependent and thus highly susceptible to climate change, it is very urgent to prepare adaptation measures against climate change. Proper countermeasures drawn up based on scientific diagnosis and assessment of the impacts of climate change on Korean agriculture are essential in establishing the vision and administrative policies of future agriculture and will provide valuable information for the local governments in establishing mid/long-term agricultural development plans and also for the farm households to prepare their farming plans.

2. Purpose and Scope of the Study

The purpose of this study is to propose systematic and phased countermeasures by analyzing the present conditions of climate change and its impacts on Korean agriculture. More specifically, it aims at identifying the relationship between climate change and agricultural production, analyzing the impacts of climate change on the rural economy by summarizing the results of preceding researches on climate change on Korean agriculture, and further proposing systematic countermeasures against climate change.

The first-year study carried out in 2008 analyzed the actual conditions of climate change and its outlook, analyzed the tendency of agricultural production, diagnosed the agricultural production with regard to climate change, reviewed the case studies for the agricultural sector done by major countries, and analyzed the impacts of climate change on the rural economy. The second-year study in 2009 includes a comprehensive analysis for the impacts of climate change, the shift in main production regions of major crops, the adaptability of the farm households and the priority of adaptation measures, based on which it proposes a master plan including a phased adaptation program for coping with climate change in the Korean agricultural sector.

Regarding the scope of this study, the actual conditions of climate change are analyzed for the years from 1920 to 2007, a period for which meteorological data is available. The changes in major agricultural production areas and agricultural production are analyzed for the years from 1960 to 2007 from which crop statistics are available. Analysis items for the arable sector are selected as grain (rice) and fruit (apple, peach, grape and Halla orange). Areas to be analyzed include main production regions of the aforementioned items and other areas that are appearing as new production areas. For the purpose of establishing the countermeasures for adaptation, the characteristics of each area (Gyeonggi area, Chungcheong area, Honam area, Yeongnam area, Gangwon area and Jeju area) are considered.

The countermeasures against climate change focus on adaptation measures based on the analysis of impacts of climate change, and therefore the mitigation measures that deal with reduction and absorption of greenhouse gas are not discussed in detail here. However, as the IPCC Fourth Assessment Report proposes plans to connect adaptation and mitigation, mitigation is still included in the scope of this study.

3. Review of the Preceding Studies

3.1. Domestic Studies

3.1.1. Impacts of climate change on agricultural climate resources and ecosystem

Impacts of climate change on the agricultural ecosystem have been studied widely in the natural science field.

J. T. Lee *et al*. (1994) forecasted the coming climate change and proposed countermeasures against it by comparing the meteorological condition of Korea during the period of 1931~1960 and that of the period 1961~1990 using warmth index (WI) and coldness index (CI) according to the Kira method, and analyzing the distribution of agricultural climate resources that significantly affected Korean agriculture and the changes in them.

B. R. Lee (1995) presented a systematic analysis of the impacts of climate change on agricultural ecosystem, using maps, by assessing the change of agricultural climate zones, preparing the agricultural climate index for each scenario, and analyzing the changes in cultivation period for each agricultural climate zone.

K. M. Shim *et al*. (2003) examined the types of meteorological disasters that affected Korea for the past 97 years (1904~2000) and analyzed the frequency of each type of meteorological disasters in each city and county that did damage to the crops for the last 10 years (1991~2000), in order to identify the regional characteristics and frequency of meteorological disasters.

S. D. Lee (2005) analyzed the impacts of climate change on ecosystem, by dividing them into the impacts on agricultural ecosystem, those on land ecosystem, those on biological diversity, and those on sea biology caused by the rise of sea level. He suggested adaptation measures through comprehensive analysis and estimate of the impacts of climate change on vegetation.

J. I. Kim (2007) analyzed major impacts and outlook of climate change, and meteorological disasters related to the climate change. This study prepared a list of preventive measures for such disasters as storm, heavy snow and heat wave. It also featured a disaster map, to present a disaster action system including evacuation of residents of the areas subject to disasters.

3.1.2. Analysis of long-term relationship between climate change and agricultural production

For a study to analyze the long-term relationship between climate change and agricultural production, J. H. Kim (1998) estimated the average annual yield of rice using a logistic function based on the SAS/ETS nonlinear model, and analyzed the impacts of cultivation factors on the average rice yield through regression analysis. Based on his estimation and analysis, he specified a model for determining average annual yield of rice and presented information for establishing the policy for rice production and grain demand-supply regulation.

Y. S. Lee *et al*. (2005) analyzed the trends in season change of average temperature and the changes in optimum temperature for rice to ripen over the last 30 years, so as to understand the vulnerability of rice to climate change. In particular, in order to estimate the full-blooming time for fruit trees, he calculated the time required using separate application formulas for the development rate (DVR) at which fruit trees approach their full-blooming time, and the development stage (DVS) when they fully bloom according to the rates. Furthermore, he examined the distribution of recent meteorological disasters in the agricultural sector, and presented the measures against meteorological disasters in the agricultural sector.

3.1.3. Impacts of climate change on the agricultural production

Y. H. Ju (1994) analyzed the changes in agricultural production caused by climate change in major countries such as USA, EU, Australia, Japan and Russia, using the crop yield examination circulation models used in advanced countries, the Goddard Institute for Space Studies (GISS) model of US Department of Environmental Conservation and the UK Meteorological Agency model, and presented the impacts of climate change on global agricultural production.

J. H. Kim and J. H. Lee (1996) estimated a logistic function using nonlinear model, to analyze the factors affecting the yield of general lowland rice, since 1965, taking into account such aspects as varieties, popularization, cultivation technology and meteorological conditions, and also identified the causes of stagnation in rice yield in the early 1990s.

Y. S. Lee *et al*. (2005) analyzed the relationship between fruit crop and meteorological factors, the seasonal demand-supply conditions of fruits and vegetables, and the impacts of meteorological factors on supply and prices of fruits and vegetables, using autoregressive distributed lag model, price flexibility function, combined method of least squares, yield function and cultivation area response function.

S. T. Yoon (2005) diagnosed the evidence of global warming based on the studies of global warming and climate change scenarios undertaken by several scholars. He estimated the expected climate change in Korea brought on by global warming and its impacts on the agricultural production of Korea, and presented the countermeasures against it.

H. J. Han *et al*. (2006) carried out a study to assess the impacts of climate change and to establish an adaptation system. To achieve this they presented the estimated quantity for rice crop for 2080 in comparison to the average annual yield of rice in 1971~2000, using the Crop Estimation through Resource and Environment Synthesis (CERES)-Rice model.

The Rural Development Administration (2007b) performed a series of studies to diagnose the blights and pests damaging each type of crop following the changes in crop cultivation areas and wintering environment, to estimate the agricultural productivity, and to develop new varieties that can adapt themselves to climate change. They undertook these studies in order to assess the impacts of global warming on the agricultural environment and present adaptation measures.

K. Y. Kim *et al*. (2008) and K. M. Shim et al. (2008) presented the results of systematic analyses of the impacts of climate change on agricultural environment, the changes in biological seasons and agricultural climate resources, and the subsequent changes in agricultural environment.

S. H. Lee *et al*. (2008) presented the results of their experiments which analyzed the impacts of temperature rise on agricultural production by investigating the correlation between temperature rise and earing seasons and yields of rice and barley in Naju area, the impacts of temperature rise on the bearing rate, the sugar content and weight of pears, the blight in pepper plants and the number of days with precipitation.

3.1.4. Analysis of climate change using GIS

H. H. Suh (2003) estimated the changes in areas suitable for growing apples according to the degree of temperature rise, based on "a model for determining climatically suitable areas for growing apples" prepared by National Institute of Horticultural & Herbal Science. This model was itself based on Geographic Information System (GIS). He suggested that as temperature rose the areas suitable for growing apples moved from south to north, from coast to midland, from planes to mountains and from urban center to suburban areas.

S. J. Jeon (2007) analyzed the impacts of global warming on tangerine growth and quality and presented a map of tangerine growing area distribution affected by the climate change, based on GIS and "a model for determining climatically suitable areas for growing tangerines" prepared by Natural Institute of Subtropical Agriculture. He estimated the change in tangerine growing areas on the assumption of temperature rise so as to provide the basic data for establishing the mid/long-term development plan for future tangerine farming.

3.1.5. Studies on the agricultural sector's climate change adaptation measures

With regard to the countermeasures to be taken by the agricultural sector against climate change, S. H. Yoon *et al*. (2001) analyzed the impacts of climate change on the domestic and overseas agricultural ecosystem based on the climate change process and estimation scenarios presented by IPCC in 2001, and proposed the countermeasures for the Korean agricultural sector against climate change.

J. T. Lee (2007) analyzed the impacts of climate change on agriculture from the perspective of agricultural production environment including agricultural ecosystem, the temperature for rice ripening and changes in suitable areas for growing apples. Lee presented countermeasures against climate change with regards to the utilization of agricultural meteorological information and the mitigation of agricultural disasters, and the development of new varieties for adaptation.

H. J. Han *et al*. (2007) assessed the impacts of climate change and the vulnerability to it and proposed a plan to establish adaptation measures to climate change through their 3-year study project on assessment of the impacts of climate change and adaptation strategies. In this study, various fields were dealt with including water resources, the ecosystem, industry, health, maritime and fisheries. The agricultural sector was included in the ecosystem, for which the assessment of vulnerability of rice to climate change was attempted using the CERES-Rice.

Y. J. Kim, W. Y. Lee and J. N. Kim (2008) proposed countermeasures for each crop against climate change and a plan for role division among the stakeholders, based on the measurement of impacts of climate change on the arable and the fruit-growing sectors of Hwacheon County in Gangwon Province.

H. J. Han *et al*. (2008) from 18 research institutes in various sectors assessed the present conditions of adaptation to climate change and its results, analyzed the overseas trends and cases of adaptation and proposed mid/long-term implementation plans for each sector and a master plan for national adaptation to climate change. This study also proposed a climate change adaptation program for the agricultural sector, a role division among stakeholders, and the tasks for future adaptation research studies.

3.2. Overseas Studies

3.2.1. Analysis of the impacts of climate change

With regard to the assessment of impacts of climate change on the agricultural sector and the countermeasures against it, numerous overseas studies have been undertaken. Solomou and Wu (1999) and Khatri *et al*. (1998) analyzed how the overall agricultural production index of the European countries during the periods of 1867~1913 (UK) and 1870~1913 (Germany) was affected by the climatic variables such as precipitation and temperature, by applying the semi-parametric estimation method. According to their analysis, it was shown that temperature rise below the average temperature resulted in the increase in production but additional temperature rise over the average temperature reduced production.

Imairaijou (1983) proposed a formula for calculating the crop index to analyze the impacts of climate change on agricultural production, and measured the extent of meteorological factors' impacts on agricultural production using the crop index and the average annual yield. Vining (1989) analyzed the impacts of individual factors of weather such as the amount of sunlight, temperature, precipitation, humidity and wind speed on the physiology and production of agricultural and livestock products, and Francisco and Guise (1988) analyzed the impact of precipitation on the crop yield.

Chang (2002) estimated the potential impact of climate change on Taiwan agriculture, using a 2-step approach. In the first step, he estimated a yield response function for major crops under climate change and in the second step, he applied the price-endogenous mathematical programming model based on the estimated function.

Wang and Mauzerall (2004) estimated the economic damages by the change in agricultural production and the reduction in crop yield which were expected to be caused by ozone change between 1990 and 2020, for the three Asian countries - Korea, China and Japan, using ozone and other chemical tracer models.

Concerning the impact of climate change on the agricultural sector and the adaptation measures, Adger (2006) estimated the temperature change for 2100 using the analysis data from IPCC and proposed the estimated average annual yields of major crops (rice, corn, wheat, soybean, etc.) for each continent based on that estimation.

Deschenes and Greenstone (2007) analyzed the impact of climate change on agricultural revenue, and also proposed the estimated impact of a temperature rise, following a prolonged global warming, on the agricultural revenue of California, USA. In particular, this study proposed a new framework for economic analysis of the impact of climate change on the agricultural sector using a hedonic function.

Tubiello and Fischer (2007) analyzed the change in production of major crops (wheat, rice, corn, millet) in major areas around the world for every 10 years between 1990~2080 in connection with a temperature rise due to global warming, using the ecological economic model. Most especially, their result emphasized that food security will become a critical matter for certain developing countries as food shortages might be exacerbated in some regions depending on the extent of climate change.

3.2.2. Studies on the climate change adaptation measures

Adaptation measures for the agricultural sector against climate change have been actively studied in Canada, USA and Japan.

Smit and Skinner (2002) distinguished the options for agricultural adaptation to climate change, and classified the adaptation options for each characteristic. They summarized the studies on the adaptation options open to Canadian agriculture, and classified them into four major categories: research and development, government programs and insurance, production methods, and financial management for farms.

Ford and Smith (2004) developed a conceptual model for vulnerability and proposed an analytic approach to measure the meteorological risk in the northern Canada as well as possible countermeasures against those risks. Through case studies, they reported the extent of current exposure to the risk in detail and identified the characteristics of adaptive capacity.

Burton and Lim (2005) reviewed the prospect of global agriculture’s adaptation to climate change, stating that continuous success of adaption depended on the actions taken by the nations in the context of ever-changing technology and the global trade liberalization.

Agriculture/Biology-specific Industrial Technology Research Institute (2006) summarized the results of research done over the past few years in the related fields, to diagnose the impacts of global warming on rice, barley, beans, vegetable, fruit tree and livestock sectors in each region and propose countermeasures for each item.

Finger and Schmid (2007) analyzed the impacts of climate change on the production of corn and winter wheat, using the ecological physical model and the expected utility function, in which the risk of climate change is considered. This study also carried out the yield analysis that took the crop-producing households' responses to the risks of climate change and subsequent price change.

Reid *et al*. (2007) introduced the vulnerability approach and analyzed the adaptive capacity of the agricultural sector to climate change, focusing on the farms in Ontario, Canada. In particular, they identified the meteorological risks to which the farms were subject and investigated the farm households' responses to the risks. The result suggested that the weather and climate were important factors on which the farming depended on for farm operation and decision- making and to which many internal external factors were related.

The Agriculture, Forestry and Fisheries Technology Council under the Ministry of Agriculture, Forestry and Fisheries of Japan (2007) estimated the change in rice yield and proposed a comprehensive strategy for the agricultural, forestry and fisheries sector of Japan to prevent, mitigate and adapt itself to global warming, using the CERES-Rice model based on the results of analyses carried out in each field.

Tarleton and Ramsey (2008) analyzed in the social, political and economic context of Manitoba, Canada the risks and opportunities posed to local farms by climate change and the adaptation measures for those farms. Through their study, it was shown that the farms had adapted well to the risks related to global warming such as drought, flood, temperature changes in summer and winter, and changes in the cultivation period and their adaptation was mostly frequently shown in their cultivation types and the changes in varieties they cultivated.

3.3. Differences from the Preceding Studies

The preceding studies on climate change undertaken for the agricultural sector have been sporadic technological research, focusing on establishing the countermeasures against climate change and reducing the related greenhouse gases. In comparison, this study focuses on analyzing the impacts of climate change and proposing the possible countermeasures in the economical and political aspects, based on scientific research results.

The first-year study applied the recent data from domestic and overseas studies and from the related experts in order to ensure an in-depth reliable analysis of the impacts of climate change on the agricultural sector. The analysis of mid/long-term prospect of climate change in Korea was made possible with the help of National Institute of Meteorological Research (Dr. W. T Kwon and Researcher Y. M. Cha). The mid/long-term prospect of climate change on the national rice production of Korea was estimated by Dr. K. M. Shim from National Academy of Agricultural Science, using the Crop Estimation through Resource and Environment Synthesis (CERES)-Rice model in which meteorological environment and crop growth were linked to each other. Analysis of the impacts of climate change on the agricultural sector, and specifically the analysis of the change in agricultural productivity that applied both non- parametric and quasi-parametric methods, were carried out by Prof. O. S. Kwon of Seoul National University. For a model for analyzing the economic impacts of climate change on the agricultural sector and a case study on the economic impacts of climate change on the US agricultural sector, Prof. Mendelssohn from Yale University, who first developed the Ricardian Model and had actively led the researches on this field, joined this study as a co-researcher.

For the second-year study, technological researches for analyzing the impacts of climate change and establishing the adaptation measures were consolidated. An attempt was made to maximize the result of this study by making the most of joint research undertaken by the domestic and overseas experts with regards the impacts of climate change on the agricultural sector. For an analysis of the impacts of meteorological disasters on the agricultural sector, Prof. T. G. Kim from Kyungpook

Table 1-1. KREI Forum on Climate Change

	Date (Place)	Main Topics
1st Forum	April 23, 2009 (Grace Hotel in Gwacheon)	· 3 articles - Policies on Climate Change (C. G Kim, KREI), A Direction of Science and Technology Researches (D. B. Lee, NAAS), and Establishment of a Resource Circulation Type Livestock System (H. S. Kang, National Institute of Animal Science) - were presented and discussed.
2nd Forum	May 21, 2009 (KREI)	· Simulation Analysis of Rice Growth Adapted to Climate Change using ORYZA2000 (C. G. Lee, National Institute of Crop Science)
3rd Forum	June 23, 2009 (Jeju Center for Global Warming)	· Adaptation Measures for the Agricultural Sector against Climate Change (C. G. Kim, KREI), A Study on Adaption of the Agricultural Sector to Climate Change (H. H. Suh, Center for Global Warming)
4th Forum	July 7, 2009 (KREI)	· Utilization of Electronic Weather Maps for the Agricultural Sector's Adaptation to Climate Change (J. I. Yoon, Kyunghee University)
5th Forum	September 3, 2009 (KREI)	· Impacts of Climate Change on Agricultural Production and Countermeasures against It (E. Y. Cho, Sookmyung University)

National University contributed his article on it. A simulation analysis of rice production for climate change adaptation measures was carried out by Dr. C. G. Lee from National Institute of Crop Science using ORIZA2000 model. For the second-year study in particular, The ‘KREI Forum on Climate Change in Agricultural Sector’ was organized (April 23, 2009) in which academic circles, related organization and experts participated to ensure consolidated studies, extended information exchange, and viable countermeasures. The KREI Forum held seminars five times.[1]

4. Study Methods

First of all, in order to analyze the impacts of climate change on the agricultural sector and to establish countermeasures to ameliorate these impacts, a review was undertaken of the domestic and overseas academic literature. Domestically, publications and research reports by such concerned organizations and researches institutes as The Ministry of Food, Agriculture, Forestry and Fisheries, The Rural Development Administration, The National Academy of Agricultural Science, The Korean Institute of Environmental Policies, and The National Institute of Meteorological Research were reviewed. Additionally, in order to understand the international trend of research studies in this field, the related literature from major countries such as Japan, USA, Australia and China, as well as the EU bloc and international organizations such as the IPCC, the OECD and the FAO were also reviewed.

[1] Data announced in “KERI Forum on Climate Change in Agricultural Sector” was published as a separate brochure to be used as a reference when looking for possible countermeasures against climate change in the agriculture sector (compiled by C. G. Kim and H. K. Jeong, 2009).

To analyze the impacts of climate change and formulate the required countermeasures, a variety of analytical methods were applied:

First, the questionnaire for the farmers was used to understand their awareness of climate change and their ideas of adaptation measures against climate change.

Second, the Parks Method, an auto-regression model using panel data, was used to analyze the impacts of meteorological disasters on the agricultural sector.

Third, a quantitative analysis method for the logistic function estimation of rice yield was applied to analyze the impact of meteorological factors on agricultural production.

Fourth, a weather-crop response function was established and nonparametric kernel analysis and quasi-parametric estimation method were used to assess the impacts of climate change on agricultural productivity.

Fifth, the Crop Estimation through Resource and Environment Synthesis (CERES)-Rice model was used to estimate the mid/long-term prospects for the impact of climate change on rice production.

Sixth, the ORYZA2000 program, as developed jointly by International Rice Research Institute and Wageningen University of Netherlandss, was used to analyze the impacts of climate change adaptation measures on crop cultivation.

Seventh, the agricultural census data (1965, 1970, 1980, 1995, 2000, and 2005) was analyzed to gain an understanding of the actual conditions and hence the prospect of changes in the production areas of major crops. GIS methodology was adopted to present the trends and prospects of those changes using actual maps.

Eighth, a Ricardian Model based on the hedonic function for farm households' assets was used to analyze the impacts of climate change on the agro-economy.

Ninth, the expected utility model was used and the quantity response function was calculated in order to analyze the farmers' decision making under the risks and uncertainty of climate change.

Tenth, the Analytic Hierarchy Process (AHP), which took into consideration such assessment criteria as efficiency, effectiveness, feasibility, and acceptability by farmers, based on the expert questionnaires, was used to determine how best to prioritize the adaptation options of the countermeasures against climate change.

To gather the experts' opinions and exchange information about the research results on climate change, researchers in this project actively attended international academic conferences concerned with climate change and thesis presentations and discussions at international organizations. Dr. Chang-Gil Kim, the principal investigator, attended the international academic conference on climate change held in Egmond, Netherlands (March 10~12, 2009) where he presented a theme paper and participated in discussions. Dr. Chang-Gil Kim also presented the impacts of climate change on Korean agriculture and the adaptation measures at the 28th Joint Working Party (JWP) of the OECD Agriculture and Environmental Policy Committee held in Paris, France (July 1~3, 2009). The opinions voiced by member countries on this occasion are included in this report. In addition, Dr. Chang-Gil Kim attended the R'09 Twin World Conference on Resource Management held in Nagoya, Japan (September 14 ~ 15, 2009), to present the agricultural sector's strategies to mitigate and adapt itself to climate change.

5. Composition of the Report

Analysis of the impacts of climate change on the agricultural sector and the countermeasures was a 2-year study project. The first-year of study focused on analyzing the impacts of climate change, while the second-year study was undertaken primarily for complementing the analysis of the impacts, categorizing the adaptation policies for the agricultural sector and developing the list of countermeasures <Figure 1-1>.

This Report is a general report that contains the results of the second-year study. It includes the main ideas of the analysis of the impacts of climate change, carried out in the first-year study. The report on the second-year study consists of eight chapters.

Chapter 1 “Introduction” describes the need for the study, the purpose and scope of the study, the preceding studies and the study methods:

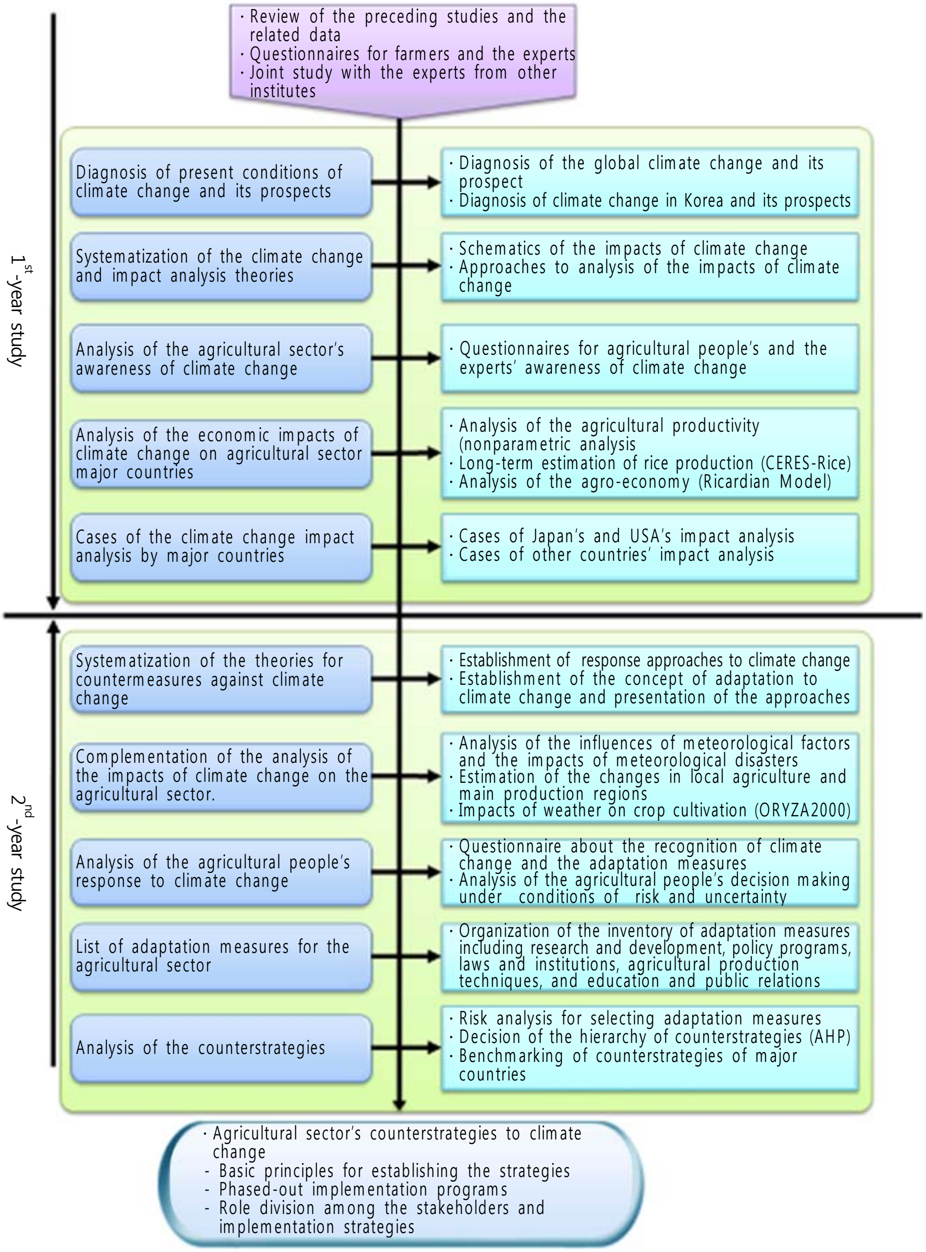
Chapter 2 describes the present conditions and prospects of climate change, by diagnosing and estimating the global climate change, based on the IPCC’s estimation of climate change. It also diagnoses and estimates the actual conditions of climate change in Korea, using the climate change data analyzed by such institutes as The National Institute of Meteorological Research, The National Academy of Agricultural Science and The Korea Institute of Environmental Policies.

Chapter 3 systemizes the basic concepts and analysis theories related to the agricultural sector’s responses to climate change. As approaches to responding to climate change, it presents the basic frameworks of mitigation and adaptation. It summarizes the theories for analyzing the impacts of climate change. In addition, it presents the concepts of applicability and adaptive capacity to climate change and the types of adaptation and approaches to climate change.

Chapter 4 describes the results of the analysis of the impacts of climate change on the agricultural sector, the related agricultural ecosystem and agricultural production. It also deals with the results of analyzing the shift in main production regions of major crops and the economic impacts of climate change on the agricultural sector.

Chapter 5 presents the results of the questionnaire research which concerned the farmers’ response to climate change, their awareness of climate change, and their adaptation to climate change. In addition,

Figure 1-1. Flowchart for the study for formulating countermeasures against climate change



chapter 5 describes the results of the analysis of the farmers' decision making under the risks and uncertainty of climate change, based on the expected utility model.

Chapter 6 analyzes the impacts of climate change on the agricultural sectors of major countries and how they have responded to climate change, taking the examples of Japan,, UK, Australia and China. The EU bloc was another example.

Chapter 7 describes the agricultural sector's countermeasures against climate change, presenting master plans and implementation strategies for adapting to climate change.

Lastly, Chapter 8 presents the summary and conclusion of this study, together with the limitations of the study.

Present Conditions and Forecast of Climate Change

In order to analyze the impact of climate change on the agricultural sector, it is necessary to understand the present conditions of climate change and estimate the future conditions. Chapter two diagnoses global warming, a representative sign of global climate change, to arrive at a correct understanding of the present conditions of climate change and make mid/long-term estimates. It also estimates the impacts of possible climate change according to each climate change scenario and then examines the impacts of temperature rise on each sector, based on the IPCC Fourth Assessment Report.

The present condition of climate change in Korea is diagnosed based on the analyses of abnormal weather conditions, including temperature and precipitation, undertaken by The National Institute of Meteorological Research (NIMR) and The Rural Development Administration (RDA). The long-term estimation of temperature and precipitation to the year 2100 is calculated using the values estimated in the A2 Scenario and A1B Scenario prepared by NIMR.

1. Diagnosis and Forecast of Global Climate Change

1.1. Present Conditions of Global Warming

Climate refers to the long-term variation in the atmospheric conditions of a specific region or regions, and thus climate change means a gradual change in the climate system, both by natural and artificial causes. Climate change is caused by changes in each component of the climate system such as the atmosphere, hydrosphere, biosphere, cryosphere and lithosphere and/or by complicate interactions among those components. The causes of climate change are largely divided into natural causes and artificial causes. Natural causes are attributed to changes caused by variations in solar activity, changes in sea water temperature, ice cap distribution, westerly waves and atmospheric waves as well as the incidence of volcanic eruptions. On the other hand, artificial causes include carbon dioxide emission from the production activities of industry and agriculture, deforestation, acid rain and the destruction of the ozone layer by Freon gas, with global warming being caused by the increase of greenhouse gases, with carbon dioxide being representative of a greenhouse gas (Presidential Advisory Council on Education, Science & Technology: PACEST, 2007).

Global warming refers to the average increase of the Earth's temperature due to the greenhouse effect caused by carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbon (HFCs), perfluorocarbon (PFCs) and sulfur hexafluoride (SF_6).[2] Global warming, meaning a continuous increase of the Earth's temperature due to the greenhouse effect, started from the Industrial Revolution, as the Industrial Revolution brought about a rapid increase in fossil fuel consumption. Global warming has attracted growing international interest as the scientific knowledge of climate has gradually accumulated since the

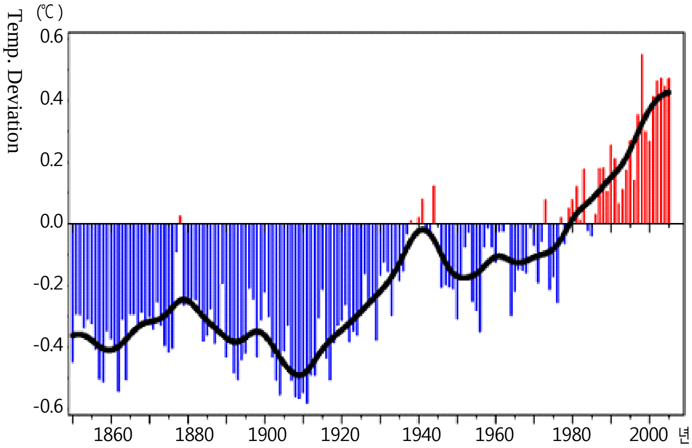
[2] The Greenhouse effect refers to a phenomenon where atmospheric elements such as water vapor and carbon dioxide prevent the solar energy that has reached the Earth from being radiated back into space, resulting in a rise in the average temperature of the Earth's atmosphere. This idea was first proposed by a Swedish chemist, Svante Arrhenius, in 1896 in a study in which he postulated that the increasing the carbon dioxide concentration in the atmosphere might result in a temperature rise (E. S. Shin and H. S. Kim, 2005. p.103).

1970s and it has now been widely accepted by the scientific community that anthropogenic greenhouse gas emissions are the primary cause of global warming.

Global greenhouse gas concentrations, based on carbon dioxide, are estimated to have increased from 280ppm before the Industrial Revolution (1750) to 379ppm in 2005. According to the analysis of average temperature of the Earth (Climate Research Unit, 2006), the increase in the Earth's average temperature since the Industrial Revolution appears to have been much higher than the increase prior to the Industrial Revolution. Moreover, global warming has significantly accelerated since 1980; the average temperature in 1998 was shown to be 0.58℃ higher than the average temperature of 1960 ~ 1990 <Figure 2-1>. As shown in the figure, 11 of the 12 hottest years since 1850 were recorded as occurring in the last 12 years.

In order to achieve a systematic and reliable diagnosis of global warming, scientific analyses of climate change have been periodically collated by the IPCC since 1990. Thus far, the IPCC has published its

Figure 2-1. Temperature deviation from the average temperature of 1961~1990



Source: Climate Research Unit (2006)

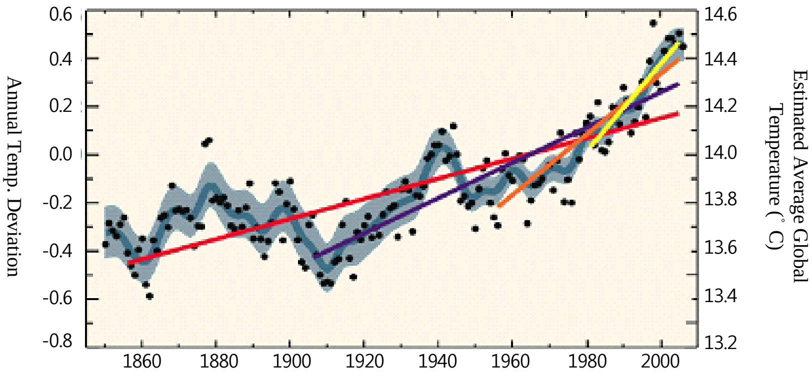
First (1990), Second (1995) and Third (2001) Assessment Report and its Fourth Assessment Report is being prepared given that Working Group I (Physical Science of Climate Change), Working Group II (Impacts, Adaptation, Vulnerability) and Working Group III (Mitigation of Climate Change) announced their reports in April 2007 (IPCC, 2007).[3]

The IPPC WGI Report, which is based on physical science, suggests that with regards to global warming the carbon dioxide concentration has increased about 1.4 times (to 379ppm in 2005) over the past 100 years when compared to the pre-industrialization concentration (280ppm). Accordingly, it is estimated that the average global temperature has risen 0.74℃ (0.56～0.92℃) over the past 100 years (1906~2005) <Figure 2-2>. Additionally, the estimates show that the average temperature of the Northern hemisphere in the late 20th century appears to be the highest in the temperature records since 1850 and that the temperature rise over the last 20 years is shown to be more than twice that of the past 100 years. This report states that there is no doubt that global warming is occurring in the climate system and affirms that greenhouse gas emissions is an artificial cause of global warming.[4]

3 The Intergovernmental Panel on Climate Change (IPCC) is an international organization founded in 1988. Its 4th Assessment Report, published in April 2007, involved 2,500 scientists around the world over a 6 year period. 130 countries acknowledged the validity of the Report (Presidential Advisory Council on Education, Science ＆ Technology, 2007).

4 The IPCC 3rd Assessment Report (2001) estimates that the average global temperature has risen by 0.6℃ over the past 100 years and that this may have been due to artificial causes. However, the 4th Assessment Report uses more assertive expressions.

Figure 2-2. Average global temperature and change trend



As global warming continues, the temperatures at the North Pole and the South Pole have risen, accelerating the rate at which the ice cap is melting, shortening the ice-breaking period in the polar lakes and thus leading to a significant rise in the sea level. Furthermore, global warming causes extreme climatic phenomena such as more severe floods, droughts and heat waves, thereby increasing the occurrence of natural disasters worldwide (Korea Meteorological Administration: KMA, 2008b).[5]

1.2. Current Conditions and Forecasts of Global Climate Change

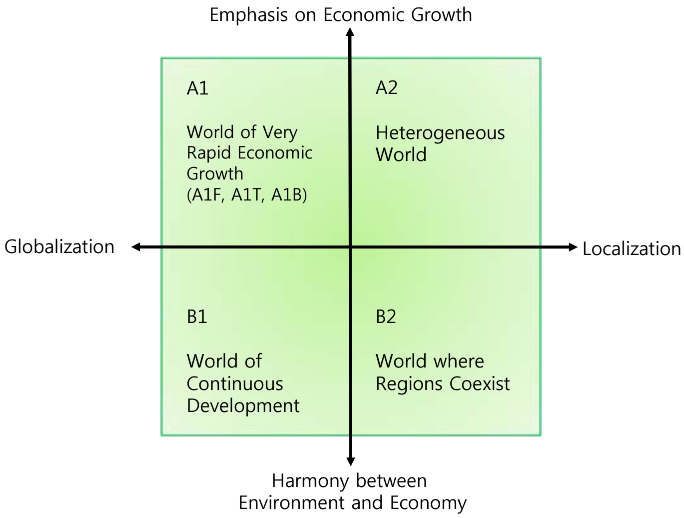
Global climate change is affected by various factors such as regional characteristics, socioeconomic variables and meteorological variables. The IPCC Assessment Report provides a number of greenhouse gas

5 A few example of natural disasters caused by global warming include a flood in China in 1995, the inundation of the Rhine in 1997, a flood in eastern Europe in 2000, a flood in Mozambique and in Europe in 2000, and a flood in Bangladesh in 2004.

emission scenarios. Different assumptions, related to demographics and socioeconomic development, are used in each scenario and thus each scenario arrives at a different future greenhouse gas concentration. The Special Report on Emission Scenario (SRES) presents four main scenarios (A1, A2, B1, B2) and three other scenarios (A1F, A1T, A1B) which are modified according to technological variable employed in the A1 scenario <Figure 2-3>.

The A1 scenario assumes very-rapid economic growth, in which the rapid growth of global economy and population peaks in 2050 and declines thereafter. It also assumes that new, more efficient technologies are introduced. The A1 scenario is split into three, each of which makes different assumptions on the future development of energy technology. The three scenarios are the fossil intensive scenario (A1F1), the non-ossil energy scenario (A1T), and a balanced-energy source scenario (A1B)

Figure 2-3. Conceptual diagram of scenarios for estimating climate change



The A2 scenario assumes a heterogeneous world with a high population growth rate, a low economic growth rate, and the most diversified, but slowly developing, technologies.

The B1 scenario assumes the same population growth rate as that of the A1 scenario but with a lower economic growth rate. In this scenario, the economic structure changes toward a service and information economy and sustainable development is pursued with an emphasis on clean and resource-efficient technologies.

The B2 scenario assumes a world where regions coexist with each other in harmony. This scenario assumes an intermediate level of population and economic growth, between A1 and B1, and focuses on regional solutions for economic, social and environmental sustainability.

The average global temperature by the end of the 21st century (2090~2099) is estimated to rise by 1.1 ~ 6.4℃ compared to the period from 1980~1999, with a rise in sea level by 18~59cm due to heat expansion and the loss of land glaciers <Table 2-1>.

Estimates of future climate change vary greatly from scenario to scenario. In the continuous development scenario (B1), in which the environmental conservation and the economic development are compatible

Table 2-1. Estimated temperature rise for 2100 in each scenario

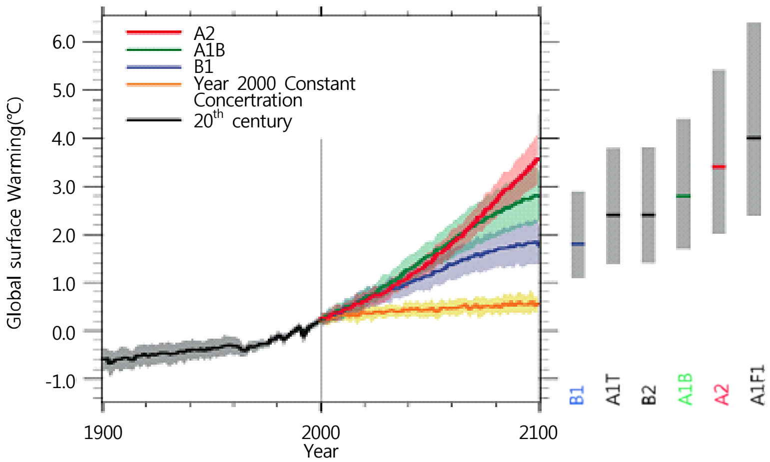
Scenario	Temperature Change (℃)		Sea Level Rise (cm)
	Optimal Estimation	Expected Range	
Very rapid economic growth (A1FI)	4.0	2.4 ~ 6.4	26 ~ 59
Non-fossil intensive energy (A1T)	2.4	1.4 ~ 3.8	20 ~ 45
Balanced-energy source (A1B)	2.8	1.7 ~ 4.4	21 ~ 48
Heterogeneous world (A2)	3.4	2.0 ~ 5.4	23 ~ 51
Continuous development (B1)	1.8	1.1 ~ 2.9	18 ~ 38
Coexistence of regions (B2)	2.4	1.4 ~ 3.8	20 ~ 43

Source: IPCC (2007), p.8.

with each other, the temperature change is estimated to be about 1.8℃ (1.1~2.9℃), while a rise of about 4.0℃ (2.4~6.4℃) is expected in the very rapid economic growth scenario (A1) with its emphasis on fossil-intensive energy sources. By 2030, however, it is estimated in all scenarios that temperature will rise at a rate of 0.2℃ for every ten years <Figure 2-4>.

According to the IPCC Fourth Assessment Report, the impact of global warming will greatly vary according to the degree of temperature rise and the latitudinal location. When the temperature rise is less than 1℃, damage due to natural disasters such as water shortages and floods are predicted in some areas. However, the report warns that if the temperature rises by 2~3℃, most areas will be subject to damage due to natural disasters and the future survival of about 20~30 percent of animals and plant species will be endangered. Furthermore, if the temperature rises by more than 3℃, significant economic and environmental damages are to be expected, including aggravated water shortages, ecosystem destruction, reduced food production, and the increased occurrence of diseases.

Figure 2—4. Estimated trend of temperature rise in each scenario



Source: IPCC (2007).

Though global warming has negative impacts in general, it is also suggested that it may have some positive impacts to a certain extent. One of the positive impacts is that the higher carbon dioxide concentrations serves to increase photosynthesis, in much the same way as fertilizer application results in the increase in crop growth or quantity. This positive impact is called the “CO_2 fertilization effect.” It was once reported that if CO_2 concentration increased by 200ppm from the present concentration, there would be an increase of about 10~ 15% in the quantity of agricultural crops, such as wheat and soybeans harvested (Ueji, Seino, and Minami. 2005).

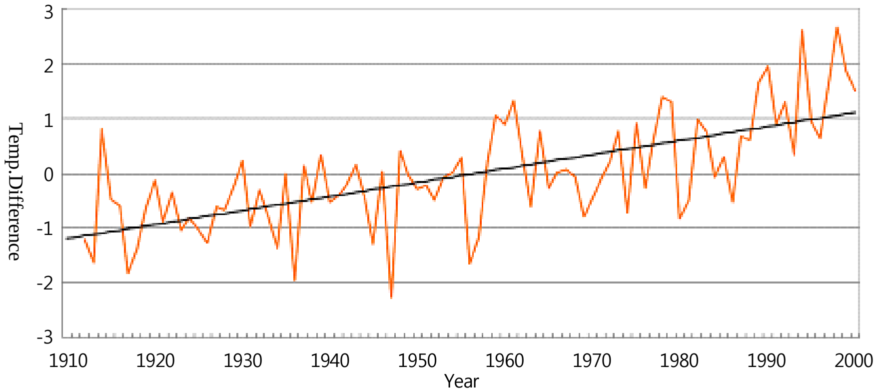
2. Present Conditions and Forecast of Climate Change in Korea

2.1. Present Conditions of Climate Change in Korea

2.1.1. Temperature change

Korea belongs to the temperate climate zone located in the Far East area of the Northern hemisphere, and is subject to four distinct seasons; spring, summer, autumn and winter. The average annual temperature is 12.4℃ nationwide, but this varies widely from 6.4℃ in Daegwanryong to 16.2℃ in Sergio. Except for mountainous areas with high temperature deviations, the average annual temperature normally ranges from 10 to 16℃. As suggested in <Figure 2-5>, the average temperature of Korea has risen by 1.5℃. This measurement is based on an analysis of meteorological observations recorded until 2000 from when modern meteorological observation first started in Korea in 1904, and is higher than the global average temperature rise of (0.74 ± 0.18℃). The main causes of the temperature rise include global warming and urbanization,

Figure 2–5. Trend of the average annual temperature difference in Korea



Source: NIMR (2006), p.4.

with urbanization accounting for 20~30% of the temperature rise (W. T. Kwon, 2005; National Institute of Meteorological Research (NIMR), 2006).

With regard to climate change, the change of seasons has also become noticeable. In the 1990s winter was 19 days shorter, when compared to the 1920's, but summer 16 days longer. In general, it appears that summer and spring have tended to become longer and winter and autumn shorter <Table 2-2>.

Table 2–2. Changes in the length of summer and winter

		Length	Increase/decrease in 1990 from 1920
Summer	1920s	Jun. 03 ~ Sept. 21	16 days increased
Summer	1990s	May 24 ~ Sept. 27	
Winter	1920s	Nov. 21 ~ Mar. 18	19 days reduced
Winter	1990s	Nov. 29 ~ Mar. 08	

Note: An average daily temperature of 5℃ or lower is defined as winter, that of 20℃ or higher as summer, and the periods in between as spring and autumn.

Source: NIMR (2006).

Based on meteorological observations at 60 points nationwide, summer temperatures between June and August rose from 23.7℃ in the 1960s through 23.5℃ in the 1970s, 23.8℃ in the 1980s and 23.9℃ in the 1990s to 24.0℃ since 2000s, recording a 1% rise over the past 40 years. However, the temperature rise in winter, between December and February, was recorded as 1.3C in the 1960s, 2.2℃ in the 1970s, 1.9℃ in the 1980s, 3.1℃ in the 1990s, and 3.2℃ in the 2000s; showing about 140 percent rise over the past 40 years <Table 2-3>. In other words, it implies that global warming in Korea has continued to worsen since the 1960s, with this phenomenon being more conspicuous in winter than in summer.

Table 2−3. Changes in the average temperatures of summer and winter for the past 40 years

Unit: ℃

	1960s (A)	1970s	1980s	1990s	2000s (B)	Difference b/w A/B
Summer	23.7	23.5	23.8	23.9	24.0	1.01
Winter	1.3	2.2	1.9	3.1	3.2	2.46

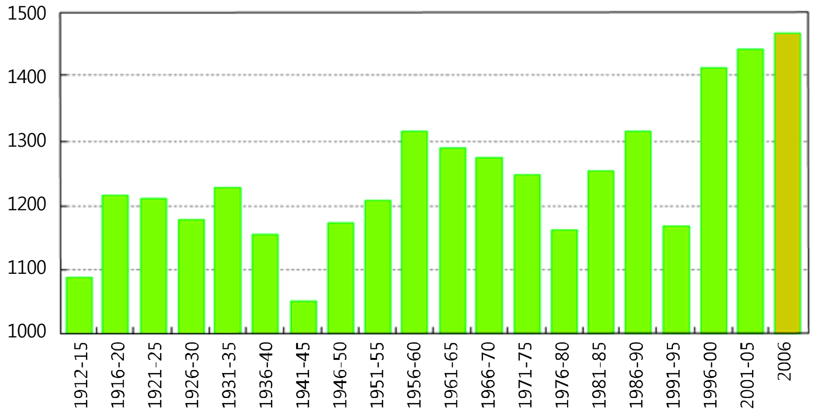
Source: K. M. Shim *et al*. (2008).

2.1.2. Changes in precipitation

Over the past 100 years, precipitation has varied from year to year, but in general the trend has been for increased rainfall. Precipitation in the early 1910s, early 1940s, late 1970s and early 1990s was smaller than during other periods. Average annual precipitation for the last 30 years (1977~2006) has shown a tendency to increase, with some fluctuations around 1,200mm <Figure 2-6>.

Average precipitations for the past four decades in Korea were 1,272㎜ in the 1970s, 1,329㎜ in the 1980s, 1,339㎜ in the 1990s and 1,470㎜ in the period from 2000 to 2006. This represents a recorded increase of 16% between the 1970s and the 2000-2006 periods. With

Figure 2-6. Trend of the precipitation change in Korea



Source: H. J. Han *et al.* (2007), p.105.

regards seasonal changes, the precipitation in the summer was 598㎜ in the 1970s, 657㎜, in the 1980s, 697㎜ in the 1990s and 761㎜ in the 2000s. This represents a recorded increase of 27% in summer precipitation between the 1970s and the period from 2000 to 2006. However, precipitation in the winter decreased by 10% from 132㎜ in the 1970s, to 125㎜ in the 1980s and 110㎜ in the 1990s and 120㎜ in the period from 2000 to 2006. <Table 2-4>. As a result, the ratio of winter precipitation to summer precipitation, which was 4.5 in the 1970s, increased by 1.4 times to 6.3 in the period from 2000 to 2206,

Table 2-4. Changes in the precipitations in summer and winter over the past 40 years

Unit: ㎜

	70s (C)	80s	90s	2000s (D)	Ratio (C/D)
Summer (A)	598	657	697	761	1.27
Winter (B)	132	125	110	120	0.90
Ratio (A/B)	4.5	5.3	6.3	6.3	-
Annual Precipitation	1,272	1,329	1,339	1,470	1.16

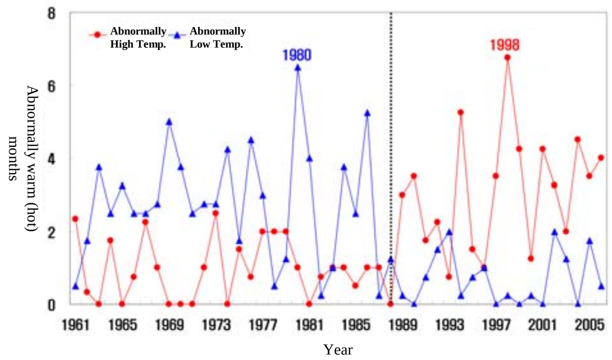
Source: K. M. Shim *et al.* (2008).

increasing the possibility of severe heavy rain in summer. The number days with heavy rain, with the precipitation of 80㎜ or more, also increased from 2.1 days a year in the 1970s to 3.0 days in the 2000-2006 period, a recorded increase of 1.43 times. Furthermore, the reduced winter precipitation has led to a shortage of water in winter and in spring.

2.1.3. Abnormal weather

The World Meteorological Organization (WMO) defines abnormal weather as a unique climatic phenomenon occurring only once in every 25 years. For the past 46 years (1961~2006), the number of months in which abnormal weather conditions occurred in four areas; being Suwon, Gangneung, Daegu and Gwangju, shows a distinct difference between the period prior to 1988 and after. Before 1988, there were more months of abnormally low temperatures while there were more months of abnormally high temperature in the period after. Nineteen-eighty had the greatest number of abnormally cold months, at 6.5 months. On the other hand, 1998 had the greatest number of abnormally warm (hot) months, at 6.8 months <Figure 2-7>.

Figure 2-7. Number of the months of abnormally high/low temperature (1961-2006)



Source: K. M. Shim *et al.* (2008), p.47.

Of the types of meteorological disasters occurring between 1904 and 2000, drought was most frequent (5,169 days), followed by heavy rain, heavy snow, abnormally high temperatures, windstorms, abnormally low temperatures, typhoons, hail, and Yellow Sand, in descending order. With regards the duration of these meteorological disasters, drought lasted the longest (45.7 days), followed by abnormally high temperatures (7.8 days), abnormally low temperatures (4.0 days), heavy snow (2.6 days), Yellow Sand (2.5 days), heavy rain (2.4 days), typhoon (2.1 days), windstorms (1.8 days), and hail (1.5 days), again in descending order <Table 2-5>. Recently however, the incidence of abnormally high temperatures, abnormally low temperatures, and heavy rain are displaying a tendency to increase.

Table 2-5. Frequency of meteorological disasters in Korea in each decade (1904 ~2000)

	Drought	Heavy snow	Wind-storm	Hail	Abnormally high temp.	Abnormally low temp.	Heavy rain	Typhoon	Yellow sand	Total
1904-1910	-	1	2	-	-	2	7	3	-	15
1911-1920	1	6	7	4	-	2	23	5	-	48
1921-1930	1	2	5	4	1	2	6	7	-	28
1931-1940	1	7	6	4	-	4	7	10	-	39
1941-1950	30	23	46	-	-	3	54	5	-	161
1951-1960	29	37	75	9	4	5	53	10	3	225
1961-1970	14	27	19	7	4	10	56	9	3	149
1971-1980	14	32	31	6	3	13	65	8	1	173
1981-1990	13	33	52	9	20	39	56	18	4	244
1991-2000	10	29	3	5	29	30	50	19	15	190
Total	113	197	246	48	61	110	377	94	26	1,272

Source: J. K. Park *et al.* (2003), p.307.

2.2. Forecast of Climate Change in Korea

According to the mid/long-term forecast of climate change in Korea as made by National Institute of Meteorological Research (NIMR), it is estimated that temperature will rise steadily in Korea until 2100 and that precipitation will also increase overall, though there may be some fluctuations from year to year (NIMR, 2006).

Based on the A2 scenario which assumes a heterogeneous world in order to estimate future climate change, it is forecast that the temperature in 2020 will be 1.5℃ higher and precipitation 5 percent higher respectively when compared to the those of the past 30 years (1971~2000); the temperature in 2050 will be 3℃ higher and precipitation 7% higher; and temperature in 2080 will be 5℃ higher and precipitation 15% higher. In addition, the sea level in 2100 is estimated to rise by about 50cm from that of the past 30 years <Table 2-6>.

On the other hand, the A1B scenario, which assumes the balanced use of energy sources in forecasting the future climate of Korea, suggests that temperature of Korean at the end of the 21st century (2071~2100) will rise by 4℃ when compared to the past 30 years (1971~2000) and precipitation will increase by 17%.[6] If the climate change occurs as

Table 2-6. Forecast of the changes in temperature and precipitation of Korea (Based on A2 scenario)

	2020	2050	2080
Temperature rise (℃)	+1.5	+3.0	+5.0
Precipitation change (%)	+5.0	+7.0	+15.0
Sea-level change	Rise of 50cm or more by 2100		

Note: 1) The A2 scenario assumes that CO_2 emission will relatively rapidly increase and its concentration in 2100 will be 820ppm, while the B2scenario assumes CO_2 concentration of 610ppm.
2) The estimated numeric values for the change are the increase/decrease from the average values of 1971-2000.

Source: NIMR (2006).

6 NIMR estimated the climate change in the Korean Peninsular for the end of the 21st century (2071~2100) based on IPCC scenario, using the Atmosphere-Ocean Combination model (ECHO-G) and the Atmospherical General Circulation model (ECHAM4) developed by Max-Planck Institute of Germany (NIMR, 2009).

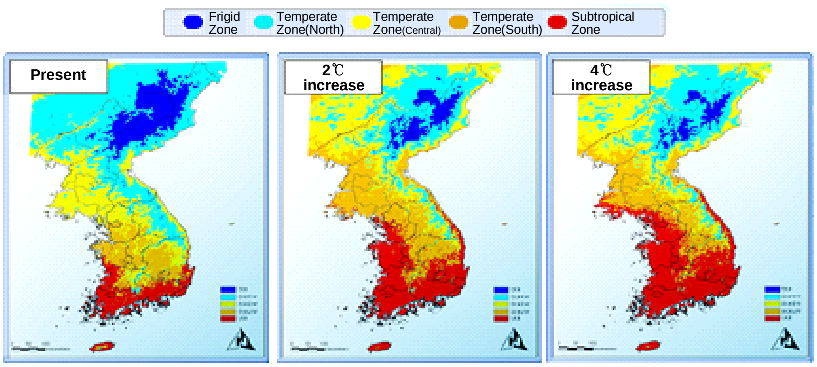
forecast by the A1B scenario, it is estimated that the frequencies of heavy rain and tropical nights will increase significantly (Korea Meteorological Agency (KMA, 2008b; NIMR, 2009).

Though precipitation has varied from year to year, without showing a distinctive trend, it appears that it has increased incrementally. Over the coming 30 years, it is forecast that precipitation will increase by about 5% when compared to that of the past 30 years.

The temperature rise is expected to result in a considerable change in the climatic zone of each region <Figure 2-8>. Assuming a temperature rise of 4℃, the subtropical climate zone, which currently ranges from Jeju Island to some areas on Korea's south coast, is expected to extend north to Chungcheong and Gyeonggi Provinces, with the exception of the Taebaek and Sobaek mountains and surrounding areas and also Gangwon Province (Y. A. Kwon *et al*., 2007).

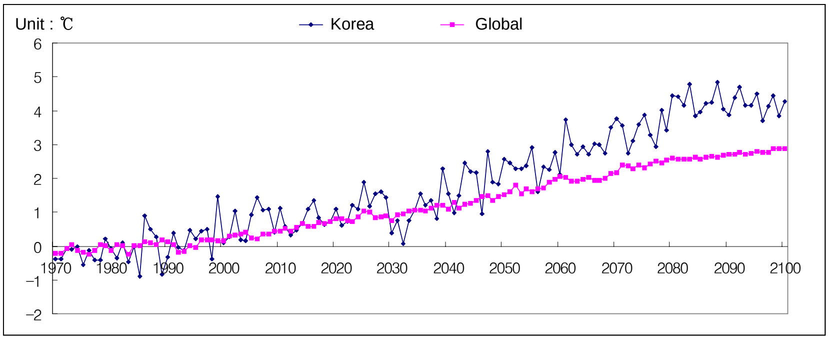
Based on the IPCC A1B scenario, which assumes a balanced use of energy sources, the NIMR mid/long-term forecasts cover the period 1860~2100 for the global climate and 1971~2100 for the Korean climate. As shown in <Figure 2-9>, the average temperature in Korea is forecast to be 1.5~2℃ higher than the average global temperature. The reasons for the higher temperature rise in Korea include the

Figure 2-8. Forecast of global warming in Korea



Source: NIMR (2009).

Figure 2-9. Forecast of temperature change based on the climate change scenario

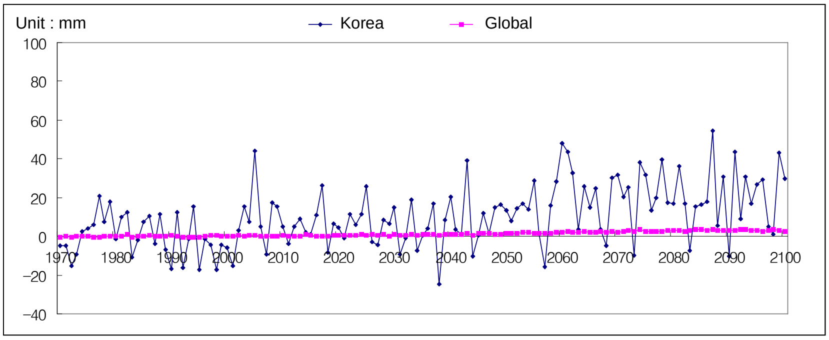


Source: NIMR (2008).

increase in carbon dioxide concentrations in Korea, and increases in population and green house gases in the neighboring Asian countries such as China (Y. M. Cha, 2007).

On the other hand, the forecast of precipitation change in Korea according to the climate change scenario (A1B) appears to be noticeably different from the forecast for the global precipitation change <Figure 2-10>. The main reason Korea is forecast to have greater changes in precipitation than the global average is because of the increase rainfall

Figure 2-10. Forecast of precipitation change based on the climate change scenario



Source: NIMR (2008).

probability which results from the increased vapor content, which in turn is caused by increased development in China and neighboring countries, which in turn increases the concentration of GHGs. (Y. M. Cha, 2007).

Theories about Countermeasures for the Agricultural Sector against Climate Change

Chapter 3

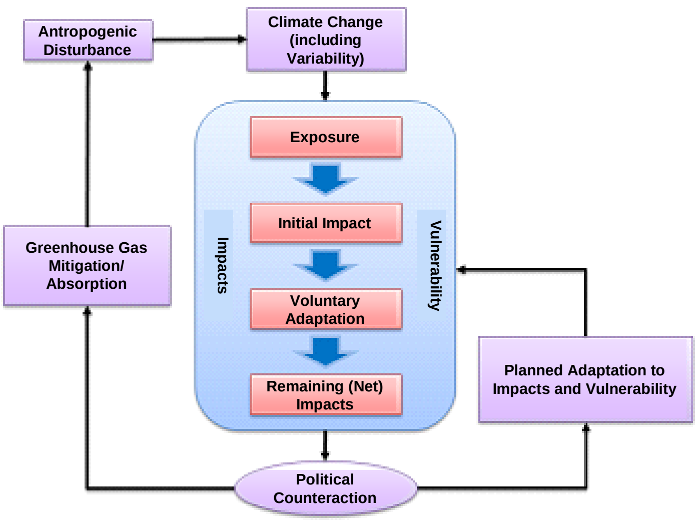
In formulating the countermeasures for the agricultural sector against climate change, several theories and methodologies are applied. Chapter three presents basic approaches to countermeasures against climate change, including both mitigation methods that deal with greenhouse gas reduction and absorption and also adaptation methods that recognize the inevitability of global warming and attempt to minimize its risks. In order to prepare countermeasures for the agricultural sector against climate change, it is first necessary to assess the impacts of climate change. With regarding impact analysis, the conceptual approaches and applicable methods to the flow of impacts of change are proposed here. As for the impact analysis methods, the integrated assessment model in which weather and crop are integrated, based on the ecoclimatic theory, the Hedonic price model (economic analysis model), and the programming simulation model are reviewed. With regards seeking out plans for use by the agricultural sector in adapting itself to climate change, the conceptual theories, including the concept of adaptive capacity and the types of, and approaches to, adaptation are presented.

1. Approaches to the Countermeasures against Climate Change

It is known that climate change has resulted from the disruption of the energy balance of the global climatic system. This disruption is caused by the increase of greenhouse gases and aerosol in the atmosphere, changes in land cover and solar radiation. Indeed, the results of scientific analyses suggest that global warming is very likely to be the resulted of human activities (IPCC, 2007). Countermeasures that the agricultural sector can consider in the face of the risks and challenges of climate change brought on by global warming are for the most part divided into mitigation methods that reduce the scale and rate of climate change by mitigating and absorbing the greenhouse gas emissions on the one hand and adaptation method that admits the inevitability of global warming, understands the impacts of climate change, and minimizes the damages it could cause <Figure 3-1>.

Once climate change starts, components of the climate system (such as atmosphere, hydrosphere, cryosphere, biosphere, lithosphere, etc.) are initially affected by the climate change as being exposed to it and attempt

Figure 3-1. Approaches to the countermeasures against climate change



Source: IPCC (2007).

to adapt themselves to that stimulus voluntarily. However, if the impact of climate change is huge, the climate system cannot handle the impact only through voluntary adaptation and thus planned adaptation that needs special measures should be attempted. If climate change still has an impact on the climate system even when the planned adaptation is in effect, it is said that there is a remaining impact. As there is a difficulty for the adaptation system for climate change to operate, efforts to reduce the scale of climate change through such mitigation measures as greenhouse gas reduction and absorption. Mitigation that reduces greenhouse gas emission contributes to avoiding, reducing and postponing various impacts of climate change. As mitigation of and adaptation to climate change are closely interrelated with each other, mitigation can be considered as belonging to adaptation measures in the long-term perspective. Therefore, adaptation to climate change is not optional but rather compulsory countermeasures against climate change.

Mitigation measures for the agricultural sector include improvement of cultivation methods through improved irrigation and fertilization control for the arable sector to suppress major greenhouse gases such as methane (CH_4) and nitrous oxide (N_2O), improvement of animal excretion treatment technologies in the livestock sector, and carbon fixing for the farmland soil.[7] In relation to the countermeasures for the agricultural sector against climate change, this study focuses on the adaptation plans based on the analysis of impacts of climate change.

[7] The measures to mitigate the climate change impact, focused on the reduction and absorption of greenhouse gas emission in the agricultural sector are suggested in the article by C. G. Kim *et al*. (2007, pp.97-118).

2. Approaches to Analysis of Climate Change Impacts

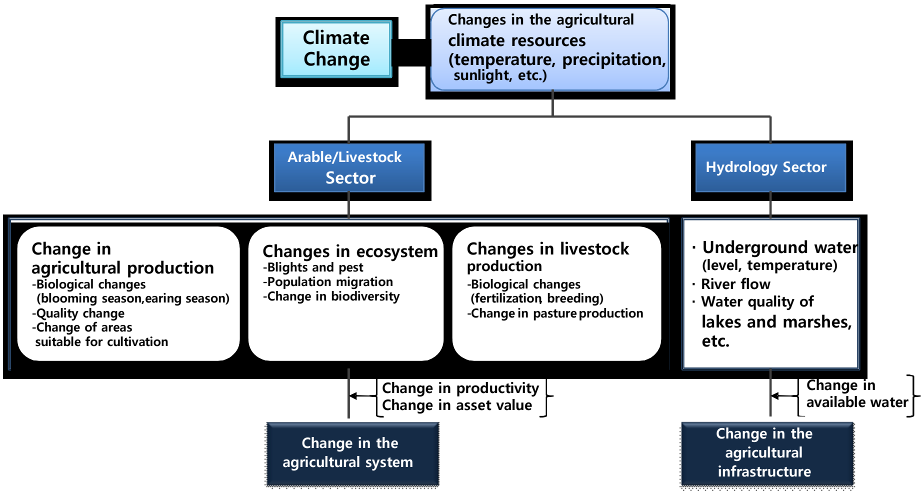
2.1. Conceptual Approach

Climate refers to an average meteorological phenomenon that has occurred repeatedly in a specific region or regions over a prolonged period of time. Agricultural production is carried out through selection of crops suitable for the climate of a specific region and the application of proper farming methods. Therefore, agriculture is a climate-dependent bio-industry with notable regional characteristics. Regional characteristics refer to the ecosystem characteristics determined by the climate of the region, and the climate is one of the representative physical characteristics of the region. Climate change disturbs the agricultural ecosystem that previously existed in a state of relative stability which by bringing about changes in agricultural climatic elements such as temperature, precipitation, and sunlight which in turn influences the arable, livestock, and hydrology sectors.

The flow of climate change impacts on the agricultural sector can be illustrated as shown in <Figure 3-2>. The climate change impact first manifested in the arable and the livestock sector are biological changes including the change of the flowering and earing seasons, quality change, and a shift in the areas suitable for cultivation.[8] Climate

[8] The impacts of climate change in the agricultural production are divided into the primary impacts and the secondary impacts. The primary impacts refer to the changes in the composition of atmosphere due to the increased greenhouse gases, which include the change in crop growth response and the change in energy and moisture balance in the farmland colony. The secondary impact caused by the change in agricultural climate resources affected by the primary impacts include the shift in suitable places of cultivation and the physical and chemical changes in the farmland soil (Y. E. Na. *et al.*, 2007, p.94).

Figure 3-2. Flow of the climate change impact on the agricultural sector



change affects the agricultural ecosystem, leading to an increase in blights and pests and causing population movement and changes to biodiversity. In the livestock sector, climate change brings about biological changes including fertilization and breeding and also affects the production of pasture.

Climate change also affects hydrology, including the underground water level, water temperature, river flow, and the water quality of lakes and marshes, by impacting precipitation, evaporation, and soil moisture content. In particular, the increase of precipitation by climate change leads to the increase of outflow while the temperature rise increases evapotranspiration, resulting in the reduction of outflow. In order to understand the quantitative impacts of climate change on water resources, a deterministic hydrology model, based on a general circulation model, is used.

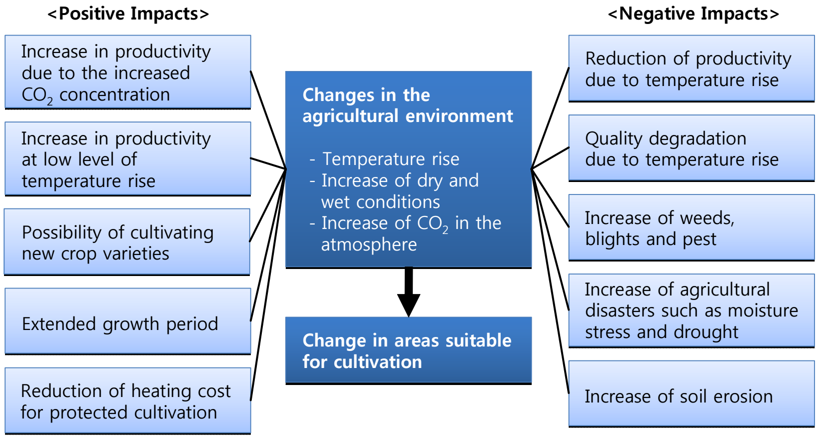
As illustrated above, climate change has wide ranging impacts on the rural economy including agricultural productivity, farm households' revenue and asset values, and also affects the agricultural infrastructure through changes in the water sources available for agriculture.

So far, the quantitative analyses of the impacts of climate change on the agricultural sector have been experimental, centering on the cross-sectional analysis. The experimental analyses are carried out on the basis of agro- economic simulation models. They are similar to the controlled experiments in which related variables are regulated, in that variables related to greenhouse gases such as temperature level and carbon dioxide emission level are regulated. In these experiments, the impact of climate change on agricultural production can also be estimated.

Agro-ecological zone analysis is carried out by using the crop simulation model (called the crop model for short) that tracks the changes in agricultural production and agro-ecological zones which result from climate change. Crop growth is determined by the interaction of three elements; the genetic characteristics of crop, the cultivation technology, and the environment (climate, soil, etc.). The crop model refers to a computer program that can estimate the crop growth and its quantity when these three elements are entered. Using the crop model, it is possible to estimate and analyze the agricultural production under climate change. The Crop Estimation through Resource and Environment Synthesis (CERES) model developed in the USA by integrating the crop model and the resource environment can assume a certain situation that is likely to happen and forecast possible results.

To analyze how, and to what extent, the change in temperature and precipitation following global warming affects the agricultural sector, various experiments, simulations and other research are carried out, both in laboratories and in the fields. As the impacts of climate change on the agricultural sector vary greatly with the related variables, it is difficult to stereotype certain analysis results. Therefore, what is attempted here is a simple classification of the impacts of climate change into positive and negative effects based on the results of the research done so far in the related fields <Figure 3-3>.

Figure 3-3. Potential impacts of global warming on the agricultural sector



The positive impacts of global warming include an increase in crop productivity due to the fertilization effect brought about by the increase in carbon dioxide concentration in the atmosphere, the expansion of the areas available for the production of tropical and/or subtropical crops (mango, avocado, atemoya, etc.), the expansion of two-crop farming due to the lengthened cultivation period, a reduction of damage to wintering crops by low temperatures, and a reduction in the of heating cost for agricultural crops grown in the protected cultivation facilities.

The negative impacts of global warming include reduced crop quantity and quality due to the reduced growth period following extreme temperature rise; reduced sugar content, crop discoloration, and reduced storage stability of fruit; increasing damage from weeds, blights, and harmful insects in agricultural crops; reduced land fertility due to the accelerated decomposition of organic substances; and the increased soil erosion due to increased rainfall.

In addition, each crop has different climate and environmental conditions requirements. So, if climate change induced temperature rise occurs, the boundary and suitable areas for cultivation move north and thus main areas of production also change. This change in the main areas of production would represent a crisis for certain areas but an opportunity for other areas, thus it cannot be classified explicitly as either a positive or negative impact.

As examined thus far, the impacts of climate change on the agricultural sector have ambivalent characteristics of positive impacts creating opportunities and of negative impacts causing crises. Therefore, it is very important to formulate adaptation strategies that can maximize the opportunities and minimize the crises, for the sound development of future agriculture.

2.2. Theories for Analyzing the Impacts of Climate Change

2.2.1. Analysis of the impacts of climate change on the agricultural production

For the quantitative assessment of the impacts of climate change, including temperature and precipitation, on agricultural production, the Integrated Assessment Model (IAM) is used. The IAM integrates scientific data and is applied mostly as a dynamic model that takes a long period of time into consideration. Typical climate-crop integration models include the CERES model and the climate change optimization model. The CERES-Rice model, for example, estimates rice growth and yield, using weather conditions, soil, cultivar parameters, and the cultivation-related information. As a model for making mid/long-term estimations of agricultural production under climate change, the CERES-Rice model is widely used for estimating rice production in the period from 2030~2100 (K. M. Shim *et al*., 2008).

ORYZA2000, a model for estimating agricultural production under climate change, was developed jointly by Wageningen University of Netherlands and International Rice Research Institute in order to perform a simulated analysis of rice growth in 2000. With the parameters set for crop and climate, this model can estimate the rice yield and the fertilization effect of carbon dioxide in each area under the impacts of climate change.

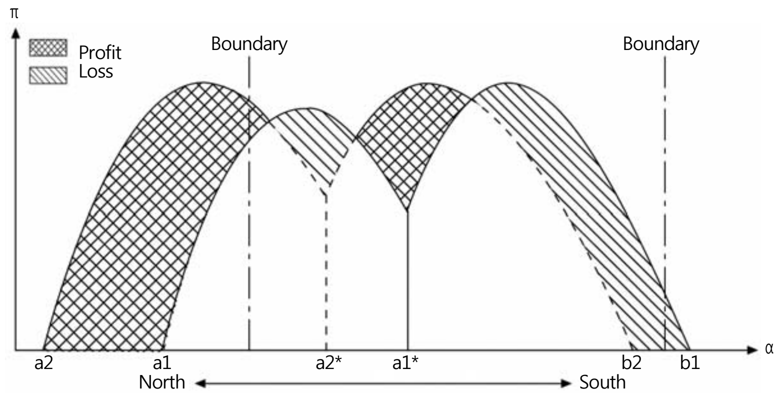
In addition to these models, there are other agricultural production estimation models that take climate change into consideration such as Agricultural Production System Simulator (APSIM), the dynamic crop model, the Erosion Productivity Impact Calculator (EPIC), and the CENTURY model, which estimates soil organism change, crop growth and carbon storage over a long period of time.

2.2.2. Analysis of the economic impacts of climate change on the agricultural sector

Economic analysis of the impacts of climate change is based on scientific facts, as scientific uncertainty is directly related to economic uncertainty. Economic impact analysis models separate the cultivation areas into two boundaries in consideration of the combined uncertainty and the spatial heterogeneity of variables (Zilberman, *et al.*, 2004).

For example, taking temperate crops and arctic crops as the vegetation and the Northern hemisphere as the cultivation area, the profit and loss of each of the two crops per unit area, both before and after climate change, can be illustrated as shown in <Figure 3-4>. As shown in the following figure, assuming that α is the distance from the North Pole, the temperate crops before climate change could be cultivated in b1~a1∗, while the arctic crops in a1∗~a1. After climate change, the temperate crops could be cultivated in b2~a2∗, whereas the arctic crops in a2∗~a2. According to this assumption, the soil in b1~b2 will most likely undergo desertification while the soil in a1~a2 will become arable. In other words, indicates the areas where economic losses occur due to desertification brought on by the impacts of global warming whereas indicates the areas where profits are made as more

Figure 3-4. Economic analysis model for the climate change impact



land becomes arable.

As climate change results in both profits and losses due to both increases and decreases of arable land, availability, it is not clear whether the overall impact of climate change is negative or positive. Therefore, other effects should be considered. Another effect is the "fertilization effect", which refers to the impact of increasing carbon dioxide on agricultural production, whereas the daylight effect refers to the phenomenon where agricultural yield decreases due to reduced daylight hours which accompany the shift north of cultivation regions. The pest effect implies that as weather becomes warmer, pests moves north and yields becomes smaller; the water effect refers to early snow melting and flooding due to global warming; and the protein effect refers to an effect where the increase in carbon concentration brings about an increase in agricultural production but also a reduction in protein production. Lastly, the settlement cost effect refers to the phenomenon where climate change requires additional costs for redistribution and settlement (a1~a2 → a1*~a2*).

2.2.3. Types of economic analysis models

In order to analyze the economic effects of climate change on agriculture, scientific in-depth analyses of the relationship between climate variables and crop variables and the relationship between climate and economic variables are needed. Most of the economic analyses concerning climate change impacts depend on the past data about climate variables and crop variables. However, it remains very difficult to carry out reliable economic analyses given that the phenomena that are likely to happen under the new conditions caused by temperature rise and precipitation change are significantly affected by many other variables. In reality, as climate change is analyzed assuming hypothetical changes several decades into the future, there are difficulties in setting future variables of price and profit and therefore several hypothetical conditions are set for analysis. Like this, there are considerable restrictions in analyzing the economic impacts of climate change. But, in general, the models used for economic impact analysis can be classified into four types:[9]

The first category is the agro-economic model, based on the crop response function and the production function, which is used for estimating the impacts of climate change on the agricultural yield and production cost. This model is subdivided into parametric method that sets specific functions and nonparametric or semi-parametric methods that do not use functions (Solomou and Wu, 1999). The agro-economic model is useful for analyzing the change in agricultural productivity and changes in farm revenue in various environmental conditions and areas under conditions of climate change.

9 Methodologies and models concerning the analysis of economic impacts of climate change on the agricultural sector are presented in detail in the articles by Chang (2002), Kurukulasuriya and Rosenthal (2003), Zilberman (2004), and Adger (2006).

The second category is the hedonic price model that reflects the impacts of climate change on asset values. This model uses the current asset values for estimating the price sensitivity of land value to climate parameters. Typical example of the hedonic price model that analyzes the economic impacts of climate change by relating the land value to the climate change is the Ricardian Model developed by Mendelsohn, Nordhaus, and Shaw (1994).[10]

The third category is the programming simulation model that estimates the optimum product supply and the demand for investment using information about climate and land utilization under hypothetical conditions. Using the agricultural sector model, it is possible to draw the balanced price, production level and profits of conservation tillage in various areas after greenhouse gas reduction (Adams, 1989; Chang, 2002). In particular, the stochastic simulation is applied for measuring the extent of changes in production and profitability in various areas by taking the concerned uncertainty and risk into consideration (van Asseldonk and Langeveld, 2007). In order to apply the mathematical programming model to the analysis of climate change impacts, various technical parameters about climate elements and environmental elements are needed. Therefore, it is used in connection with the climate-crop integration model.

10 Regarding approaches to the analysis of economic impacts of climate change, Mendelsohn, Nordhaus, and Shaw (1994) present the Ricardian model, pointing out that the crop response function and the production function approach are unrealistic given that they do not take adjustment and adaptation related to climate change into consideration. The Ricardian model approach is to measure the economic, climatic, and environmental factors from the land value, which is preferred to the traditional estimation methods as it automatically takes farmers' efficient adaptation to climate change into consideration. However, it has been argued that the Ricardian model has a shortcoming, which is that the adjustment cost is not considered in the relationship between climate change and profit from land.

The last category includes the Computable General Equilibrium (CGE) model and the Dynamic Integrated model of Climate and the Economy (DICE) that relate climate change to the agricultural production and the economic system (Lewandrowski and Schimmelpfennig, 1999; Cline, 2007). These models are utilized for estimating the macroscopic impacts of climate change on the growth of the agricultural sector and gross domestic product.

3. Approaches to Adaptation to Climate Change

3.1. Concepts of Adaptation and Adaptive Capacity

With regard to climate change, adaption has been defined in a number of ways. According to the IPCC, adaptation is defined as "adjustment in natural and human systems in response to actual or expected climatic stimuli and their effects." The UNFCCC defines adaptation as "regulating process of ecological and socioeconomic systems to reduce possible damages from actual and expected climate change, that is, actions taken to help communities and ecosystems cope with changing climate conditions."

As the adaptation process contributes to reducing the negative risks associated with climate change and provides opportunities to use climate change for positive effects, it plays an important role in mitigating the impacts of climate change. Adaptation includes both actions taken to directly mitigate the damages from climate and enhance future adaptive capacity and actions which contribute to indirectly mitigating the damages from climate change.

The implementation of adaptation should satisfy several conditions including economic strength, technology, information, infrastructure, institutions, and equity, which are referred to as the components of adaptive capacity. Sometimes, adaptation may be implemented for free or at low cost. But in most cases, implementation of viable adaptation measures is accompanied by a certain amount of additional expense. In addition, implementation of adaptation presupposes applicable technologies. The prerequisites for the effective implementation of adaptation measures are firstly, that the necessity of adaptation measures should be acknowledged and secondly, that the most suitable adaptation measures should be selected through an assessment of the adaptation measures available.

In relation to adaptation to climate change, adaptive capacity or adaptive capability refers to potential of a specific system to regulate itself, reduce potential damages, or use opportunities in response to climate change, or to cope with the consequences of climate change (IPCC, 2001). In other words, it refers to both the ability to effectively plan and implement adaptation and to respond to increasing risks and pressure. Thus increasing adaptive capacity or adaptive capability will reduce the frequency and extent of the harmful consequences of climate change. Though adaptive capacity can be obtained by means of combining the aforementioned components, the relative importance of each of the components varies with the circumstances in which adaptation is implemented and the nature of the disasters. Each component is neither independent nor exclusive of one another, but closely interrelated with one another. The components that affect adaptive capacity include the system's accessibility to wealth, information and technology; relative distribution of education and health care, and social flexibility.

Meanwhile, vulnerability refers to the risk associated with climate change in the absence of adaptation, such as the extent of adverse impacts of climate change, which include climate variability and extreme climate phenomena and the extent of the inability to cope with the adverse impacts. Therefore, vulnerability can be considered as a function of the scale and speed of climate change to which the system is exposed, and the sensitivity and adaptive capacity of the system. Here, the sensitivity of the system refers to the extent of impacts that climate disturbance has on the system. In other words, it is the system's capacity to adapt itself to changes. Adaptive capacity means the capacity of a system, region or society to adapt itself to the climate change impact. The expansion of adaptive capacity is thus a substantive means of coping with the uncertainty of climate change. However, assessment of vulnerability must precede the establishment of adaptation policies for climate change, and this requires that the impacts of the present climate be assessed first. The impact assessment enables the identification which parts of the system are vulnerable and to what degree. Elements to be considered for the assessment of vulnerability include a definite estimation of climate change, the identification of the subjects of vulnerability, an estimation of the degree of socioeconomic exposure to climate change, and adaptation to the expected climate change.

3.2. Types and Approaches for Adaptation of the Agricultural Sector

3.2.1. Types and inventory of adaptation of the agricultural sector

Types of adaptation to climate change are divided into three categories: those which reduce the sensitivity of systems significantly affected by climate change (enhancement of storage capacity of reservoirs, cultivation of heat-resistant crops, and preparation against floods, etc.); those which modify the exposure of a system to the impacts of climate change (utilization of the investment in provision against risks and Early Warning Systems), and those which increase the resilience of the social/ecological system (resource preservation). Resilience in adaptation to climate change refers to the capacity of a community or biological system to organize or adapt itself to stresses and changes by absorbing the changes and/or obstacles. It can be interpreted as the extent to which a system can withstand changes and stresses while maintaining its functions and structure.

Types of adaptation are classified according to such factors as the characteristics, intention, and point-of-time of the system. The system is divided broadly into the natural system and the human system. Adaptation is classified into autonomous and planned adaptation depending on intention; pre-adaptation and post-adaptation depending on point-of-time; short-term and mid/long-term adaptation depending on term; and adaptation for each rural household unit, community unit, and nation depending on the spatial range. It can also be divided into pre-adaptation and post-adaptation depending on the time of application and into short-term and mid/long-term adaptation depending on the period of application. In addition, it can be roughly classified into the national-level, regional-level, sector-level, and project-level adaptation depending on the scope of application.

The main groups in charge of implementing adaptation measures are broadly divided into the private sector, including farmers and concerned enterprises, and the public sector, including central and the local governments. The private sector pursues the maximization of private profit, while the public sector pursues public value. Representative cases of application according to response time and main sector in charge are listed in the following table <Table 3-1>.

In reality, a wide variety of programs for the agricultural sector's adaptation to climate change depend on the national and/or regional conditions. For Canada, adaptation measures are classified into five programs: research and development (crop development, meteorological and climate information system, resource management innovation), government programs and insurance (agricultural subsidies, private insurance, resource management program), agricultural production techniques (agricultural production, land utilization, irrigation, cultivation time control) and financial management for farm households (crop insurance, crop future trading, income stabilization program, household

Table 3-1. Cases of adaptation according to response time and main sector in charge

		Response Time	
		Pre-adaptation	Post-adaptation
Main Sector in Charge of Response	Private Sector	· Utilization of the private insurance market · Private R&D and investment	· Change of crop cultivation and applicable agricultural techniques · Regulation of the insurance market · Verification of adaptation options of the minimum expense
	Public Sector	· Utilization of Early Warning System · Construction of public infrastructure (irrigation systems) · Communication of risks in the agricultural sector · Utilization of subsidies · Publicly available R&D	· Recovery from the aftermath of disasters · Compensation for the consequences of the impacts · Insurance contract · Compensation system · Subsidies and supports

Source: OECD (2006b).

income) (Smit and Skinner, 2002).

Japan, on the other hand, classifies agricultural sector adaptation measures against climate change into 12 categories: preservation of water and soil, improvement of the soil quality, tillage activities, efficiency of water use, governmental and customary policies, R&D of new technologies, construction of infrastructure, education and public acknowledgement, land management, water resource management, human activities, and farmhouse adaptation at other levels (Agriculture, Forestry and Fisheries Research Council under Ministry of Agriculture, Forestry and Fisheries of Japan. 2007).

In a study undertaken by the Korean Ministry of Environment to establish a master plan for adaptation to climate change, Korea classifies the adaptation measures for the Korean agricultural sector into five categories: technical measures (28 measures), legal and institutional measures (7), economical measures (7), public relations and education

(6) and assessment (monitoring and vulnerability assessment, 14). This amounts to 62 detailed measures in total. (H. J. Han *et al*., 2008).

Through comprehensive review of domestic and foreign adaptation measures, this Study draws an inventory of the adaptation measures applicable to the Korean agricultural sector as shown in <Table 3-2>. The inventory contains total 19 adaptation programs including five programs for research and development, eight for infrastructure management, 1 for economic adaptation, 3 for legal and institutional improvement, 2 for education and training, 1 for monitoring, and 4 for technology and management measures applicable to farm households.[11]

Table 3-2. Inventory of the adaptation measures applicable to the agricultural sector

Category	Detailed Adaptation Programs
R&D	① Breeding ② Production technology development ③ Base technology development ④ Resource management information ⑤ Climate information system
Infrastructure management	⑥ Farmland management ⑦ Agricultural water management ⑧ Agricultural facility management
Economic means	⑨ Provision of grants
Legal & institutional Improvement	⑩ Expansion of insurance system ⑪ Resource management system ⑫ Formulation of adaption measures for each region
Education & training	⑬ Manpower training ⑭ Education and public relations
Monitoring	⑮ Assessment of adaptation and vulnerability
Technology & management applicable to farm households	⑯ Production technology management ⑰ Soil management ⑱ Water supply management ⑲ Financial management for farm households

11 For more information about 19 measures presented as the adaption inventories for the agricultural sector, see <Schedule 5>.

3.2.2. Approaches to adaptation of the agricultural sector to climate change

Approaches to agricultural sector adaption to climate change are classified into three categories: impact-based, context-based, and process-based approaches <Table 3-3>.

The impact-based approach provides answers to such questions as: “How much impact does climate change have on each field/item?” and “How much could the negative impact of climate change be mitigated if adaptation measures are taken?”

The impact-based approach mainly deals with estimating the extent of national and regional climate change according to a climate change scenario based on the general circulation model, analyzing the impacts of climate change on the distribution of suitable cultivation areas, agricultural production and the farm household economy. In addition, it includes the analysis of impacts of climate change given specific adaptation measures taken against climate change.

The context-based approach provides answers to such questions as “What influence does climate change have on producers?” “What are the factors that facilitate adaptation?” and “What are the restricting factors?” This approach tries to identify climate factors and non-climate factors (socioeconomic factors) that affect the farm households’ adaptation to climate change, to apprehend the risks of climate change, and to select and utilize optimum adaptation measures. The context-based approach is thus important for the agricultural sector when seeking proper adaptation strategies to climate change. This approach applies various analysis methods such as questionnaires, qualitative analysis, and quantitative analysis of risks and uncertainty.

The process-based approach answers such questions as “How does the adaptation process work?” “Under what conditions is adaptation achieved?” “What conditions affect the type of adaptation to be introduced?” “What are the feasible adaptation measures in consideration

Table 3-3. Approaches to adaption of the agricultural sector to climate change

Approach	Key Questions	Description
Impact-based Approach	· What are the expected impacts of climate change? · How serious is climate change? · What are adaptation measures to cope with the expected impact? · How much can a specific adaptation measure mitigate or offset the impact?	· Select a climate change scenario based on general circulation model · Make a model of the impacts of climate change on a specific sector of agriculture (e.g., yield) · Change in the areas suitable for cultivation, due to the secondary impacts · Estimate other impacts including adaptation
Context-based Approach	· What are the conditions that affect the producers? · How do the producers handle the conditions? · What facilitates or restricts the actual adaptation?	· Identify climatic/non-climatic factors that affect the decision-making of the farm households · Utilize risk factors and risk management strategies - Conservation tillage, variety conversion, irrigation system · Select and utilize various adaption measures - Government insurance, R&D, and financial support
Process-based Approach	· How does adaptation process work? · Under what condition adaptation is achieved? · What are the factors that influence the adaptation measures to be introduced? · What are the adaptation measures feasible under future conditions? · Are there any methods to facilitate adaptation?	· Analyze the farmers' decision-making on adaptation - Responses to actual adaptation measures - Identify measures for implementing the adaptation initiative · Estimate the present and future adaptive capacity - Present exposure and adaptive capacity - Future exposure and adaptive capacity (awareness, institution, technology, etc.)

Note: Abstracted from the report by Wall *et al.*(2007)

of future conditions?" and "What are the methods that can facilitate adaptation?" This approach analyzes the farmers' decision-making and capacity to undertake adaptation measures, the present and future exposure and the corresponding adaptive capacity to climate change. Factors that may affect adaptive capacity include people's awareness, adaptation technologies, human/social capitals, and the risk management system, including laws and institutions.

To establish adaptation policies for the agricultural sector to climate change following global warming, seven factors need to be considered. These are economic variability, variability of the sector, mainstreaming, adaptation barriers, sufficient support, communication, and adaptive capacity improvement <Table 3-4>. With regards the first factor, economic variability, an income stabilization program is recommended. One that can cope with future climate change and meteorological risks taking into consideration various economic variables including income, interest rate, energy cost, and dollar value. The second factor, the degree of variability within the sector, recommends the use of flexible political programs in which the characteristics of each item/regions is reflected. The third factor, mainstreaming, recommends research and development for the integration of risk management strategies of other fields and farm management system strategies, and the reorganization of the agricultural policy regime to one which focuses on adaptation to climate change. The fourth factor, the adaptation barrier, recommends that the costs and advantages of adaptation be analyzed and the results applied to the genetic engineering technologies. This would ensure efficient policy implementation based on a comprehensive consideration of the pressure on farm management by adaptation measures, the genetically engineered solutions for adaptation measures, and their conflicts with existing policies. The fifth factor, sufficient support, recommends the establishment of an incentive system for improving options for technological adaptation and farm management methods, in consideration of technical support, knowledge transfer and financial

Table 3-4. Matters to be considered when establishing the adaptation strategies for the agricultural sector's adaptation to climate change

	Factors to be considered	Main programs	Policy recommendations
Economic variability	· Variable factors - Income, interest rate - Energy cost - Dollar value	· Income stabilization	· Main objective of agricultural policies is to stabilize the food and agricultural sector · Utilize the related policy programs of other ministries. · Utilize the income stabilization program to cope with the future climate change and the meteorological risks
Variability of the sector	· Variability of required conditions - Consideration for each item and region - Farm system type	· Fair and flexible program	· Develop policy programs that can satisfy various conditions, needs and expectations of each region
Mainstreaming	· Consideration for risk strategies of other sectors · Integration of farm management systems	· R&D for strategy integration · Identification of potential barriers · Practical farming experiences	· Estimate the adaptation barrier, including policy/program environments in R&D · Reorganize the agricultural policy regime for adaption to climate change.
Adaptation barrier	· Pressure on farm management laid by adaptation options · Genetically engineered solutions · Conflicts with the existing policies	· Efficient policy implementation - Analysis of the cost and advantages of adaptation - Application of genetic engineering technologies	· Support for R&D in the related fields - Develop policies and programs based on the results of assessing the cost/ benefits of adaption options to climate risks
Sufficient support	· Improvement of some options - Support for technologies lagging behind - Knowledge transfer and financial support	· Improvement of technological and political adaptation options · Support for farm management methods based on adaptation options to climate change	· Establish an incentive system that producers can accommodate easily · Provide proper support for implementation of adaptation measures
Communication	· Weakness of the reliability of information about the risks of climate change · Limitation of information capacity	· Production of reliable information · Development of information sharing program	· Enhance the users' access to information · Provide reliable information and ensure reliable policy execution · Public relations on policy effects and create consensus on them
Adaptive capacity improvement	· Enhancement of the farm's risk management capacity · Enhancement of awareness of adaptation	· Development and operation of education and training programs for adaptation · Benchmarking of effective domestic and foreign adaption cases	· Establish the legal/institutional foundation · Form the consensus for adaption through education and training · Develop a variety of viable adaptation technologies

Note: Abstracted from the report by Wall, Smit, and Wandel (2007) support for the fields lagging behind, and to provide proper supports for implementing adaptation measures. The sixth factor, communication, recommends improving user access to information and the formation of a national consensus on policy effects. This could be achieved by producing reliable information and developing information-sharing programs so as to deal with such issues as the reliability of information about climate change risk and the limitation of information capacity. For the final factor, adaptive capacity, it is recommended that a legal/institutional foundation be established and that a list of viable adaptation technologies be prepared. This would allow the creation of education and training programs for adaptation to climate change and the benchmarking of domestic and overseas cases such that farm capacity for risk management and awareness of adaptation would be improved.

Assessment of the Impacts of Climate Change on the Agricultural Sector

Chapter 4

Practical analysis of the impacts of climate change on the agricultural sector can be done for several aspects: the biological aspect, the aspect of agricultural production, and the economic aspect. Chapter 4 summarizes, firstly, the analysis of the impacts of climate change on the agricultural ecosystem and the farm household economy; secondly, the results of the first-year study and finally, sums up the impacts of climate change assessed during the second-year study in connection with the analysis of the changes of main production regions of agricultural products and that of the impacts of meteorological disasters and adaptation measures.

First of all, the changes in agricultural climate resources brought on by climate change and its impacts on the agricultural ecosystem (including blights and pests and crop production) are investigated. Additionally, the impacts of meteorological disasters on the agricultural sector and those of meteorological factors on the agricultural production, especially rice production, are analyzed. Changes in the season for rice cultivation, the amount of fertilizer applied, and the time for irrigation are analyzed in terms of the effects of adaptation measures on the agricultural production. Also, in order to understand the changes in crop growth in consideration of adaptation measures, simulation analyses were carried out for different CO_2 concentration and temperature rises using ORYZA2000, of which results are presented here. Second, using the time series statistics about agricultural production, the present conditions of the shift in main production regions of major agricultural products such as apples, peaches, grapes, Halla oranges, and tropical fruits due to climate change are analyzed and future changes forecast. Lastly in this chapter, the economic impacts of climate change on the agricultural sector are analyzed through the following analyses: the productivity analysis for rice, Korean cabbage, radish and apples using both nonparametric and semi-parametric analysis methods; the long-term forecast of rice productivity and the analysis and forecast of the shift in cultivation regions of apples and tangerines due to temperature rise, using CERES-Rice model; and an analysis of its impacts on the agricultural economy, including the farmland price and the agricultural gross income, based on the Ricardian model.

1. Impacts on the Agricultural Ecosystem

1.1. Change in the Agricultural Climate Resources

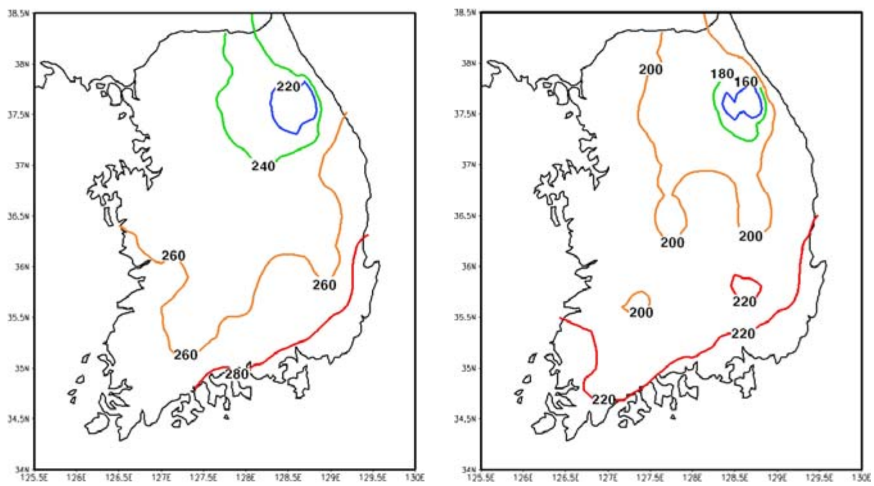
1.1.1. Changes in the plant period and crop temperature

Agricultural climate resources refer to the growth period of crops, the distribution of crop temperature and the occurrence of drought and low temperature during this period (B. R. Lee, 1995). Plant period, which refers to the period in which average daily temperature is continuously higher than 5℃, is an important index for the wintering and growth of crops, due to the fact that wintering crops start growing when average daily temperature exceeds 5℃ in spring and go to winter sleep when temperature falls below 5℃ in winter. It is especially important for perennial crops like fruit trees as their growth restarts when temperature exceeds 5℃. Early or late sprouting and blooming in a specific area is closely related to high or low average daily temperature of the area since the crop temperature started in that area.

The plant period in Korea ranges from 201 days to 280 days, with about 70 days variation. Depending on the sum of temperature during this period, the diversity of vegetation distribution is created and the areas suitable for crop cultivation are decided. Over the last 19 year period from 1988-2006, the average first day of the plant period in 56 areas (except for the Jeju area) was March 7, which was on average five days earlier than the previous 19 years (1969-1987, March 12). Meanwhile, the average last day of plant period was November 23, which was on average four days later, resulting in a plant period of about nine days longer than before (K. M. Shim *et al*., 2008). The average duration of plant periods for the last 19 years appear to be shortest in the Daegwanryeong area at 210 days, around 250 days in the central inland region, 270 days or so in the southern region, and longest in the southern coastal areas at 280 days <Figure 4-1>.

With regards the change of temperature, one of the agricultural climate resources, the crop temperature can be analyzed. When the

Figure 4-1. Changes in the duration of plant periods

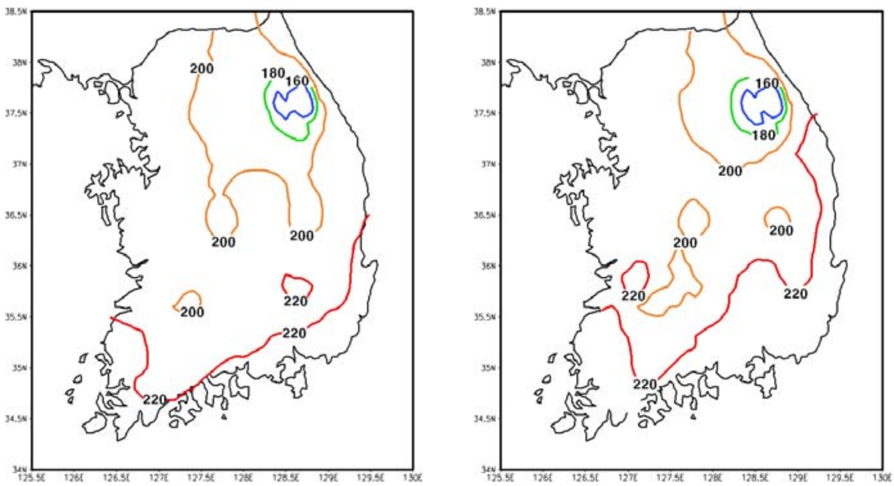


<1969~1987> <1988~2006>

Source: K. M. Shim *et al*. (2008).

temperature exceeds 10℃ the environmental condition in which summer crops start growing and wintering crops, which are mostly fruit trees, speed up their growth including sprouting and blooming, are met. Therefore, crop temperature plays a very important role in the cultivation of fruit trees. Over the 19 year period from 1988-2006, the period during which the average daily temperature has been consistently 10℃ or higher was 214 days on average nationwide, which was, on average, four days longer than the previous 18 year period (210 days) <Figure 4-2>. However, there is considerable variation by region with Taebaek semi-highlands and Sobaek mountain areas such as Jecheon, Keumsan and Imsil having periods that were 2~4 days shorter despite temperature rises. Some central areas such as Suwon, Cheongju and Daejeon experienced the longest crop temperature period of about 10 days longer than that of the previous 18 years. (K. M. Shin et al., 2008)

Figure 4−2. Changes in the duration of crop temperature period



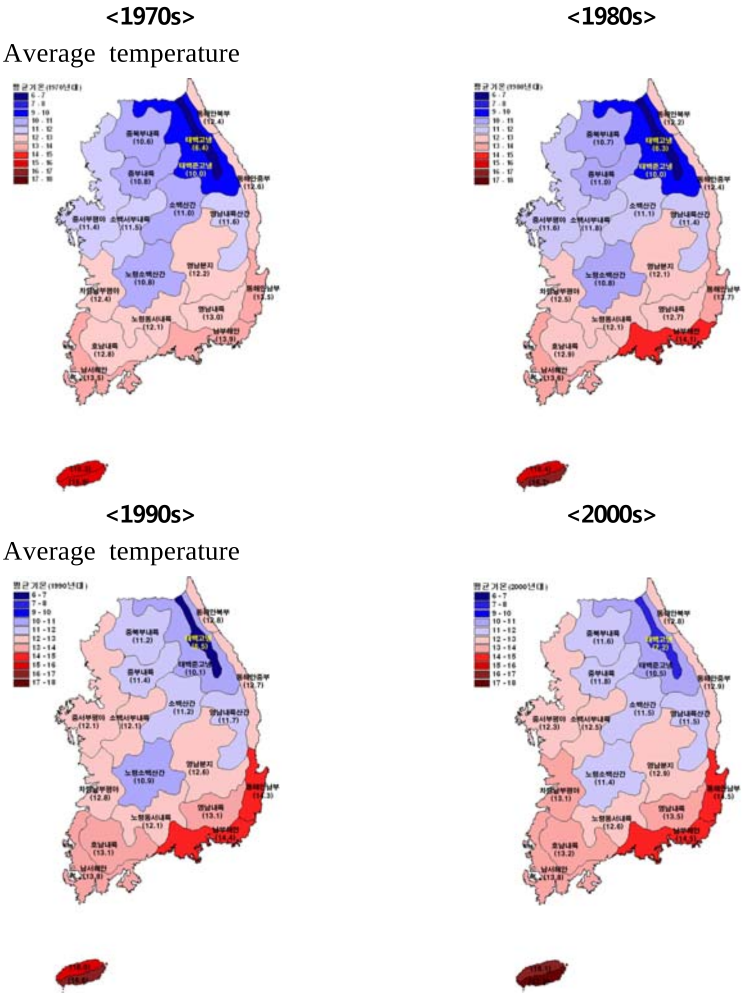
<1969~1987> <1988~2006>

Source: K. M. Shim *et al*.(2008).

1.1.2. Agricultural climate changes in the agricultural climate zone

An agricultural climatic area is divided into agricultural climate zones according to different agricultural climatic conditions. With regards Korea, the average temperature of each agricultural climate

Figure 4-3. Changes in the average temperature of each agricultural climate zone



Source: RDA (2008).

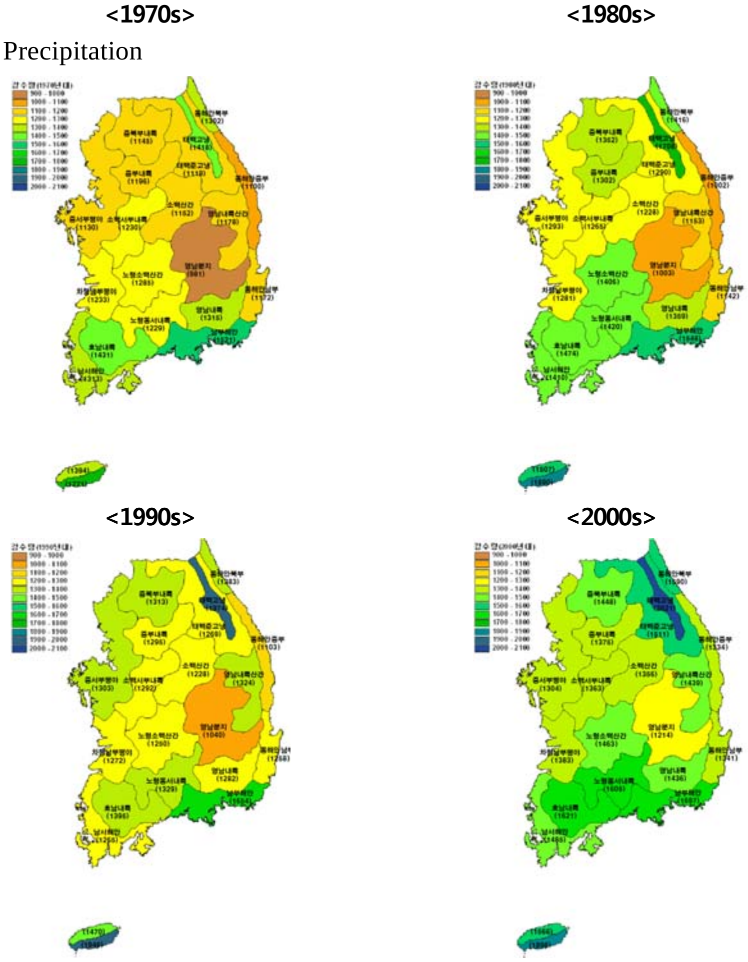
zone has risen by 0.95℃ for the past 35 years (1973~2007). The climate zone which has shown the lowest temperature rise is the Yeongnam inland/mountain zone (Yeongju, Mungyeong, etc.), which recorded a 0.2℃ rise. On the other hand, the mid-northern inland, the central inland, and the southeastern coastal zones has seen a temperature rise of 1.36~1.47℃. The average temperature of the mid-western planar zone (Seosan, Boryeong, etc.) and the Charyeong southern planar zone (Gunsan, Buan, Jeongeup, etc.), the granaries of Korea, rose by 1.05~1.33℃ and the Taebaek highland zone including Daegwanryeong also experienced a temperature rise of 1.04℃ <Figure 4-3>.

Precipitation, meanwhile, had increased by 283㎜ on average for the past 35years (1973~2007). The Taebaek highland zone including Daegwanryeong, the Taebaek semi-highland zone, and the Yeongnam inland/mountain zone had the greatest increase rate of 452~778㎜, while the Yeongnam inland zone (Milyang, Jinju, etc.) had the lowest increase rate of 132㎜ <Figure 4-4>. The increase in precipitation was not spread evenly through the year, with summer precipitation showing a rapid increase, while winter precipitation has actually decreased slightly since the 1970s. Rainfall patterns are thus becoming increasingly lopsided.

1.2. Blights and Pests

Temperature rise due to global warming has given rise to new types of blights and pests causing damage to crops. Most notably, damage to apples, peaches, grapes, and soybeans by brown grasshoppers has been reported to be increasing. The first case of damage caused by brown grasshoppers was reported in Chungju and Danyang in Chungbuk Province while many cases of extensive damage to peach and grape crops in orchards near the mountains in Okcheon, Cheongwon and Boeun around Yeongdong, Chungbuk Province and Suwon have been

Figure 4-4. Changes in the precipitation of each agricultural climate zone



Source: RDA (2008).

reported since 2006. The scale of the damage amounted to 20ha. However, in 2007, about 30ha of the orchards across Chungbuk Province was reported to be damaged.

Rice stripe tenuivirus, a viral disease which affects rice, has spread north, extending the blight zone. In total some 14,137ha, across the nation into areas such as Gyeonggi, Chungnam, Jeonam, Jeonbuk and Gyeongnam Provinces.

Lycorma delicatula is a pest that affects fruit trees, causing damage to grape, peach, and apple crops. After being detected first in 1979, cases of damage by Lycorma delicatula subsided. In 2007, however, it returned to damage grape crops in Yeongi County in Chungnam Province and Suwon in Gyeonggi Province. It was reported that it damaged about 91 ha of grape orchards in Suwon in 2008.

1.3. Impacts on Production of Each Crop

1.3.1. Rice

For rice, the cultivation period is the basic consideration for production planning. This is in turn decided by the climate conditions and the variety of rice sown. Among several agricultural climate conditions, the critical factor is temperature in deciding the rice cultivation period. In general, rice is a summer crop and when temperatures rise, the area available for cultivating rice extends north, while the cultivation method and variety of rice sown also changes so as to adapt to the temperature change. As far as the choice of rice varieties for transplantation is concerned, the cultivation regions suitable for early-maturing varieties of rice will become suitable for medium-maturing varieties and those suitable for medium-maturing varieties will become suitable for late-maturing varieties. Indeed, it is reported that even mountain areas at an altitude of 600m or higher, where rice cultivation has not been possible due to low temperatures, may also become suitable for cultivating some early-maturing varieties of rice.

According to the Korean meteorological data, the proper season for earing of rice (an average temperature during the ripening period:

21~23℃) was around August 15 in the 1970s but since 2000, it has been delayed by about a week, until August 21. An average temperature of 21~23℃ during the ripening period is favorable for production of high-quality rice. However, if the average temperature during this period is higher than this range, the rice cannot ripen fully, resulting in the production of poor-quality rice. The rice grains will weigh less, contain more protein, and become less tasty and nutritious.

When the temperature rises, this accelerates the development rate of rice, shortening the growth period. However, if rice grows too fast, it cannot ripen fully and for the reasons mentioned above, rice productivity is reduced. Analysis shows that global warming not only shortens the ripening period but also lowers the fertility rate and increased crop breathing at night due to high temperatures <Table 4-1>. In short, research shows that a temperature rise during the ripening period reduces the weight of each grain, increases its protein content, and thus reduces overall rice quality (K. M. Shim *et al.*, 2006).

Table 4-1. Lowering of rice quality due to the rise in ripening temperature

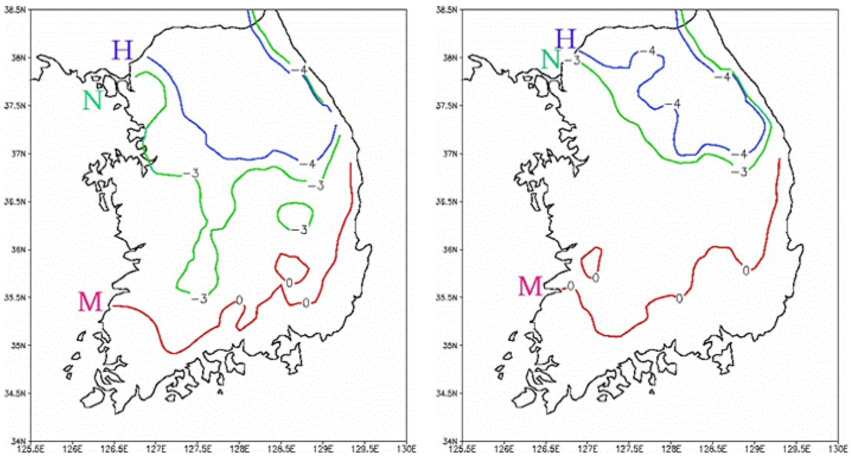
Ripening temperature (℃)	Brown rice (1,000 grain weight) (g)	Rice protein (%)	White spot ratio (1/4 or higher, %)	Remarks
21.5	22.1	8.5	9.4	Tested variety:
23.0	21.5	8.7	12.3	*Ilpoombyeo,*
24.5	20.8	9.0	21.7	*Nampyeongbyeo*

Source: RDA (2007b).

1.3.2. Barley

Suitable areas for cultivating barley have been selected so as to avoid damage from severe cold during the cultivation period. At present, barley is cultivated in such areas as Donghae and Yeongduk along the east coast, Sacheon and Buseong along the south coast, and Yeonggwang and Gunsan along the west coast. However, it is rarely cultivated in the midland areas. The reason for these reasons being suitable for the cultivation region of barley is firstly, because the coastal areas are less cold than the midland areas in winter and secondly, the temperature during the ripening period or barley is lower than in the midlands, and thus grains can ripen to their full weight. Analysis indicates that as a result of the 'mild winter' which spanned a period from 1987 to 2000 and during which time the temperature remained within the range between 1.5~2.5℃, the limit line for cultivating winter barley has been readjusted. According to the analysis of the average and the lowest temperatures in January for 12 years from 1987 to 1998 compiled for a National Academy of Agricultural Science (NAAS: 2000) study on winter barley cultivation regions following global warming, the safe zone for winter barley cultivation has shifted far to the north <Figure 4-5>.

Figure 4-5. Shift in the safe zone for winter barley cultivation



Note: H stands for hulled barley, N naked barley, and M malting barley.
Source: K. M. Shim et al.(2004), p.222.

1.3.3. Vegetables

Fruit and vegetables that require hot temperatures to grow, such as watermelons, peppers and tomatoes, grow faster and are of better quality (including a higher sugar content) as temperature rises. This is true until temperatures reach the growth inhibition limit (35℃). Conversely, for open-field vegetables that favor cooler temperatures, such as radishes and Korean cabbage, high temperature may result in a lowering of produce quality. With regards hot peppers, at temperature below 15℃ or above 30℃, the plant pollens are not properly set to the fruit, or many of fruits drop despite being set. Strawberries also have flowering problems at high temperatures. Some vegetables like onions, green onions and lettuce may have problems at high temperature, as this causes the flower to split.

When temperature rises, it is possible to reduce the energy requirements for heating greenhouses in winter. It also becomes possible to move the cultivation of winter cabbages, which have been cultivated in greenhouses in Jejudo and the south coastal areas, out to the open field.

1.3.4. Fruit trees

Climate change not only affects the growth of fruit trees but also their fruit quality, the harvest time and fruit storage. Apple trees are perennial and so can produce fruit over an extended period of over ten years in the same place once they are planted. Therefore, given this long fruiting period, changes in climatic conditions significantly affects the productivity and quality of apples. The average annual temperature in Korean apple cultivation areas is lower than 13.5℃. If temperatures exceed this it is difficult to produce good-quality apples. The regions suitable for cultivating apples should have average annual temperature of 13℃ or less and have the winter temperature characteristics of the midlands or basins. However, due to global warming, the regions suitable for apple cultivation have shifted north and/or to highlands. The cultivation regions for pears, peaches, grapes, and sweet persimmons have also shifted north with some areas in the southern region having become unsuitable for cultivating those fruits due to high temperatures. Also, due to temperature rise, in the south region where high winds are uncommon, the cultivation of kiwi fruits has become popular and in Jeju Island, subtropical fruits are now cultivated.

For Jeju Island, global warming has accelerated crop growth and raised the average annual temperature. The average annual temperature in Jejudo, which was 15.1~15.9℃ in 1970, rose by 0.5~1.6℃ to 15.6~17.5℃ in 2004. As a result, the sprouting season for Unshiu orange was advanced by about ten days from April 14 in 1994 to April 5 in 2004.

2. Analysis of the Impacts of Meteorological Factors on Agricultural Production

2.1. Impacts of Meteorological Disasters on the Agricultural Sector[12]

It is feared that as climate change proceeds, the frequency of meteorological disasters will increase and thus damages in the agricultural sector by these disasters will also increase. Depending on the type of meteorological disasters (heavy rain, typhoon, tidal wave, gust, windstorm, snow damage, etc.), the amount of damage is expected to

12 This section is an excerpt from “Analysis of the Impact of Climate Change on Agricultural Crops by Disaster Types” contributed by Prof. T. G. Kim (Kyungpook National University).

differ depending on climatic variables such as average annual temperature, the difference between the highest and the lowest temperature (on average), precipitation, and maximum daily precipitation. In order to estimate damages to the crops and to seek proper measures to minimize the damages, it is necessary to analyze what impacts climate change has on crop damages in connection with each type of disaster.

To analyze the impacts of each climatic variable on crop damages depending on the type of each disaster, a model can be formulated with the damage rates of disasters as the dependent variables and with climatic variables as independent variables:

$$y = g(\underline{x}) + \varepsilon$$

where y is the disaster-to-damage ratio (damaged area/cultivation area × 100), and $\underline{x}$ is a variable considered as the vector of climatic variables such as average annual temperature, difference between the highest and the lowest temperatures, precipitation, maximum daily precipitation, and year.

Analysis data was taken from the set of panel data combined from the annual data of nine provinces. The data about damaged areas in the agricultural sector was taken from Annual Disaster Report 1985~2007 published by the National Emergency Management Agency (NEMA) and the climate data sourced from the KMA’s Annual Climatological Report. The damaged area in each province was divided by the entire cultivation area in its province to calculate the disaster-to-damage ratio. For climate data, the average annual temperature, the difference between the highest and the lowest temperatures, precipitation, and maximum daily precipitation in each province in each year were used. The multiple regression model estimation was set by using the Parks' Method, which is an auto-regression model.

Basic statistics of variables used for analysis are listed below:

The result of the estimation shows that each meteorological factor has an impact on crop damage according to each type of disaster. For damage by heavy rain, it appears that the impact of precipitation and

Table 4-2. Basic statistics of major variables for analyzing the impacts of disasters

	Average	Minimum	Maximum	Standard deviation
Damage by heavy rain (ha)	4,173	0.00	95,786	11,987
Damage by typhoon (ha)	5,322	0.00	132,294	16,464
Damage by tidal waves (ha)	4	0.00	282	28
Damage by gust (ha)	3	0.00	155	16
Damage by storm (ha)	205	0.00	7,031	822
Damage by snow (ha)	29	0.00	1,703	199
Cultivation area (ha)	232,183	11,640	3,245,159	230,047
Average annual temperature (℃)	12.7	9.5	25.0	2.0
Difference between the highest and the lowest temperature	9.9	5.9	12.5	1.5
Precipitation (mm)	1,441	713	2,952	355
Maximum daily precipitation (mm)	144	72	330	46

maximum daily precipitation has the statistical significance at a level of one percent.

It is analyzed that whenever precipitation increases by 1mm, the damage by heavy rain increases by 2.59×10^{-3}~3.15×10^{-3}% points and whenever maximum daily precipitation increases by 1mm, it increases by 0.01~0.02% points.

Damage by typhoon appears to have the statistical significance of one percent or average annual temperature and 10% for maximum daily precipitation. It is estimated that as average annual temperature rises by 1℃, the damage by typhoon increases by 0.29~0.30% points and as maximum daily precipitation increases by 1mm, it increases by 0.01% points.

It is analyzed that a rise in average annual temperature leads to increased damage due to typhoons, gusts, and snows. An increase in difference between the highest and the lowest temperature results in an increase in damage due to tidal wave, gust, storms and snow. In

Table 4−3. Estimation by a model analyzing the impact of disasters on the agricultural sector

Variable	Heavy rain	Typhoon	Hail/ lightning	Tidal wave	Gust	Storm	Snow
Constant term	-6.764 (-2.33)**	-2.678 (-0.88)	0.489 (2.15)**	-0.001 (-1.21)	-0.007 (-4.48)***	-0.137 (-0.79)	-0.047 (-3.01)***
Average annual temperature	0.013 (1.37)	0.030 (1.69)*	-0.001 (-1.15)	4.18e-07 (0.06)	3.90e-05 (5.25)***	0.001 (1.19)	1.88e-04 (3.34)***
difference between the highest and the lowest temperatures	0.028 (1.33)	-0.017 (-0.91)	-0.001 (-1.20)	1.40e-05 (1.78)*	2.10e-05 (2.70)***	0.002 (1.95)*	2.31e-04 (2.86)***
Precipitation	2.59e-04 (4.26)***	4.70e-5 (1.04)	-4.64e-06 (-2.08)**	6.16e-09 (0.48)	-2.45e-08 (-1.86)*	1.06e-06 (0.37)	7.34e-08 (0.43)
Maximum daily precipitation	0.002 (4.00)***	0.001 (3.09)***	8.79e-06 (0.61)	7.42e-08 (1.07)	8.12e-08 (1.22)	-2.00e-05 (-1.55)	1.21e-07 (0.14)
Year	-0.134 (-4.82)***	0.020 (0.51)	-0.009 (-2.40)**	2.30e-05 (0.78)	7.90e-5 (1.51)	-0.006 (-3.71)***	0.001 (1.33)
R^2	0.3322	0.1212	0.0739	0.0466	0.178	0.1074	0.1008
df	201						

Note: *** Significant at a level of 1%, ** at a level of 5%, and * at a level of 10%; the number in ( ) is t-value.

addition, an increase in precipitation leads to the damage by heavy rain whilst reducing the damage by hail/lightning and gust. Maximum daily precipitation is analyzed to contribute to damages by heavy rain and typhoons.

The climatic variables extracted from the above estimation results, which show the impact on crop damages by each disaster type, reveal that, as averst temperatures leads to an increase in the damages by tidal waves, gust, storm, and snow. When precipitation increases, damage caused by heavy rain increases while damage due to hail/lightning and gust are reduced. An increase in maximum daily precipitation appears to result in increased damage by heavy rain and typhoage annual temperature rise, damage from typhoons, wind gusts, and snow also increases. Also, an increase in difference between the highest and the loweon.

Table 4-4. Impacts of climatic variables on disasters

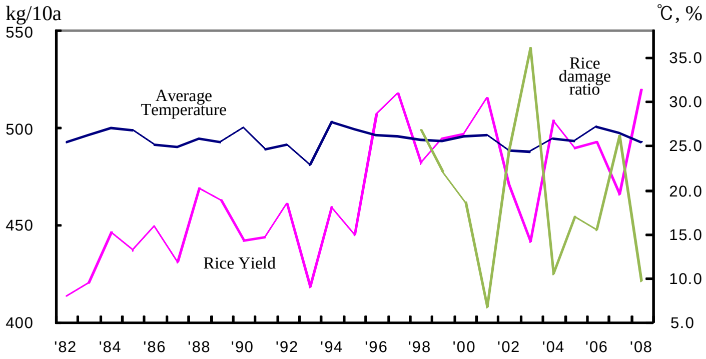
Variable	Heavy rain	Typhoon	Hail/ lightning	Tidal wave	Gust	Storm	Snow
Average annual temperature		+			+		+
Difference between the highest and the lowest temperature				+	+	+	+
Precipitation	+		−		−		
Maximum daily precipitation	+	+					

2.2. Factors Affecting the Rice Yield

The agricultural yield is not only affected by meteorological factors but also by a complicated interaction between technological factors, such as breeding, dissemination, cultivation and political supports. Since the preceding studies for analyzing the changes in agricultural yield by climate change took only the meteorological factors into consideration, it is difficult to understand the extent of the impact of the climate change in comparison to other factors. Therefore, in order to analyze the change in agricultural yields more precisely, it is necessary to take technological factors such as breeding, dissemination and cultivation into consideration in addition to the meteorological factors. Acting on this, in addition to meteorological factors, technological factors are taken into consideration in analyzing the change in the yield of rice, the representative crop of Korea.

<Figure 4-6> shows the relationship between the meteorological factors and the rice yield. The relationship between average temperature during the ripening period in August and the rice yield shows the pattern that high temperature in August leads to an increase in the rice yield. It also appears that the rice damage ratio (ratio of damaged

Figure 4-6. Trends of the change in average temperature and the change in rice yield (1982~2008)



Note: 1) Average temperature is the average of temperatures of 8 metropolitan cities (Suwon, Chuncheon, Cheongju, Daejon, Jeonju, Gwangju, Daegu, and Busan).

2) Rice damage ratio (Ratio of damaged sampling zone refers to the sum of damages by blight, pest, flood, and wind, based on the internal data from KOSTAT 1998 and thereafter.

Source: Ministry of Food, Agriculture, Forestry and Fisheries, KMA, KOSTAT, each year

sampling zone) falls when the August temperature is high. In other words, the average temperature during the ripening period in August is an important variable that affects the change in rice yield.

The rice yield had shown a continuous tendency to increase but since 2000, it changed to a holding or decreasing tendency. Changes in the rice yield are caused by high-quality breeding policy, increase in the environment-friendly rice cultivation area, and climate change, including temperature rise and extreme weather conditions like typhoons and drought.

2.2.1. Methods of analysis

Rice yield is realized by farmers' effort by means of a process of 'breeding → dissemination → cultivation,' upon which the quantitative capacity and dissemination rate of the cultivar, the cultivation technologies and efforts of farm households, and the meteorological factors work in combination. In this section, the impact of each factor is analyzed to identify its effect quantitatively.

For this analysis, it is necessary to review the terms related to yield. First of all, the quantitative capacity yield is a simple average of the quantitative capacity that a new cultivar can make under normal cultivation and meteorological conditions. It refers to the maximum quantity that farm households can produce when they cultivate only the new cultivar under normal meteorological conditions.

'Dissemination yield' is an average quantity weighted by the ratio of quantitative capacity of the disseminated variety to the cultivation area of the variety. It indicates the dissemination level of high-yield varieties as well as the theoretical yield that farm households can produce when they cultivate a variety of their choice under normal meteorological conditions using normal cultivation methods <Appendix Table A1>.

'Average annual yield' refers to the yield by farm households from which the change of quantity caused by meteorological factors is excluded. Therefore, as the farm households' cultivation technologies and efforts to increase the yield are improved, the average annual yield approaches the dissemination yield.

'Farm household yield' is the quantity realized from the cultivar disseminated and cultivated by the farm household. With the difference from average annual yield being due to meteorological conditions, as such it indicates a relatively good harvest or a bad harvest.

In estimating the above-mentioned yields, the data about dissemination yield is available from 1982. As a result, the data about quantitative capacity yield, dissemination yield, and farm household yield between 1982 and 2008 are used in this study <Appendix Table A2>. Basic statistics used for estimating the yields are as shown in the following table <Table 4-5>.

Table 4–5. Basic statistics of the yield used for estimating the logistic curve

Unit: kg/10a

	Quantitative capacity yield	Dissemination yield	Farm household yield
Mean	518	490	467
Minimum	488	455	413
Maximum	546	525	520
Standard deviation	18	22	32
Distortion rate	-0.040	-0.041	0.134
No. of samples	27	27	27

2.2.2. Estimated yields

In order to identify the trend of changes in the above-defined quantitative capacity yield and dissemination yield of rice, a logistic curve is estimated. A general formula for the logistic curve is *Y=a/(1+be-cT)*, where *a* indicates the value of final *Y*. Estimation is carried out using EXCEL 2007. Using EXCEL 2007, *a* is set, and then the initial value of *b* is given 1/10 of the value of a and *c* a value between 0~1. With 'Find Solution,' the optimized coefficient value is obtained. As a result of estimation, the following trend formula is obtained:

Trend formula for quantitative capacity yield: $Y = 786.5990/(1+0.6190*e^{-0.0126*T})$ (3-1)

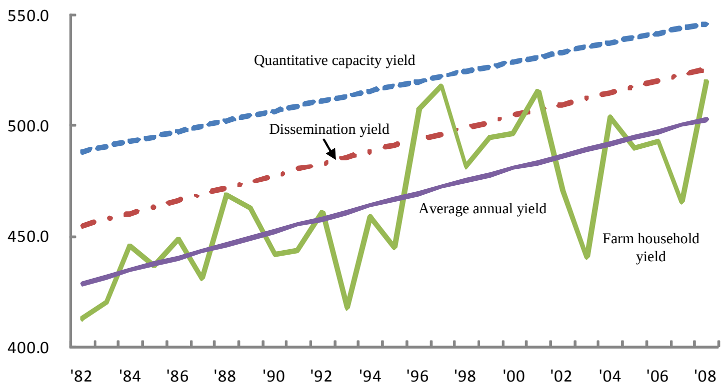
Trend formula for dissemination yield: $Y = 770.4140/(1+0.7059*e^{-0.0153*T})$ (3-2)

As it does not take meteorological conditions into consideration, average yield per unit indicates the yield level when the meteorological conditions are average year conditions and other factors are set according to the trend. As a result, the average method, the weighted average method, or the regression method can be applied in estimating this yield. The regression method is to estimate the time-series quantity that increases annually, for which square-root function and exponential function are widely used. Of the three applicable methods, the average method is the easiest to apply but also has the limit that it cannot reflect the increase in quantity caused by the improvements in the technology level. The regression method using square-root function assumes that the effect of annual technology progress diminishes gradually. In theory however, the quantity increases to infinity and thus it is not suitable as a function for reflecting the recent yield stagnation. Therefore, in this analysis, the following trend formula is obtained by applying the logistic function:

Trend formula for average annual yield: $Y = 753.1254/(1+0.7700*e^{-0.0161*T})$ (3-3)

The quantitative capacity yield, dissemination yield, average annual yield, and actual farm household yield estimated for every other year using the logistic function is shown in <Figure 4-7>. In this graph, the gap between quantitative capacity yield and dissemination yield is set as the dissemination factor; the gap between dissemination yield and average annual yield as the cultivation factor; and the gap between average annual yield and farm household yield as the meteorological factor < Appendix Table A1>).

Figure 4-7. Trend of changes in quantitative capacity yield/ dissemination yield/average annual yield/farm household yield of rice



2.2.3. Interpretation of yield stagnation (2002~'03 and 2006~'07)

The farm household yields of rice in 2002~2003 and 2006~2007 were reduced from its average annual yields by 6.5% and 3.8% respectively. In order to analyze the causes of such reduction or stagnation in 2002~2003 and 2006~2007, the gap between the quantitative capacity yields in 2002~2003 and 2006~2007 and the quantity actually realized through the farm household yield is broken down by applying the same conditions as those of the previous five years to the processes of 'breeding factors → cultivation factors → meteorological factor.'[13]

Contribution of the breeding factors is calculated by subtracting the average of quantitative capacity yields in 1997~2001 (526.8kg) from that of quantitative capacity yields in 2002～2003 (534.4kg), which is 7.6kg. When the realization rate of each of the dissemination/cultivation/meteorological factors is applied to this breeding factor contribution, its contribution to the farm household yield is calculated, which is 6.9kg.

Table 4-6. Breakdown of the factors to the overall yields in 2002-03 and 2006~07

Unit: kg

Year	Quantitative capacity yield (A)	Dissemination yield (B)	Average annual yield (C)	Farm household yield (D)	B/A (%)	C/B (%)	D/C (%)
1997~2001	526.8	501.6	477.8	477.8	95.2	95.3	100.0
2002~2003	534.4	510.8	487.6	456.0	95.6	95.4	93.5
2001~2005	535.5	512.2	489.0	489.0	95.7	95.5	100.0
2006~2007	543.0	521.3	498.6	479.5	96.0	95.6	96.2

Note: Except the farm household yield, the estimated quantitative capacity, dissemination, and average annual yields are used, each of which is the average of the corresponding year.

[13] For more detailed information about the breakdown of climatic factors for analysis of their impact on the rice yield, see the article by J. H. Kim (1998, pp. 38-39).

Contribution of the dissemination factors is calculated by subtracting (the quantitative capacity yield in 2002~2003 × the dissemination factors in 1997~2001) from the estimated dissemination yield in 2002~2003, which is 2.0kg. That is, when the dissemination factors (95.2%) in 1997~2001 are applied to the quantitative capacity yield in 2002~2003 (534.4kg), the theoretical dissemination yield is 508.8kg, which tells that the average of actual dissemination yields in 2002~2003 (510.8) increased by 2.0kg. When the realization rate of the cultivation/ meteorological factors in 199720'01 is applied to this dissemination factor contribution, its contribution to the farm household yield is calculated, which is 1.9kg.

Contribution of the cultivation factors is calculated by subtracting (the estimated dissemination yield in 2002~2003 × the cultivation factors in 1997~2001) from the average annual yield in 2002~2003, which is 0.9kg. That is, when the cultivation factors (95.3%) in 1997~2001 are applied to the dissemination yield in 2002~2003 (510.8kg), the theoretical average annual yield is 486.7kg, which tells us that the average of actual average annual yields in 2002~2003 (487.6) increased by 0.9kg. When the realization rate of the meteorological factors (100%, as the average annual yield is assumed) in 1997~2001 is applied to this dissemination factor contribution, its contribution to the farm household yield is calculated, which is 0.9kg.

Contribution of the meteorological factors is calculated by subtracting (the average annual yield in 2002~2003 × the meteorological factors in 1997~2001 (100%, as the average annual yield is assumed)) from the farm household yield in 2002~2003, which is -31.6kg. The cause of yield stagnation in 2006~2007 can also be analyzed by breaking down the gap between the quantitative capacity yield in 2006~2007 and the quantity actually realized through the farm household yield through application of the same conditions as those of previous 5 years (2001~2005) <Appendix Table A3>.

The results of analyzing the causes of yield stagnation in 2002~

2003 and 2006~2007 are summarized in <Table 4-7>. It appears that the yield stagnation in 2002~2003 was caused by the technological factors (23.6%) but more significantly by the meteorological factors (76.4%). It is alleged that this was caused by Typhoon ‘Rusa’ in 2002 and Typhoon ‘Maemi’ in 2003 resulted in a temperature drop and sunlight shortage during the ripening period. The yield stagnation in 2006~2007 was also caused mostly by the meteorological factor, which accounted for 66.5% while the technological factors accounted for 33.5%. It is presumed to be because the rice yield was reduced due to damages by wind as Typhoon Nari swept over the country in 2007.

Table 4-7. Contributions by each factor to rice yield stagnation in 2002~2003 and 2006~20

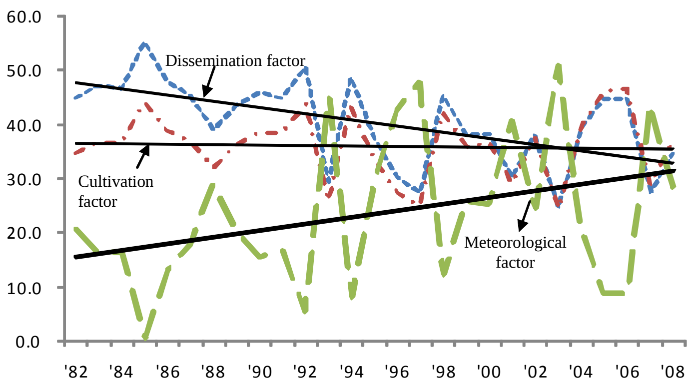
	2002~2003		2006~2007	
	Contribution (kg)	Contribution ratio (%)	Contribution (kg)	Contribution ratio (%)
Technological factors	9.8	23.6	9.6	33.5
- Breeding factors	6.9	70.7	6.8	71.3
- Dissemination factors	1.9	19.8	1.9	19.4
- Cultivation factors	0.9	9.4	0.9	9.3
Meteorological factors	31.6	76.4	19.1	66.5
Total	41.4	100.0	28.7	100.0

2.2.4. Analysis of the climatic impacts on rice yield

Based on the quantitative capacity, dissemination, average annual, and farm household yields of each year, the changes in the rice yield of each year are broken into such factors as dissemination factor, cultivation factor, and meteorological factors <Appendix Table A2>. For all except the farm household yield, all yields are estimated using the logistic function. Here, the gap between quantitative capacity yield and dissemination yield becomes the dissemination factor; the gap between dissemination yield and average annual yield the cultivation factor; and the gap between average annual yield and actual yield the meteorological factors <Attached Table 4>.

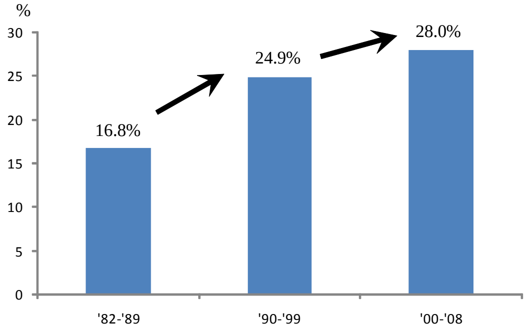
<Figure 4-8> illustrates the ratio of contribution by each of dissemination, cultivation, and meteorological factors to the change in rice yield. The dotted line in the figure indicates the weight of each factor in the overall change while the solid line shows the trend of each dotted line. According to the breakdown of the factors of change and the trend of each factor, the dissemination factors contributed the most in the 1980s but has continuously decreased since then, while the contribution ratio of the cultivation factors has hardly changed; however the contribution ratio of the meteorological factors has constantly increased.

Figure 4−8. Ratio of contribution of each factor to the rice yield change



Among the factors of rice yield change, the contribution ratio of the meteorological factors was 16.8% in the 1980s, but has gradually increased to 24.9% in the 1990s and then to 28.0% in the 2000s <Figure 4-9>.

Figure 4-9. Change in the contribution ratio of the meteorological factors to the rice yield



2.3. Summary of the Impact Analysis for Meteorological Factors

The change in agricultural production is affected not only by meteorological factors but also by technological factors such as breeding, dissemination, and cultivation and political supports as well. In order to identify the extent of the impacts of the meteorological factors on the change in agricultural production in comparison to other factors, the change in the yield of rice, Korea's representative crop, was analyzed.

To understand the trend of changes in quantitative capacity, dissemination, and average annual yields, a logistic curve was estimated. Then, the gap between quantitative capacity yield and dissemination yield was set as the dissemination factor; the gap between dissemination yield and average annual yield as the cultivation factor; and the gap between average annual yield and farm household yield as the meteorological factor.

The rice yield in Korea has shown a stagnating or decreasing trend since the 2000s. The factors contributing to such a change in the rice yield, high-quality variety development policy, increase of environment-friendly cultivation, and climate change including temperature rise have been mentioned.

To analyze the cause of stagnation in the farm household yields of rice in 2002~2003 and 2006~2007, the same conditions as those of previous five years were applied in such an order as ‘breeding factors → cultivation factors → meteorological factors’ and the gap between quantitative capacity yield and the quantity actually realized through the farm household yield was broken down. The result of analyzing the contribution of each factor to the rice yield stagnation shows that the yield stagnation in 2002~2003 was accounted for by the technological factors (23.6%) and by the meteorological factors (76.4%) and the yield stagnation in 2006~2007 was accounted for by the technological factors (33.5%) and the meteorological factors (66.5%), revealing that the meteorological factors made a very significant contribution to the yield change. Such a significant contribution is thought to be caused by the typhoon induced temperature drop and sunlight shortage during the ripening period.

The analysis of the factors contributing to the rice yield change shows that the contribution ratio of dissemination factors has continuously decreased; that of cultivation factors has hardly changed; while that of meteorological factors has shown an increasing trend. Among the factors contributing to the rice yield change, the contribution of meteorological factor appears to have gradually increased (16.8% (1980s) → 24.9% (1990s) → 28.0% (2000s)) though its contribution ratio was not very high in the years when meteorological disasters occur.

3. Analysis of the Impacts of Adaptation Measures on Agricultural Production[14]

[14] The simulation analysis using ORYZA2000 is an abstract of main results of the research commissioned to Dr. C. G. Lee (National Institute of Crop Science, RDA).

3.1. Background of Analysis of the Impacts of Adaptation Measures

Increases in CO_2 concentration and the subsequent global warming can have both positive and negative impacts on crop growth. In order to mitigate negative impacts of climate change, the farm households will have to utilize adaptation measures. For this reason, and in order to understand how adaptation measures affect crop growth, a simulation analysis is required.

In this section, the impacts of adaptation measures on the rice yield are analyzed including the changes in rice growth, the nitrogenous content of each unit of farm household, irrigation, and cultivation time by temperature and CO_2 concentration. For this, the change in annual potential productivity of each rice ecotype and the growth model in each year caused by climate change (temperature and CO_2) is analyzed. Following this the annual rice productivity, taking into consideration the adaptation measures (control of the nitrogenous fertilizer level and the amount of irrigation) in each year is estimated.

This crop growth simulation provides basic data for analyzing the expected economic utility used when measuring the extent of individual farm household's application of climate change adaptation measures and the effectiveness of those measures.

3.2. Analysis Models

To analyze the impacts of climate change adaptation measures, "ORYZA2000" is used, which is the rice growth model developed jointly by International Rice Research Institute (IRRI) and by International Rice Research Institute and Wageningen University of Netherlands in 2000. The environment for the rice growth model in ORYZA2000 is characterized by the following three conditions: First is the potential productivity condition: meteorological data such as light, temperature and CO_2 and the variety characteristics (cultivars) for growth type and physiological process determine the growth of crop. Second is the accessible productivity condition. Accessible growth is determined by limiting factors on potential productivity, such as moisture and nutrient availability. Third is the actual productivity condition, for in reality growth is further reduced by additional restraining factors such as weeds and pests. At present, ORYZA2000 simulates the growth model under the potential productivity condition or the accessible productivity condition in which nitrogenous fertilizer level and moisture are limited, on the assumption that the additional restraining factors such as weeds and pests are completely controlled.

The rice growth simulation in ORYZA2000 requires meteorological data such as sunlight, the lowest and the highest temperatures, and precipitation as well as cultivar parameters such as development rate, rate of distribution of assimilation product to each organ, the speed of assimilation product's travelling during the ripening period, and the specific leaf area (SLA). In this study, the cultivar parameters of the early-maturing variety *Odaebyeo*, the medium-maturing variety *Hwaseongbyeo*, and the medium/late-maturing variety *Ilpoombyeo*, are applied for simulating the growth model of each rice ecotype.

3.3. Analysis Data

For simulating the rice growth model according to the climate change scenario, 56 areas were selected from those where a meteorological station or observatory was located and whose average annual data had been built up over the past 30 years. Island areas and the areas where rice cultivation was impossible were excluded. All the areas selected for simulating the potential productivity according to the climate change scenario were used, of which 17 areas were used for the growth modeling taking into consideration adaptation measures (nitrogenous fertilizer level and irrigation control) under the climate change conditions. The 17 areas were Cheolwon, Chuncheon, Gangneung, Suwon, Cheongju, Daejon, Andong, Daegu, Jeonju, Gwangju, Jinju, Jecheon, Cheonan, Imsil, Haenam, Yeongnam, and Milyang, which represented the agricultural zones (Central, Honam, Yeongnam, etc.) of the different altitudes in Korea.

For simulating the rice growth model according to the climate change scenario, meteorological data was produced. The growth model was simulated using the meteorological data for the average annual yield over several 30 year periods: 1971~2000 (base years), 2011~2040, 2041~2070, and 2071~2100. As for climate change scenario itself, A1B scenario of IPCC was applied. From the climate change scenario data provided by KMA, data on the highest and lowest temperatures and precipitation applicable to the growth model was created. In addition the carbon dioxide concentration for the years of the growth model was decided using the data from the IPCC climate change scenario.

The distribution of average annual temperature and precipitation (average of 56 areas) over the years simulated by the growth model shows that the highest and lowest temperature, precipitation, and CO_2 concentration are all increasing as global warming progresses, in comparison to the base years (1971~2000). According to A1B climate change scenario, the planet-wide global temperature rise for the coming 100 years is 2.8℃. In this study, however, the highest temperature and the lowest temperature are estimated to rise by 4.0% and 4.4℃ respectively. Therefore, global warming in Korea is expected to be much more severe than the planet-wide global warming <Table 4-8>. CO_2 concentration in 2071~2100 is estimated to be 661ppm, which is twice the concentration (345ppm) in the base years <Table 4-9>.

Table 4-8. Average annual temperature and precipitation for the years in the growth model

Meteorological factors	Year of growth model				Deviation from 1971-2000		
	1971~2000	2011~2040	2041~2070	2071~2100	2011~2040	2041~2070	2071~2100
Highest temp. (℃)	17.9	19.0	20.4	22.0	1.1	2.5	4.0
Lowest temp. (℃)	7.3	8.5	10.1	11.7	1.2	2.8	4.4
Precipitation (mm)	1,286	1,367	1,518	1,557	82	232	271

Note: Average annual temperature and precipitation is the average value of 56 areas.

Table 4-9. CO_2 concentration according to the climate change scenario (A1B)

Unit: ppm

Years	ISAMS	BERN	Average
1971-2000	346	345	345
2011-2040	438	434	436
2041-2070	552	542	547
2041-2100	666	655	661

Note: ISAMS and BERN are types of Carbon Cycle Model (CCM).

3.4. Analysis Results

3.4.1. Change in the productivity of each rice ecotype and growth model, for each model period

To analyze the change in productivity of each rice ecotype and growth model by temperature for each model period (30 years), the temperature of each period of the growth model for the climate change scenario and the CO_2 concentration of the base year were applied. The result shows that the productivities of early-maturing, medium-maturing, and medium/late-maturing varieties were all reduced as global warming progresses, relatively worse in the northern areas and for medium/late-maturing variety. <Table 4-10 and Appendix Table A4>.

To analyze the change in productivity of each rice ecotype and growth model by CO_2 concentration for each model period (30 years), the temperature of the base year and the CO_2 concentration of each period of the growth model for the climate change scenario were applied. The result shows that the productivity increased regardless of rice ecotypes, with much more increase in medium/late-maturing variety than in early-maturing and medium-maturing varieties <Appendix Table A5>.

A temperature rise results in a decrease in rice productivity, while a rise in CO_2 concentration results in an increase in rice productivity. For each temperature rise of 1℃, the rice productivity per ha is estimated to decrease by an average of 292kg: 178kg for early-maturing variety, 304kg for medium- maturing variety, and 395kg for medium/late-maturing variety. For CO_2 concentration increase of each 100ppm, the rice productivity per ha is to increase by an average of 231kg: 201kg for early-maturing variety, 254kg for medium- maturing variety, and 238kg for medium/late-maturing variety.

When temperature and CO_2 concentration from the climate change scenario for each period (30 years) of the growth model are applied simultaneously, the productivity of early-maturing variety appears to increase slightly; that of medium-maturing variety decreases a little; and that of medium/late-maturing variety decreases significantly. In general, the southern areas experience a greater decrease in the productivity due to global warming than the northern areas do. This is because the southern regions are not suitable for cultivating the early-maturing variety, its productivity at the base year is relatively low and thus the decrease is relatively large. In addition, as the growth period of medium/ late-maturing variety is relatively long and most regions in Korea are suitable for its cultivation, the decrease in productivity by

Table 4—10. Change in the productivity of each rice ecotype and growth model for each period

Classification		Ecotype	Deviation from 1971～2000				Gross average
			2011～2040	2041～2070	2071～2100	Average	
Meteorological environment	Average temperature (℃)		1.1	2.6	4.2	2.7	2.7
	CO_2 concentration (ppm)		91	202	316	203	203
Rice productivity (kg/ha)	Temperature change, CO_2 fixed	Early-maturing variety	-232	-465	-601	-433	
	Temperature change, CO_2 fixed	Medium-maturing variety	-421	-777	-969	-722	-695
	Temperature change, CO_2 fixed	Medium/late-maturing variety	-556	-1,012	-1,222	-930	
	Temperature fixed, CO_2 change	Early-maturing variety	217	372	567	385	
	Temperature fixed, CO_2 change	Medium-maturing variety	312	486	570	456	415
	Temperature fixed, CO_2 change	Medium/late-maturing variety	321	435	457	404	
	Temperature & CO_2 change	Early-maturing variety	31	13	88	44	
	Temperature & CO_2 change	Medium-maturing variety	-53	-124	-144	-107	-183
	Temperature & CO_2 change	Medium/late-maturing variety	-219	-513	-729	-487	
Change in rice productivity by the change in unit temperature (kg/ha/1℃)		Early-maturing variety	-211	-179	-143	-178	
		Medium-maturing variety	-382	-299	-231	-304	-292
		Medium/late-maturing variety	-506	-389	-291	-395	
Change in rice productivity by the change in unit CO_2 concentration (kg/ha/100CO_2 ppm)		Early-maturing variety	238	184	179	201	
		Medium-maturing variety	342	241	180	254	231
		Medium/late-maturing variety	353	216	145	238	

Note: For the period of 1971～2000, average temperature was 12.6℃; CO_2 concentration 345ppm; the productivity of each ecotype 4,752kg/ha for early-maturing variety, 4,777 kg/ha for medium-maturing variety, and 5,180kg/ha for medium/late-maturing variety.

global warming is greater than early-maturing and medium-maturing varieties.

3.4.2. Estimation of the rice productivity in consideration of adaptation measures

For growth modeling in consideration of adaptation measures against climate change (nitrogenous fertilizer level and irrigation control), 17 representative areas were selected. For adaptation measures, nitrogenous fertilizer levels (0, 30, 60, 90, 120, 150, 180, 210kg/ha) and irrigation days (0, 3, 6, 9, 12, 15, 30, 200 days) were set. The number of irrigation days referred to the number of days when dried rice field was irrigated, and the amount of irrigation each time was 75mm.

When the cultivation period was fixed regardless of rice ecotype, nitrogenous fertilizer level and irrigation control, the rice productivity appeared to rather increase in the order of early-maturing, medium-maturing, and medium/late- maturing varieties <Appendix Table A6>. For each ecotype, the early-maturing variety did not show a significant decrease in rice productivity by the fixed cultivation period but showed a large increase by the shifted cultivation period for each period of the growth model. For the medium/late-maturing variety, the rice productivity decreased significantly by the fixed cultivation period, but in comparison to other ecotypes, it decreased less by the shifted cultivation period for each period of the growth model. The medium-maturing variety showed an in-between trend of early-maturing and medium/late-maturing varieties. It appeared that when the cultivation period was fixed, the ripening period temperature rose significantly along with global warming. This will cause the rice to ripen poorly and thus result in reduced productivity, when compared to the model in which the cultivation period is altered, for each period of the ORYZA2000 growth model <Appendix Table A7 and Table A8>.

Analysis of the impacts of nitrogenous fertilizer level and irrigation control on the rice productivity shows that the nitrogenous absorption by plants and the rice productivity tended to increase as the nitrogenous fertilizer level went up, regardless of rice ecotype and period of the growth model but conversely it decreased when the nitrogenous fertilizer level exceeded 180kg per ha. In fact, most rice varieties cultivated in Korea still produce less when the nitrogenous fertilizer level was 150~180kg because of pests and mutual shading. In order to reflect this phenomenon, the rice productivity in our model was set using the nitrogenous nutrient index, to decrease when the nitrogenous fertilizer level reaches a certain limit (180kg/ha) or beyond. It appeared that regardless of rice ecotype and period of the growth model, irrigation requirements increased and the rice productivity also increased as the period of irrigation to the dried rice field shortened.

In comparison to the days or the amount of irrigation, the nitrogenous fertilizer level appeared to have more impact on rice productivity. As Korea experience substantial precipitation during the rice cultivation period and most farm households in Korea have good irrigation facilities, the impact of irrigation does not seem to be large.

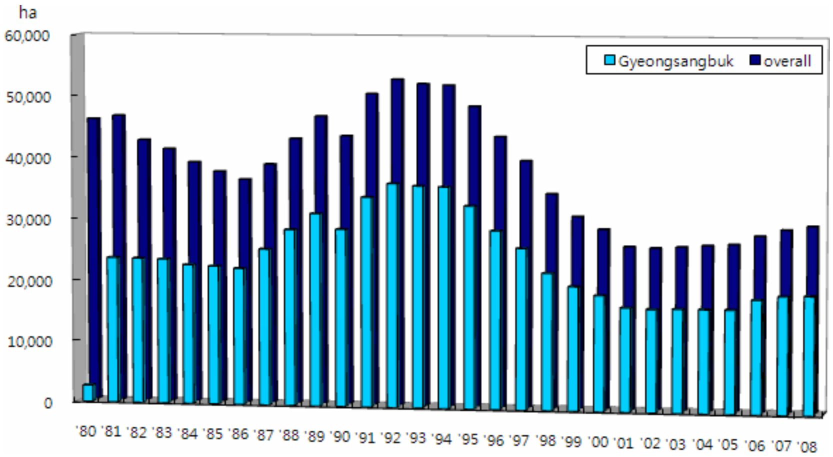
4. Analysis of the Shift of Main Production Regions of Major Crops

4.1. Apples

4.1.1. Cultivation characteristics of apples

The apple cultivation region had continuously increased since the mid-1980s and peaked at 52,098ha in 1994, decreasing thereafter, including during a sharp fall of the apple price in 2000. Since 2003, however, it has been slowly increasing again <Figure 4-10>. As far as

Figure 4-10. Shift in the apple cultivation regions (1980-2008)



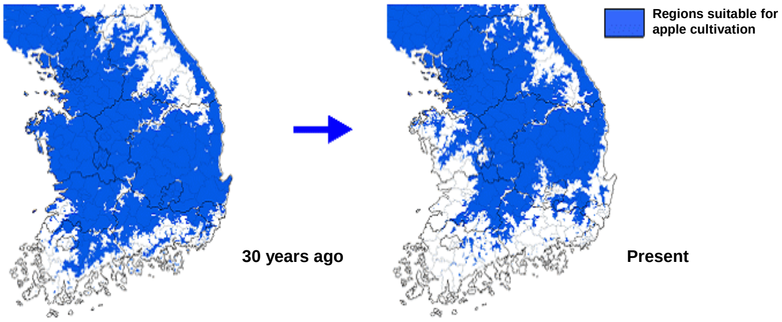
Source: MIFAFF, *Statistics on Agriculture, Food and Fisheries*, annual; KOSIS.

the distribution of cultivation regions is concerned, Gyeongbuk Province accounts for 60% of the entire cultivation region, followed by Gyeongnam, Chuncheong and Jeonbuk Provinces.

Regions suitable for apple cultivation have the winter temperature characteristics of inlands or basins, with an average annual temperature of 8~11℃ and a growing season average temperature of 15~18℃. In Korea, the average annual temperature of the apple cultivating regions is 13.5℃ or less. Due to climate warming, the regions suitable for apple cultivation are shifting north, expanding the safe regions for apple cultivation <Figure 4-11>.[15]

15 The safe cultivation region refers to the lowest temperate zone in which wintering crops can endure during the winter time, not dying from cold (i.e. the region where winter crops can be cultivated).

Figure 4-11. Northward shift in the apple cultivation regions due to global warming



Source: RDA (2009).

4.1.2. Characteristics of the shift in main apple production regions

As it is not easy to determine increase or decrease in the overall shift of apple cultivation regions based on the apple cultivation area, the shift in apple cultivation regions is analyzed based on the percentage of cultivation area.

Among main regions of apple production, the cultivation area devoted to applies and its percentage of the cultivation area increased in such areas as Yeongju, Uiseong, and Andong (Gyeongbuk); Cheongsong, Geochang, Bonghwa (highland/semi-highland area); and Milyang (mountain area) <Figure 4-12>. Though they are not main production regions, Yeongduk and Yeongyang (Gyeongbuk), Jangsu and Muju (Jeonbuk) and Goesan, Yeongdong, Boeun, and Danyang (Chungbuk) are experiencing increases in the apple cultivation area and its percentage <Figure 4-13>. These regions, which were once inland mountain areas and/or semi-highland areas with big daily temperature ranges deemed unsuitable for apple cultivation, are thought to have become more suitable for apple cultivation due to temperature rise caused by global warming.

While the cultivation area in Gyeongsan, Yesan, Yeongcheon, and

Cheongdo in Gyeongbuk Province, the main regions of apple production in the 1970s, have been reduced, the one in Jecheon, Dangjin, Jeongeup, Jangseong, Gokseong and Iksan has remained without significant changes.

Figure 4-12. Main apple production regions where the cultivation area increased

(Cultivation area basis) (Cultivation area percentage basis)

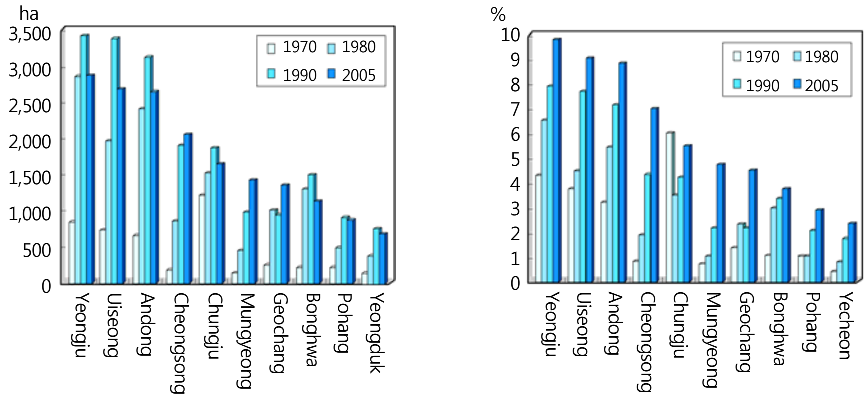
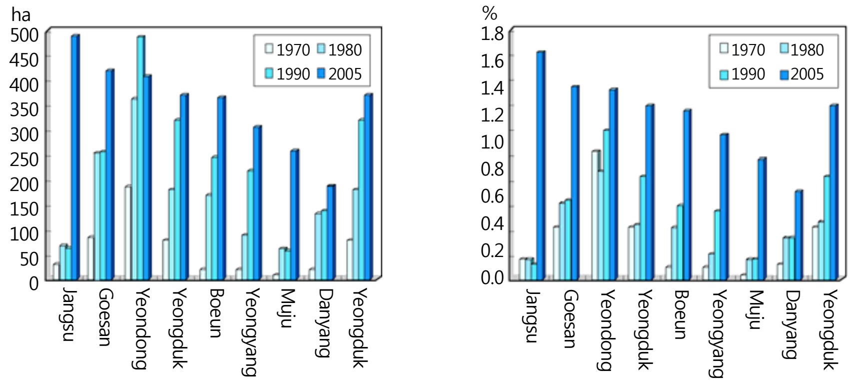


Figure 4-13. New regions where the percentage of cultivation area has increased

(Cultivation area basis) (Cultivation area percentage basis)



Comparison between the main regions of apple production in 1970 and 2005 (based on top 10% of the cultivation area) shows that Gunwi, Andong, Yeongju, Yeongcheon, Yesan, Uiseong, and Chungju have remained as the main regions of apple production. In addition to the above-mentioned changes in apple production regions, the main regions of apple production were changed from Gyeongsan, Gyeongju, Chilgok, and Cheongdo in 1970 to Cheongsong, Mungyeong, Geochang, Bonghwa, and Sangju in 2005.

As the main apple cultivation regions, which used to be Gyeongbuk and Gyeongnam Provinces in 1970, gradually shifted north, it appears that even highland/semi-highland areas or mountain areas such as Geochang, Jangsu, Muju in Gyeongbuk Province had become main apple cultivation regions by 2005 <Table 4-11>.

Table 4-11. Shift in the main apple cultivation regions over the years

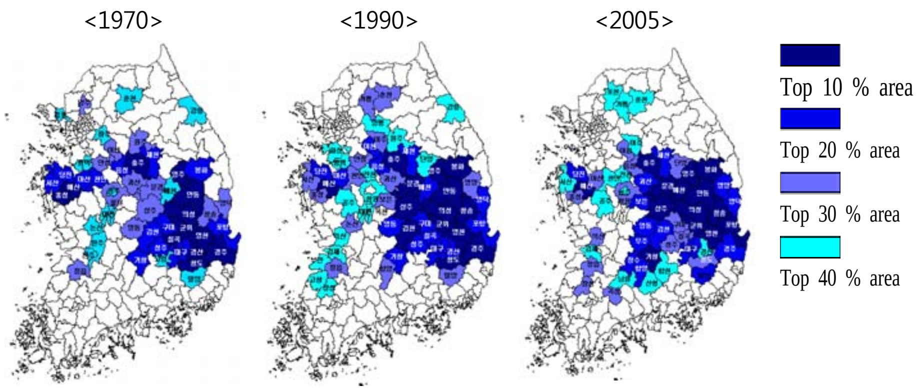
Unit: Ea

			# of regions	Regions
1970	Total # of regions		124	
		Top 10% regions	12	Gyeongsan, Yeongcheon, Chungju, Yesan, Gyeongju, Yeongju, Chilgok, Uiseong, Gunwi, Hongseong, Andong, Cheongdo
		Top 20% regions	25	Daegu, Seongju, Gimcheon, Eumseong, Asan, Jecheon, Seosan, Cheonan, Geochang, Dangjin, Gumi, Pohang, Bonghwa
		Top 30% regions	37	Sangju, Yeongdong, Wonju, Cheongsong, Anseong, Icheon, Mungyeong, Cheongwon, Jeongeup, Yangju, Goesan, Yeongduk
		Top 40% regions	50	Gangneung, Jeonju, Yecheon, Wonju, Goryeong, Cheongju, Pyeongtaek, Chuncheon, Milyang, Nonsan, Gwangju, Gimpo, Daejon
1990	Total # of regions		144	
		Top 10% regions	14	Yeongju, Uiseong, Andong, Yeongcheon, Sangju, Cheongsong, Chungju, Yesan, Gunwi, Bonghwa, Gyeongju, Gimcheon, Cheongdo, Mungyeong
		Top 20% regions	29	Geochang, Pohang, Yecheon, Jecheon, Gyeongsan, Gumi, Icheon, Chilgok, Yeongdong, Asan, Dangjin, Daegu, Eumseong, Seongju, Yeongduk

			# of regions	Regions
		Top 30% regions	43	Hongseong, Nonsan, Cheonan, Hamyang, Gapyeong, Goesan, Boeun, Anseong, Yeoju, Yeongyang, Jeongeup, Chuncheon, Seosan, Milyang
		Top 40% regions	58	Iksan, Gangneung, Cheongwon, Gimje, Gongju, Danyang, Pyeongtaek, Gochang, Jincheon, Jangseong, Hwaseong, Wonju, Daejon, Yangpyeong, Buan
2005	Total # of regions		140	
		Top 10% regions	14	Yeongju, Uiseong, Andong, Cheongsong, Chungju, Mungyeong, Geochang, Bonghwa, Yesan, Sangju, Pohang, Yeongcheon, Yecheon, Gunwi
		Top 20% regions	28	Milyang, Jecheon, Hamyang, Jangsu, Goesan, Yeongdong, Yeongduk, Gimcheon, Boeun, Dangjin, Yeongyang, Gyeongju, Muju, Daegu
		Top 30% regions	42	Eumseong, Danyang, Cheongdo, Seongju, Gumi, Jeongeup, Asan, Jangseong, Chilgok, Gokseong, Icheon, Hongseong, Iksan, Cheongwon
		Top 40% regions	56	Gapyeong, Gongju, Cheongju, Gimje, Jincheon, Pocheon, Namwon, Cheonan, Seosan, Gyeongsan, Yeoju, Sancheong, Hapcheon, Chuncheon

Source: KOSIS. “Agricultural Census Analysis Report.” 1970, 1990, 2005.

Figure 4-14. Shift in the apple cultivation regions

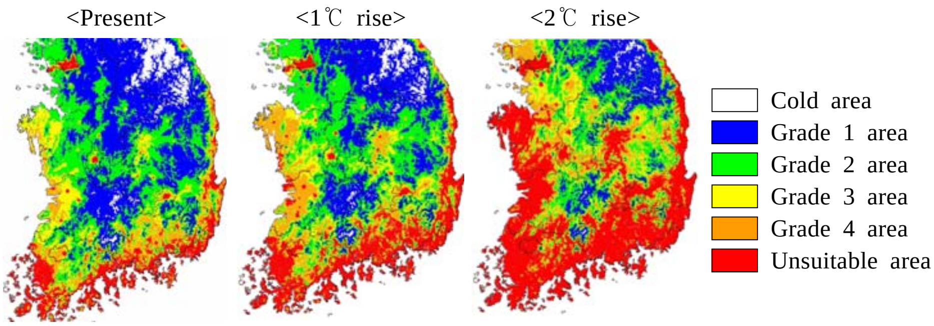


4.1.3. Prospect of the shift in main apple production regions

H. H. Suh *et. al* (2004) forecast the shift in suitable cultivation regions for Fuji apple based on its coloration. At present, almost all areas except the southern regions, some coastal regions, inland planes, and metropolitan regions are climatically suitable for cultivating apples. However, if the average temperature during the growing season rises by 1℃, the suitable cultivation regions will shift north and thus the total growing area will be reduced gradually, causing the mountain regions to become suitable for apple cultivation. With a temperature rise of 2℃, most regions in Korea will become unsuitable for apple cultivation <Figure 4-15>.[16]

It is expected that due to global warming, the apple cultivation regions will continue shifting north with those in Gyeongnam and Chungnam Provinces continuing to decrease. On the other hand, Gyeongbuk, Gyeonggi, and Gangwon areas which are located in higher

Figure 4-15. Prospect of the shift in suitable cultivation regions depending on the extent of average temperature rise during the growth period of Fuji apple



Source: H. H. Suh *et al.* (2004).

16 According to the KMA climate change scenario, the rise of 2℃ in average temperature during the apple growth period will be realized in 2050 or later, in the present state of things (H. H. Suh *et al.*, 2004)

latitudes than the present apple cultivation regions are expected to become suitable for apple cultivation in time <Table 4-12>.

Table 4-12. Prospect of the shift in apple cultivation regions due to global warming

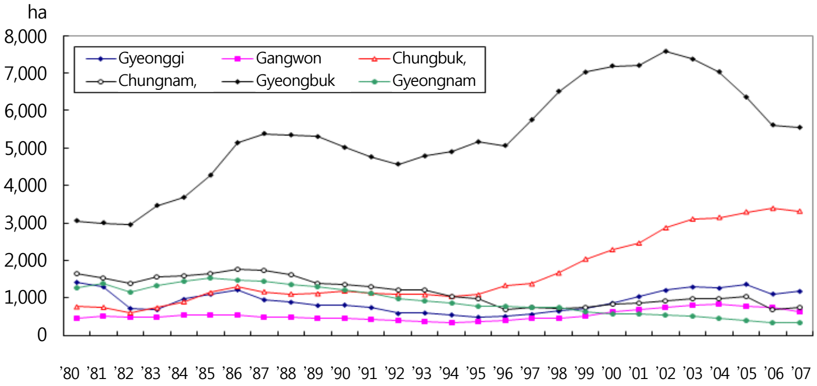
Increasing regions	Main production regions	Yeongju, Uiseong, Andong, Cheongsong, Chungju, Mungyeong, Geochang, Bonghwa, Pohang, Yecheon, Milyang, Hamyang
Increasing regions	Newly increasing areas	Jangsu, Goesan, Yeongdong, Yeongduk, Boeun, Yeongyang, Muju, Danyang
Decreasing regions		Yesan, Yeongcheon, Gunwi, Gimcheon, Gyeongju, Daegu, Eumseong, Cheongdo, Seongju, Gumi, Asan, Chilgok, Icheon, Hongseong, Cheongwon, Cheonan, Seosan, Gyeongsan
Regions remaining the same		Jecheon, Dangjin, Jeongeup, Jangseong, Gokseong, Yeongwol
Main regions of apple production in the future		· Regions at higher altitudes than the current cultivation regions in Gyeongbuk Province (Bonghwa, Cheongsong, Yeongju, Andong, etc.) · Highlands and mountain regions in Gyeongnam Province such as Milyang, Geochang, Hamyang, etc. · Highland regions in Jeonbuk Province such as Jangsu and Muju · North regions in Gyeonggi Province (Pocheon, Gapyeong), some areas in Gangwon Province (Chuncheon, Yanggu, Hwoeingseong, Yeongwol, etc.)

4.2. Peaches

4.2.1. Cultivation characteristics of peaches

The cultivation area for peaches had been decreasing until 1996 but increased thereafter to a total area of 15,880ha by 2003. Gyeongbuk Province, which accounted for 73% of the entire peach cultivation area in 2002, accounted only for 53% of it by 2007. However, the peach cultivation area is increasing in Chungbuk, Gyeonggi and Gangwon Provinces.

Figure 4-16. Shift in the main regions of peach cultivation



Source: MIFAFF, *Statistics on Major Agricultural, Forestry, and Fisheries Foods*, Annual Report.

The optimum growth temperature for peaches is 12~15℃ on average. Peaches are winter-hardy during the period of dormancy, but in the areas where the lowest temperature during the cultivation cycle of about 15 years reaches -25℃, their growth becomes unstable. Even though winter is the period of voluntary dormancy, peach flower buds will freeze to death at temperatures below the lower limit temperature.

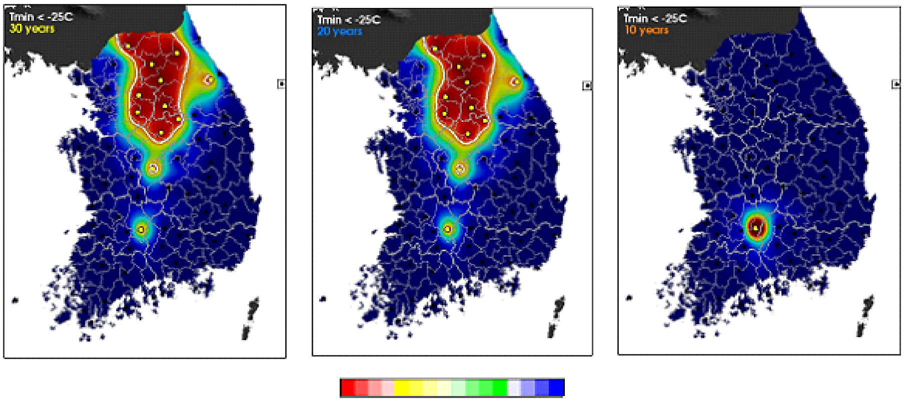
Peaches have low moisture-resistance and thus are greatly affected by precipitation. Therefore, it is better to cultivate peaches in areas with less precipitation. Most especially, if there is a great deal of rain in May and June, the period during which new branches grow, the root loses its physiological functions due to lack of sunlight, reduced anabolism, and wet soil while new branches grow in abundantly consuming most of nutrients, and thus depriving the fruit. The result of this is that many pear fruits fall from the tree before they become ripe. Should it rain a great deal in summer, the ripening period, the lack of sunlight causes reduced sugar content in fruit, resulting in poor quality fruit. Also, too much moisture tends to increase pest infestation.

When temperature rises, the risk and frequency of frost damage decreases. In <Figure 4-17>, the regions within the boundary of white

Figure 4-17. Peach cultivation regions likely to be at risk of frost damage

(Daehwa early-maturing, Okubo, Gido white-flesh peach, Saja ear-maturing, and Dongrang early-maturing varieties)

<1971~2000> <1981~2000> <1991~2000>



Risky zone ←→ Safe zone

Source: H. H. Seo, *et al*.(2002).

line have high probability of frost damage. It appears that as time goes, the range of frost damage risk area becomes smaller.

4.2.2. Characteristics of the change in main peach production regions

Among the main regions of peach production, the cultivation area and its percentage have increased in Yeongcheon (Gyeongbuk), Chungju, Eumseong, and Yeongdong (Chungbuk), and Icheon (Gyeonggi). Though they may not be main production regions, it appears that the cultivation area and its percentage are increasing in Wonju, Chuncheon, Hoengseong (Gangwon), Sangju, Uiseong, Yeongju, Cheongsong (Gyeongbuk and semi-highlands), Namwon, Imsil, Muju (Jeonbuk and semi-highlands), and Yeoju (Gyeonggi). The regions that were once unsuitable for peach cultivation due to low temperatures are now becoming suitable cultivation regions because of global warming <Table 4-13>.

The cultivation area in some main regions of peach production such as Gyeongsan and Cheongdo (Gyeongnam) is falling over time, while remaining the same in Yeongi, Daegu, Okcheon, Cheongwon, and Gyeongju.

Figure 4–18. Main regions of peach production where the cultivation area increased

(Cultivation area basis) (Cultivation area percentage basis)

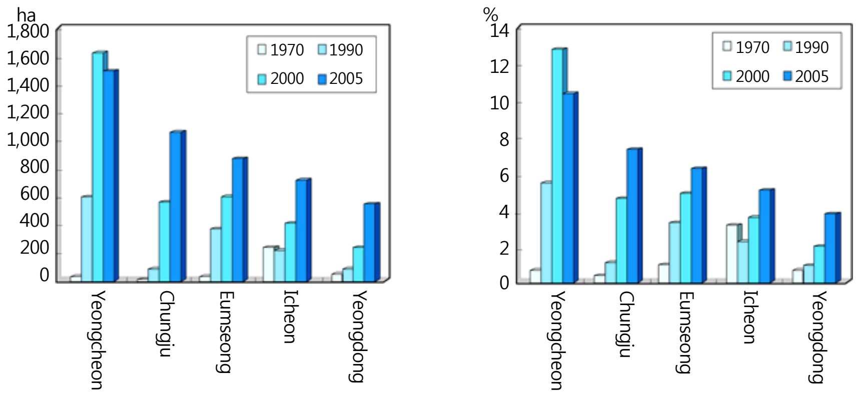


Figure 4–19. New regions where the percentage of peach cultivation area increased

(Cultivation area basis) (Cultivation area percentage basis)

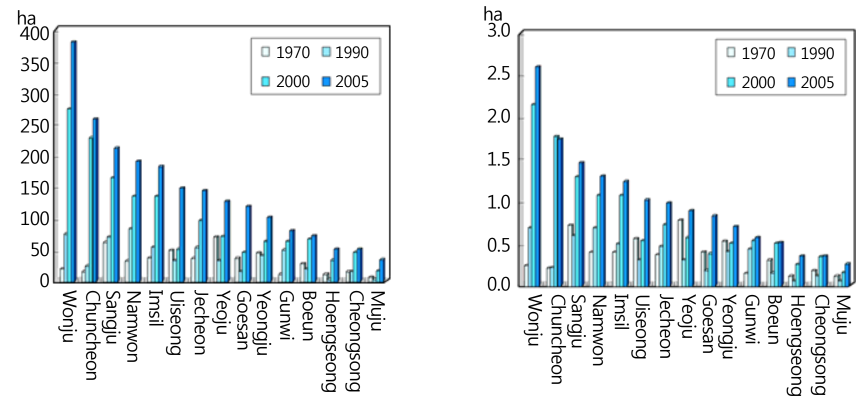


Table 4-13. Shift in the main regions of peach cultivation

Unit: Ea

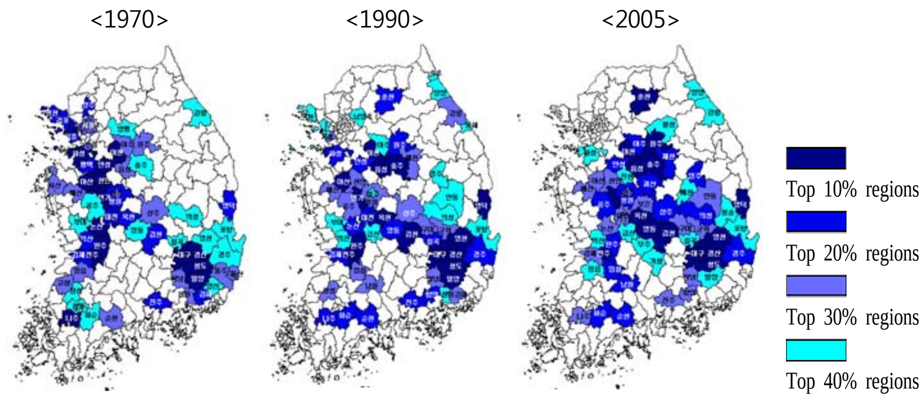
			# of regions	Regions
1970	Total # of regions		147	
		Top 10% regions	15	Naju, Nonsan, Bucheon, Icheon, Wonju, Asan, Milyang, Cheonan, Jeonju, Yeongi, Daegu, Anseong, Gyeongsan, Cheongdo, Hwaseong
		Top 20% regions	29	Gihae, Jinju, Incheon, Daejon, Yeongduk, Shiheung, Gimje, Gimcheon, Pyeongtaek, Cheongwon, Iksan, Yangju, Okcheon, Gimpo
		Top 30% regions	44	Yesan, Changwon, Wonju, Changnyeong, Ulsan, Seoul, Gochang, Suwon, Yeoju, Eumseong, Suncheon, Cheongju, Jeongeup, Sangju, Seosan
		Top 40% regions	59	Yeongcheon, Chungju, Gwangju, Gongju, Hwasun, Gangneung, Chilgok, Gyeongju, Buyeo, Yeongdong, Jangseong, Uiseong, Yangpyeong, Yangsan, Pohang
1990	Total # of regions		149	
		Top 10% regions	15	Cheongdo, Gyeongsan, Yeongcheon, Jeonju, Yeongduk, Daegu, Eumseong, Wonju, Yeongi, Okcheon, Milyang, Icheon, Gimcheon, Chungju, Asan
		Top 20% regions	30	Nonsan, Haman, Wonju, Hwaseong, Jinju, Chilgok, Anseong, Suncheon, Naju, Hwasun, Chuncheon, Gimje, Yeongdong, Daejon, Gyeongju
		Top 30% regions	45	Gimhae, Gumi, Sangju, Cheongwon, Namwon, Changnyeong, Cheonan, Jangseong, Yesan, Imsil, Gongju, Jecheon, Gangneung, Gunwi, Shiheung
		Top 40% regions	60	Pohang, Kumsan, Yeongju, Iksan, Cheongju, Yangyang, Donghae, Yeoju, Uiseong, Andong, Incheon, Sokcho, Changwon, Buyeo, Namyangju
2005	Total # of regions		151	
		Top 10% regions	15	Yeongcheon, Gyeongsan, Cheongdo, Chungju, Eumseong, Icheon, Yeongdong, Yeongi, Daegu, Wonju, Okcheon, Yeongduk, Gimcheon, Jeonju, Chuncheon
		Top 20% regions	30	Sangju, Namwon, Imsil, Uiseong, Jecheon, Suncheon, Yeoju, Cheongwon, Goesan, Yeongju, Hwasun, Gyeongju, Wonju, Anseong, Gongju
		Top 30% regions	45	Gimje, Nonsan, Andong, Gunwi, Jinju, Changnyeong, Cheonan, Boeun, Daejon, Cheongju, Gumi, Naju, Haman, Yesan, Asan
		Top 40% regions	60	Hwaseong, Yangyang, Gangneung, Kumsan, Hoengseong, Cheongsong, Jeongeup, Yecheon, Chilgok, Muju, Milyang, Geochang, Jincheon, Iksan, Pohang

Source: KSAT. "Agricultural Census Analysis Report." 1970, 1990, 2005.

Between 1970 and 2005, Gyeongsan, Yeongi, Icheon, Jeonju, Cheongdo, Daegu were main regions of peach production. In 1970, the top 10 of main peach cultivation regions included Naju, Nonsan, and Asan in addition to the above six regions, but in 2005, Yeongcheon, Chungju and Chuncheon replaced them.

The map analyzed using GIS shows that main peach cultivation regions in the 1970s were limited to the west coastal regions and Gyeongnam but spread out virtually nationwide by 2005. In other words, the conclusion is that the peach cultivation regions are expanding due to the temperature rise and frost damage decrease following global warming.

Figure 4-20. Shift in the main peach cultivation region



4.2.3. Prospect of the shift in main peach cultivation regions due to climate change

Though it seems that future increase in precipitation will cause the peach cultivation area in Gyeongnam Province to be reduced further, it is expected that temperature rise will expand the peach cultivation area to the highlands, semi-highlands, mountain areas, and Gyeonggi and Gangwon Provinces <Table 4-14>.

Table 4-14. Shift in the peach cultivation regions and prospect of future cultivation regions, due to global warming

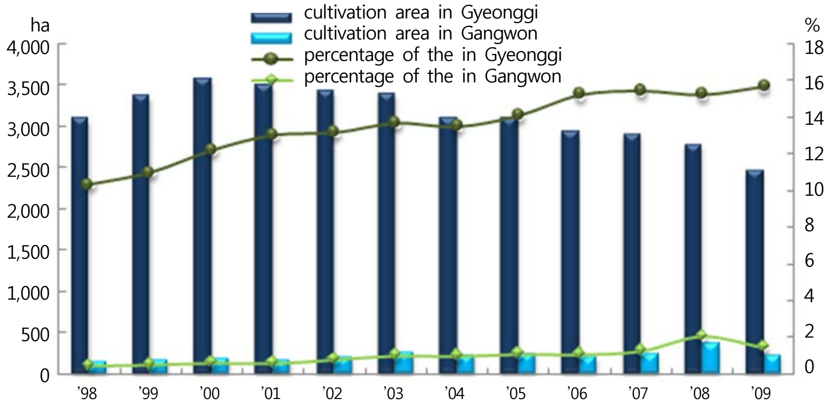
Increased regions	Main production regions	Yeongcheon, Chungju, Eumseong, Icheon, Yeongdong
	Newly increased regions	Wonju, Chuncheon, Sangju, Namwon, Imsil, Uiseong, Jecheon, Yeoju, Goesan, Yeongju, Gunwi, Boeun, Hoengseong, Cheongsong, Muju
Reduced regions	Reduced regions	Naju, Nonsan, Wonju, Asan, Milyang, Cheonan, Anseong, Hwaseong, Gimhae, Jinju, Incheon, Daejon, Shiheung, Gimje
	Recently reduced regions	Gyeongsan, Cheongdo, Yeongduk, Gimcheon, Jeonju, Suncheon, Hwasun
Maintaining regions		Yeongi, Daegu, Okcheon, Cheongwon, Gyeongju, Andong, Gumi, Yangyang, Yecheon, Geochang, Yanggu, Samcheok, Jangsu
Future peach cultivation regions		· Chungju, Eumseong, Icheon, Wonju, and Chuncheon in Chungbuk and Gangwon Provinces will emerge as main peach cultivation regions. · The peach cultivation area will expand to most regions across the country, except Gyeongnam and Jeonnam Provinces, and Jejudo Island.

4.3. Grapes

4.3.1. Cultivation characteristics of grapes

While the overall grape cultivation regions are decreasing, both the cultivation area and its percentage in Gangwon and Gyeonggi Provinces are increasing. The grape production area in Gyeonggi Province increased from 3,086ha in 1998 to 3,557ha in 2000 but had decreased to 2,462ha by 2009. Gyeonggi province's percentage of the entire grape cultivation area increased from 10.3% in 1998 to 15.6% in 2009. The grape cultivation area in Gangwon Province increased from 140ha in 1998 to 371ha in 2008 but again this fell back to 226ha by 2009. The province's percentage of the entire grape cultivation area increased 0.5% in 1998 to 2.0% in 2008.

Figure 4-21. Change in the grape cultivation area and its percentage in Gyeonggi and Gangwon Provinces



Source: KOSTAT (kostat.go.kr).

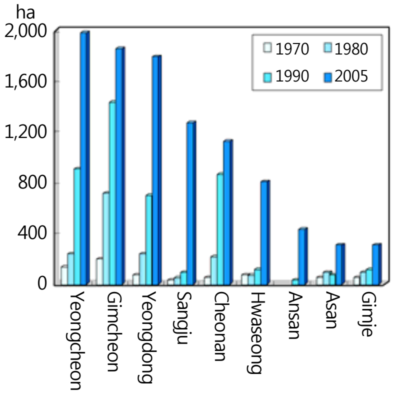
The optimum growth temperature for grapes is 20~25℃, and the soil pH ranges between pH 6.0~6.5. Grapes can grow well even in barren soil and are highly moisture-resistant and xeric, so that they can be cultivated in a wide range of areas.

4.3.2. Characteristics of the shift in main regions of grape production

Among main regions of grape production, the cultivation area and its percentage have increased in Yeongcheon, Gimcheon, Yeongdong, and Sangju (Gyeongbuk); Hwaseong and Ansan (Gyeonggi); Cheonan and Asan (Chungnam); and Gimje (Jeonbuk). Though they may not be main production regions, it appears that the cultivation area and its percentage are increasing in Gapyeong, Pocheon (Gyeonggi), Yeongwol (Gangwon), Geochang, Muju (semi-highlands), and Namwon. The date suggests that those regions that were once unsuitable for grape cultivation due to low temperatures have became suitable for grape cultivation due to the effects of global warming.

Figure 4-22. Main regions of grape production where the cultivation area increased

(Cultivation area basis)



(Cultivation area percentage basis)

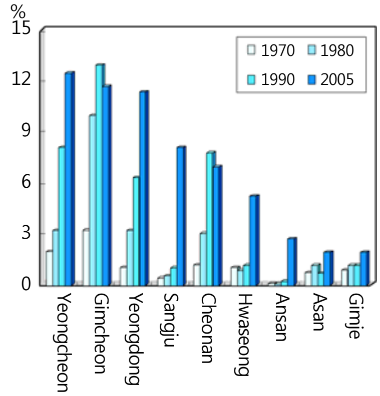
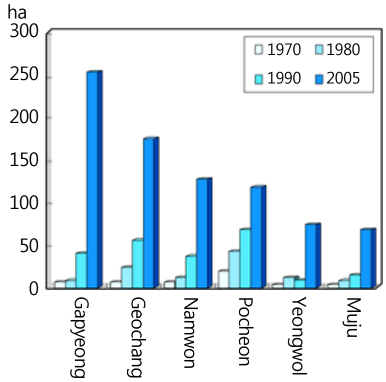
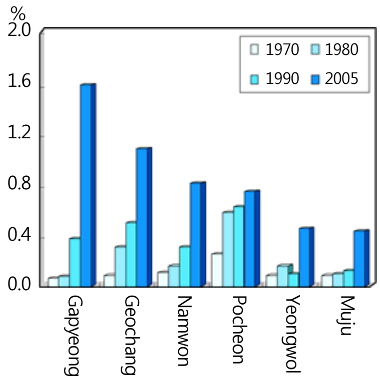


Figure 4-23. New regions where the percentage of grape cultivation area increased

(Cultivation area basis)



(Cultivation area percentage basis)



The cultivation area in main grape cultivation regions such as Gyeongsan (Gyeongnam) has decreased while the area in Anseong, Chilgok, Yeongi, Boryeong has remained almost the same.

Comparison of the main regions of grape production in 1970 and 2005 (based on top 10% regions) shows that Yeongcheon, Gimcheon, Gyeongsan, Daegu, Anseong, Okcheon have ranked as the top 6 regions since 1970. In 1970, grapes were produced in Daejon, Bucheon, Milyang, and Changwon in addition to the above 6 regions. But, in 2005, Yeongdong, Sangju, Cheonan, and Hwaseong replaced those regions <Table 4-15>.

According to the map showing suitable cultivation regions, grapes were cultivated mostly in Gyeongnam Province and the west coastal regions in 1970. In 2005, however, the suitable regions for grape cultivation had expanded to include Gyeongbuk, Chungbuk, Gyeonggi, and Gangwon Provinces. Also, in 2005, it appeared that the highlands, semi-highlands and even the mountain areas that had previously been unsuitable for grape cultivation such as Geochang, Muju became available for grape cultivation <Figure 4-24>.

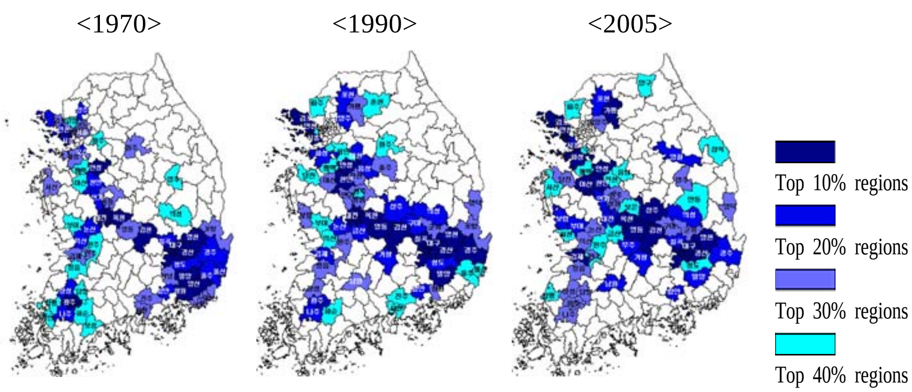
Table 4－15. Shift in the main grape cultivation regions

			# of regions	Regions
1970	Total # of regions		140	
	(dark navy)	Top 10% regions	14	Gyeongsan, Daejon, Bucheon, Milyang, Changwon, Okcheon, Gimcheon, Daegu, Gwangju, Gimhae, Anseong, Yeongcheon, Shiheung, Yangsan
	(blue)	Top 20% regions	28	Gyeongju, Yangju, Nonsan, Incheon, Naju, Cheongdo, Yeongi, Chilgok, Suwon, Haman, Jangseong, Ulsan, Iksan, Cheonan
	(light blue)	Top 30% regions	42	Hwaseong, Yeongdong, Gimpo, Cheongwon, Wonju, Gimje, Pohang, Busan, Jeonju, Jinju, Seosan, Changnyeong, Sacheon, Seoul
	(cyan)	Top 40% regions	56	Damyang, Asan, Yeongju, Hampyeong, Goyang, Buyeo, Boseong, Pyeongtaek, Wonju, Hwasun, Gwangju, Muan, Uiseong, Jeongeup

			# of regions	Regions
1990	Total # of regions		153	
		Top 10% regions	15	Gimcheon, Gyeongsan, Yeongcheon, Cheonan, Yeongdong, Daegu, Gimpo, Okcheon, Anseong, Daejon, Gyeongju, Milyang, Incheon, Shiheung, Chilgok
		Top 20% regions	31	Eumseong, Haman, Hwaseong, Gimje, Uiseong, Kumsan, Namyangju, Gwangju, Sangju, Cheongdo, Naju, Nonsan, Gumi, Pocheon, Icheon, Geochang
		Top 30% regions	46	Cheongwon, Asan, Changwon, Jeongeup, Yeongi, Jincheon, Boryeong, Jangseong, Chungju, Pohang, Gunwi, Gapyeong, Wonju, Yeongduk, Namwon
		Top 40% regions	61	Chuncheon, Sacheon, Iksan, Hwasun, Dangjin, Buyeo, Cheongju, Paju, Wonju, Bucheon, Suwon, Yongin, Ulsan, Jinju, Pyeongtaek
2005	Total # of regions		156	
		Top 10% regions	16	Yeongcheon, Gimcheon, Yeongdong, Sangju, Gyeongsan, Cheonan, Hwaseong, Daegu, Ansan, Anseong, Asan, Gimje, Gapyeong, Gimpo, Okcheon, Incheon
		Top 20% regions	31	Gyeongju, Daejon, Geochang, Chilgok, Namwon, Pocheon, Milyang, Yeongi, Boryeong, Uiseong, Yeongwol, Shiheung, Muju, Buyeo, Haman
		Top 30% regions	47	Yeongduk, Gwangju, Jeonju, Jangseong, Gumi, Cheongwon, Naju, Iksan, Yeongju, Damyang, Cheongju, Nonsan, Namyangju, Gunwi, Jeongeup, Dangjin
		Top 40% regions	62	Suwon, Kumsan, Cheongdo, Pyeongtaek, Jincheon, Samcheok, Andong, Wonju, Boeun, Paju, Seocheon, Yeonggwang, Yanggu, Eumseong, Seosan

Source: KOSIS (2010).

Figure 4-24. Shift in the grape cultivation regions



4.3.3. Prospect of the shift in main grape production regions due to climate change

As temperature rises due to global warming, it is expected that the grape cultivation region will expand further. It is also expected that the northward shift of grape cultivation regions will make Gyeongbuk, Chungbuk and Gyeonggi Provinces the main production regions and expand the grape cultivation area even further to Gangwon Province <Table 4-16>.

Table 4-16. Prospect of the shift in grape cultivation regions due to global warming

Increased regions	Main production regions	Yeongcheon, Gimcheon, Yeongdong, Sangju, Gyeonggi Hwaseong, Ansan, Chungnam, Cheonan, Asan, Gimje
Increased regions	Newly increased regions	Gapyeong, Pocheon, Yeongwol, Geochang, Muju, Namwon
Reduced regions		Gyeongsan, Okcheon, Gimpo, Daejon, Milyang, Shiheung, Haman, Gwangju, Naju, Nonsan, Namyangju, Cheongdo, Bucheon, Changwon, Yangju, Wonju, Gimhae, Yangsan
Maintaining regions		Anseong, Chilgok,Yeongi, Boryeong, Jangseong, Gumi, Yeongju, Gunwi, Samcheok, Yanggu, Cheongsong, Gangneung, Hamyang, Donghae, Yeongyang, Yeoncheon, Hongcheon, Jeongseon, Pyeongchang
Future grape cultivation regions		· Gyeongbuk, Chungbuk and Gyeonggi Provinces are expected to emerge as main production regions. · It is expected that the grape cultivation area will expand to Gyeonggi and Gangwon Provinces.

4.4. Halla Oranges

4.4.1. Cultivation characteristics of Halla oranges

The halla orange was first introduced to Jeju Island in the early 1990s but at that time it was not well disseminated due to technical limitations. However, when the limitations of the cultivation technology were overcome in the late 1990s, the dissemination of Halla oranges was expanded. Halla orange has been mostly cultivated in Jejuddo but as temperature is rising due to global warming, its cultivation regions are gradually expanding to include Jeonnam and Gyeongnam Provinces. The cultivation area for Halla oranges was 1.5ha in 1994 but this increased sharply to 265ha in 2000 and then to 1,101ha in 2004, However, the rate of increase subsequently slowed and the area in 2007 was 1,137ha.

The viable temperature for Halla oranges is 15℃ or higher for germinating and for the seedling to grow, 20~25℃ is needed for the fruit to mature, and 4~5℃ is needed for storage. Thus, regions whose average annual temperature is 16.5℃ or higher and whose winter temperature does not fall below 3℃ are suitable for cultivating Halla oranges.

4.4.2. Characteristics of the shift in main production regions for Halla oranges

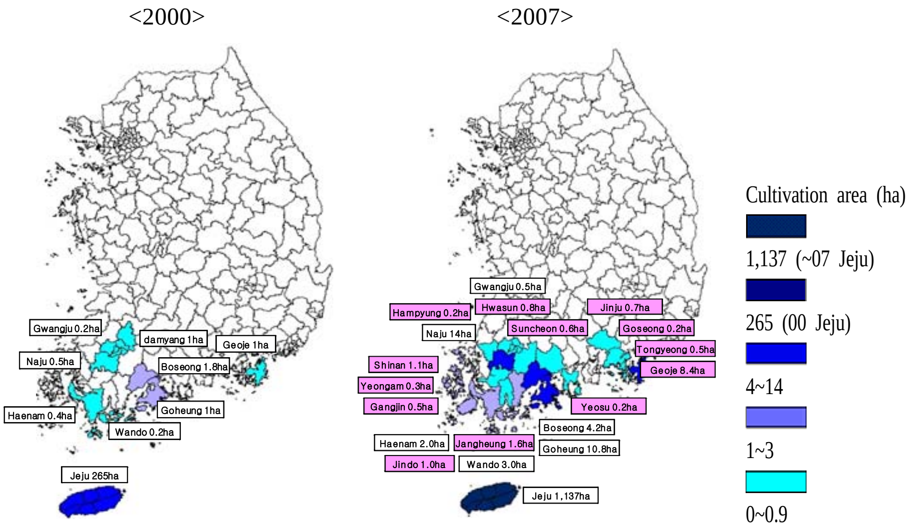
Halla orange, which had been cultivated only in Jeju Island and in some parts of Jeonnam Province in 2000, began being cultivated in Gyeongnam Province in 2007, with a corresponding increase in its cultivation area. The Halla orange cultivation area in 2000 was 265ha in Jeju and 4.2ha in 7 cities and counties in Jeonnam Province. In 2007, this had increased to 1,137ha in Jeju, 40.8ha in 16 cities and counties in Jeonnam, and 9.8ha in 4 cities and counties in Gyeongnam.

It appears that the regions suitable for cultivating Halla oranges have shifted north due to global warming.

4.4.3. Prospect of the shift in main Halla orange production regions due to global warming

It is expected that the Halla orange cultivation region will keep expanding due to global warming in the Korean Peninsula. It is also expected that temperature rise will lead to a switch from greenhouse cultivation to open field cultivation in Jeju and expand the cultivation areas to other regions in Jeonnam and Gyeongnam Provinces <Table 4-17>.

Figure 4-25. Shift in the Halla orange cultivation regions



Note: Colored regions in 2007 map indicate new cultivation regions.
Source: Jeonnam Agricultural Research and Extension Service, Jeju Provincial Office

Table 4-17. Prospect of the shift in Halla orange cultivation regions due to global warming

2000	· Seogwipo (Jeju) · 7 cities and counties in Jeonnam: Gwangju, Naju, Damyang, Buseong, Haenam, Goheung, and Wando
2007	· Seogwipo, Jejushi (Jeju) · 16 cities and counties in Jeonnam: Gwangju, Hwasun, Hampyeong, Naju, Shinan, Yeongam, Gangjin, Haenam, Jindo, Jangheung, Wando, Boseong, Goheung, Yeosu, and Suncheon · 4 cities and counties in Gyeongnam: Geoje, Tongyeong, Jinju, and Goseong
Future Halla orange cultivation regions	· Open-field cultivation of Halla oranges in Jejudo Province is expected to increase more. · Goheung, Naju (Jeonnam), and Geoje (Gyeongnam) are expected to become main Halla orange production regions on land. · The cultivation region will shift to north to Milyang (Gyeongnam) and Jangseong (Jeonnam).

4.5. Tropical Crops

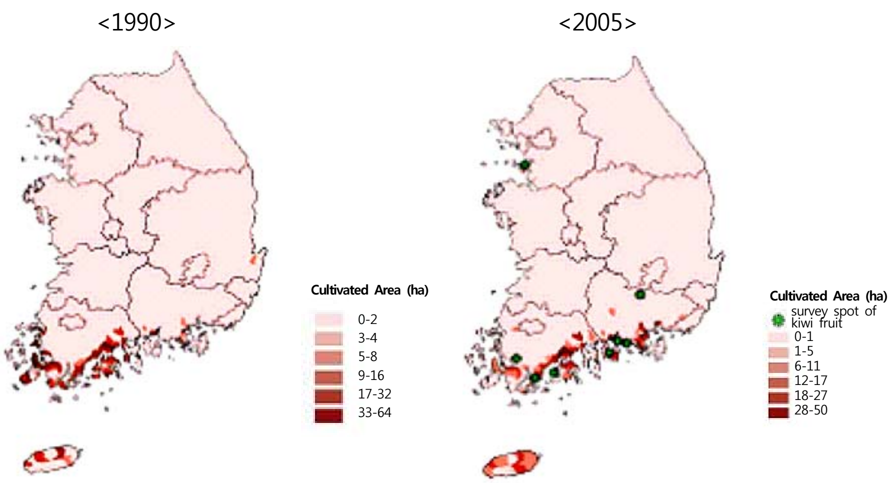
Global warming has also made it possible to cultivate tropical crops that could not previously have been cultivated in Korea, as well as expanding their cultivation area after introduction.

For example, the main production regions of kiwi fruit which is a relatively new crop to Korea had been cultivated mostly in Jeju Island and some south-coastal regions such as Mokpo, Haenam, and Goheung in Jeonnam Province and northern Jeju in 1990. This area expanded to include Sacheon (Gyeongnam) and the entire region of in Jeju Island by 2005 (Y. S. Kwak *et al*., 2009). The fact that the cultivation regions had expanded over a short 15 year period may be attributed to the increased consumption of kiwi fruits. However, more importantly it is because global warming has expanded warm regions suitable for cultivating kiwi fruits. In very much the same way, figs are also cultivated in more regions than before. As the regions suitable for cultivating subtropical fruits such as kiwi fruits and figs are expanding, it is expected that the regions suitable for cultivating tropical fruits such as guava and Avocado will also expand.

In order to cultivate tropical fruits temperature is but one of many considerations; precipitation, soil, wind, and sunshine being the others. In this section, however, the viable temperatures for subtropical fruits such as guava, atemoya, mango, and papaya will be discussed.

Tropical fruits can be cultivated in the regions where temperature does drop below zero. Guava is more resistant to low temperatures than other subtropical fruits. The optimum temperature range for guava growth is 23~28℃. If the temperature during its flowering season drops below 23℃ or if the temperature during its growth exceeds 27℃, the fruiting rate drops. For atemoya, the highest temperature ranges between 22~28℃ and the lowest temperature ranges between 10~20℃, with 20~26℃ being the average temperature required for the fruit to

Figure 4-26. Shift in the kiwi fruit cultivation regions



Source: Y. H. Moon *et al.* (2009).

ripen. Viable temperatures for mango cultivation range between 24~27℃. When the temperature drops below 5℃ during the flowering or fruiting season, severe damages is expected and if the temperature exceed 37℃ this will result in heat injury. Viable temperatures for papaya cultivation is 21~33℃, with a lowest temperature limit of 12~14℃. If papaya is exposed to the lowest temperature limit for several hours, its growth and production will be adversely affected. At temperatures higher than 30℃, its capacity for photosynthesis drops dramatically.

Among tropical fruits, guava, avocado, atemoya, mango, pitaya, and papaya are mostly cultivated in protected facilities, either heated greenhouses or non-heating facilities in Jejudo, which tells that Jeju is the first region suitable for cultivating tropical fruits. Based on A1B scenario[17], one of climate change scenarios applicable to the Korean Peninsula, the regions suitable for cultivating tropical fruits on land other than Jeju Island are expected to be as shown in Figure <4-28>.[18]

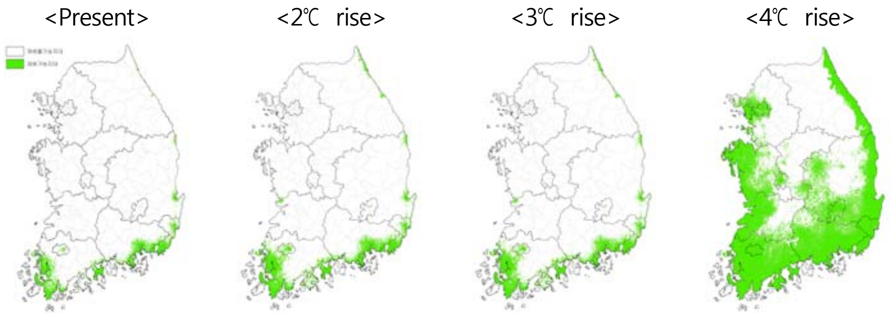
Among tropical fruits, guava is most likely to be cultivated in the near future though only a very small area will be suitable for its cultivation at current temperature zone. However, if temperature continues rising, the guava cultivation region will expand to Jeonnam and Gyeongnam Provinces in 40 years (on the assumption of 2℃ rise) and then to the regions along the west and the east coasts in 70 (3℃ rise). Therefore, if only temperature is considered, it is expected that global warming will expand the guava cultivation region to a considerable area.

In addition to guava, avocado, it is expected that atemoya, mango, pitaya, and papaya will also be cultivated in more northern regions in the order of ‘guava, avocado → atemoya, mango → pitaya → papaya.’

17 According to the estimation by A1B Scenario, it is expected that the average annual temperature of Korea in the end of the 21st century will rise by about 4℃ and the precipitation by about 17% from the average year (1971～2000).

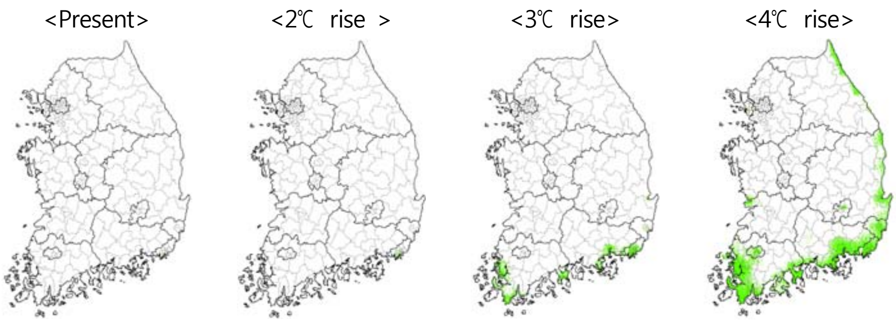
18 The above picture is quoted from the article by H. H. Suh, et al.(2009), and its spatial resolution is 30m×30m.

Figure 4-27. Prospect of the shift in strawberry guava cultivation regions due to temperature rise



Source: H. H. Seo, *et al*.(2009).

Figure 4-28. Prospect of the shift in tropical guava cultivation regions due to temperature rise



Source: H. H. Seo, et al.(2009).

4.6. Implications

The shift in main production regions of major crops such as apples, peaches, grapes, and Halla oranges due to climate change was discussed above. Most of the crops discussed above are fruit trees. While annual crops may be sown or planted by selecting the proper cultivation periods, fruit trees being perennials cannot be replaced once they are planted and therefore they are most affected by climate change.

As discussed above, the suitable regions for crop cultivation have shifted north and the cultivation areas for peaches and grapes have been expanding. Though the cultivation area is expanding, the area does not imply a safe cultivation region and in some regions damages caused by abnormal temperatures are expected.

According to the recent reports, the zone under the risk of frost damage during the wintering season has been reduced in size due to global warming. Despite this, it appears that the frost damage has not decreased but rather increased. This is because the frost damage occurs not only due to very low temperature during winter or early spring but also by a sudden drop in temperature during a warm spring. Therefore, it is important to set the boundary for safe cultivation regions by assessing the conditions for safe cultivation based on climate analysis. Also, it is essential for certain regions that do not have previous cultivation experience of specific crops that they cultivate the crops only after confirming that they can indeed be cultivated safely in their regions through continuous trial cultivations.

On the other hand, not all the impacts on the agriculture sector due to climate change are negative.. The northward shift in the cultivation regions of a crop gives certain regions that had been unsuitable for cultivating a particular crop an opportunity to do so and existing cultivation regions an opportunity to introduce a new crop.

The analysis of the shift in main production regions of major crops has the following implications: First, in order to cope with the northward shift in the existing crop cultivation regions, action needs to be taken by regions that might become suitable for cultivating a particular crop. The southern regions, Jeonnam and Gyeongnam Provinces as well as Jeju Island, where tropical crops can be cultivated should prepare proper countermeasures and find opportunities brought about by climate change. They have to review the adaptability of subtropical fruits such as tangerines, kiwi fruits, and figs to the inland, and select and develop varieties that can adapt themselves to each region, so as to replace the temperate fruit trees. They also have to review the adaptability of tropical fruits such as mango and papaya to the inland and verify their cultivation limits, to select and develop revenue-creating crops in preparation against climate change. Second, global warming by climate change has powerful impacts on the agricultural system of a region that can shatter the foundation of its agricultural system. For this reason, viable adaption to future global warming requires reliable estimation of the shift in suitable cultivation regions. Most especially, opportunities for crops and fruit trees can be found through scientific impact assessment and viable, long term adaptation measures. Third, there is an urgent need to discover cases of the positive impacts of climate change on each region and each item, and so prepare plans to make the positive use of them.

Table 4-18. Forecast of future main production regions of each crop due, following global warming

Apples	· Regions at higher altitudes than the present cultivation regions in Gyeongbuk Province (Bonghwa, Cheongsong, Yeongju, Andong, etc.) · Highlands and mountain regions in Gyeongnam Province such as Milyang, Geochang, and Hamyang · Highlands in Jeonbuk Province such as Jangsu and Muju · Northern regions of Gyeonggi (Pocheon, Gapyeong), some regions in Gangwon (Chuncheon, Yanggu, Hoengseong, Yeongwol, etc.)
Peaches	· Chungju, Eumseong, Icheon, Wonju, and Chuncheon in Chungbuk and Gangwon Provinces are emerging as main production regions. · Expected to expand to most regions across the country, except Gyeongnam, Jeonnam, and Jeju Provinces.
Grapes	· Gyeongbuk, Chungbuk, and Gyeonggi Provinces are expected to become main production regions. · Expected to expand to Gyeonggi and Gangwon Provinces.
Halla oranges	· Open-field cultivation of Halla oranges are expected to increase more in Jeju Island.

	· Goheung and Naju in Jeonnam Pronvice and Geoje in Gyeongnam Province are expected to become main production regions on land. · Expected to shift north to Milyang in Gyeongnam Province and Jangseong in Jeonnam, in addition to the existing cultivation regions.
Tropical crops	· The cultivation regions for kiwi fruits that could only be cultivated in Jejudo, Jeonnam and some part of Gyeongnam Province are expected to expand north. · The cultivation regions for tropical fruits such as guava, avocado, atemoya, mango, pitaya, and papaya are also expected to gradually shift north to the entire regions on land.

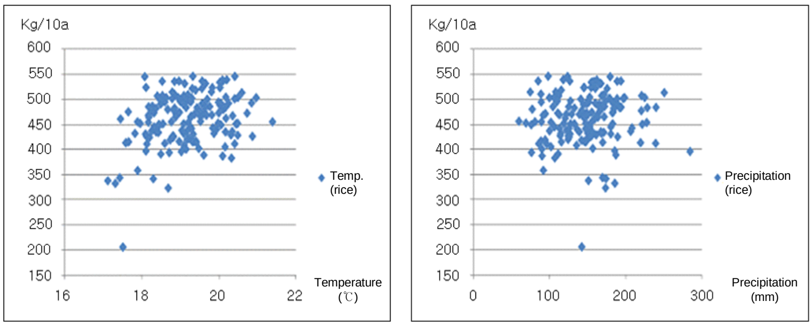
5. Analysis of Economic Impact on the Agricultural Sector

5.1. Analysis of the Impact of Climate Change on Productivity

The analysis of the impact of climate change including temperature and precipitation, on agricultural productivity, the parametric method that carries out regression analysis assuming certain functions and the nonparametric/semiparametric method, which carries out flexible analysis without assuming any function, are both applied. The nonparametric analysis includes various models and each model has unique advantages and disadvantages, so that proper models need to be selected depending on the data used and the objects analyzed. This study used the kernel regression analysis which is the most basic of the nonparametric analysis methods, and the partially linear model which is one of the popular semiparametric analysis methods (C. G. Kim *et al*., 2008).

Rice, the representative crop in Korea's agricultural sector and whose statistical data has well been established, was used for analyzing the impact of climate change on agricultural productivity. If the average national data is used for analysis, the dimension of observation will be so small that the problem of statistical significance may occur. So the panel data, combining yearly data for main production regions, was used for this study. Using *Ilbanbyeo* data for the period from 1975 to 2006 for five provinces such as Gyeonggi, Chungnam, Jeonbuk, Jeonnam, and Gyeongbuk, the change in rice productivity by climate variables such as temperature and precipitation was analyzed. Before the 1990s, *Tongilbyeo* and *Ilbanbyeo* were produced concurrently. However, as the productivity per unit area differed greatly between these two varieties, only the data about *Ilbanbyeo* was used for analysis The relationship between the rice yield and the average temperature between April and August, the rice growth period, and average monthly precipitation during the period can be illustrated as shown in <Figure 4-29>. One data value, which seems to be an abnormal observation, indicates very low productivity and it is observed that every region had low productivity in 1980 due to cold weather damage. In general, however, it appears to be difficult to identify an obvious relationship between temperature or precipitation and rice productivity only with this graph.

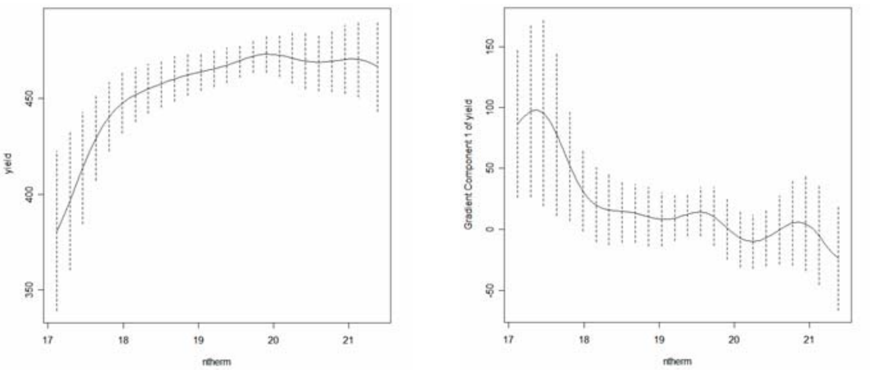
Figure 4-29. Relationship between rice yield and temperature/precipitation



With regard to estimation using nonparametric kernel functions, kernel regression analysis was carried out for the relationship between rice yield and average temperature for the period between August and October, by applying temperature which is a continuous variable to kernel function. As a result, the impact of average temperature on rice growth during the abovementioned period was estimated as illustrated in <Figure 4-30>. Vertical dotted line indicates 95% confidence interval for each estimated value obtained through bootstrapping (number of samplings: 399 times). In this graph, it is suggested that as average annual temperature rises within a certain range, rice yield rises too but if temperature rise exceeds this range, it results in a lowering of the rice yield.

In the relationship between temperature and rice yield, when temperature goes higher than 19℃, the confidence interval of derivative includes zero and thus the impact of temperature change on yield is statistically considered zero. On the other hand, when temperature is lower than 19℃, derivative of the estimated nonparametric model is calculated to be 24.4kg on average, implying that temperature rise of 1℃ during the growth period of rice temperature will lead to an increase of 24.4kg on average in rice yield per 10a. The observation

Figure 4–30. Relationship between the rice yield and the average temperature during rice cultivation period



for temperature higher than 20℃ suggests that temperature rise of 1℃ results in a decrease of 6.2kg in rice yield per 10a. In order to obtain high statistical credibility for the effect of additional temperature rise in high temperature areas, it is necessary to reflect future temperature changes in the analysis and increase the temperature distribution in the data. Though statistical significance of the impact of future temperature rice on decrease in rice yield is weak, it is obvious that a future temperature rise will not result in an increase in rice yield.

5.2. Mid/long-term Prospect of Agricultural Production

According to the estimation of yields of early-maturing (*Odaebyeo*), medium-maturing (*Hwaseongbyeo*), and late-maturing (*Dongjinbyeo*) varieties of rice using CERES-Rice model based on National Institute of Meteorological Research's climate change scenarios for the period of 2011~2100, it is estimated that the earing seasons for all three varieties will be about seven days earlier in the mid-term (2011~2040) and up to 20 days earlier in the long term (2071~2100) and their physiological maturing period will be shortened by up to one month. In addition, the analysis of change in rice productivity, using CERES-Rice model with the A2 climate change scenario for the Korean Peninsula, shows that the national average of rice yield per 10a simulated through the average climate map for 1971~2000 was 539kg, with Chungnam Province recording the highest yield of 591kg and Gangwon Province the lowest yield of 493kg <Table 4-19>.

It is estimated that if temperature rises by 2℃ from average annual temperature due to global warming, the national average of rice yield per 10a will become 515kg, which is a 4.5% reduction from the average annual yield. Province by province, Jeonnam and Jeonbuk showed the biggest decrease of 5.9~6.9% from the average annual yield, while Chungnam and Chungbuk showed a relatively small decrease

Table 4-19. Mid/long-term estimate of rice yield using CERES-Rice model

Unit: kg/10a, %

Province	Average annual yield	2℃ rise		3℃ rise		4℃ rise		5℃ rise	
		Yield	Percentage	Yield	Percentage	Yield	Percentage	Yield	Percentage
Gangwon	493	471	95.5	450	91.3	457	92.6	443	89.8
Gyeonggi	520	501	96.3	480	92.3	470	90.4	449	86.5
Gyeongnam	517	488	94.4	474	91.6	463	89.4	444	85.9
Gyeongbuk	550	532	96.7	506	92.1	503	91.5	481	87.6
Jeonnam	535	498	93.1	481	89.9	474	88.6	431	80.6
Jeonbuk	531	500	94.1	487	91.7	472	88.8	456	85.8
Chungnam	591	575	97.3	549	93.0	529	89.6	495	83.8
Chungbuk	523	510	97.6	484	92.5	494	94.4	457	87.3
Average	539	515	95.5	495	91.8	486	90.1	459	85.1

Source: Kim C.G. and K.M. Shim (2009).

of about 2.4~2.7%.

If temperature rises by 3℃ from average annual temperature, the national average of rice yield per 10a will be 495kg, which is an 8.2% reduction from the average annual yield. Province by province, Jeonnam showed the biggest reduction of 10.1% from the average annual yield while Chungnam showed the smallest reduction of seven percent.

If temperature rises by 5℃ from the average annual temperature, the national average of rice yield per 10a will be 459kg, which is 14.9% reduction from the average annual yield. Province by province, Jeonnam showed the biggest reduction of 19.4% from the average annual yield, followed by Chungnam which showed the least decrease of 16.2%. On the other hand, it is estimated that Gangwon Province will experience a 10.2% reduction, a relatively small percentage. The cause of this decrease in rice yield is analyzed as being due to the reduced fertility rate at high temperature, respiration loss due to high temperatures at night as well as by the shortened ripening period brought on by global warming.

5.3. Analysis of Impact on the Agro-economy

5.3.1. Ricardian Analysis Model

The use of an Agro-economic model, which uses the crop production function for analyzing the economic impact of climate change, brings with it the problem of underestimation as it does not reflect the indirect impacts of climate change such as crop conversion and adjustment of input factors in adapting to climate change. As suggested in the thesis introduction, the Ricardian model was developed to solve this problem (Mendelsohn, Nordhaus, and Shaw, 1994). This model assesses the economic impact of climate change by estimating the current value of farmland price as the discounted value of future rent. Basically, it assumes that, in a long-term balanced state in which all production elements that change along with climate change, farmland price represents the quasi-rent which is the profit from utilizing the farmland.[19] The Ricardian model has an advantage with regard to climate change impact assessment as it can include adaptation that cannot be accurately measured or identified. It measures the change in farmland value or revenue by taking into consideration both direct impact such as changes in crop productivity due to climate change and indirect impacts such as replacement effect of input production factors and changes in farmland utilization, so that it is widely used for analyzing the

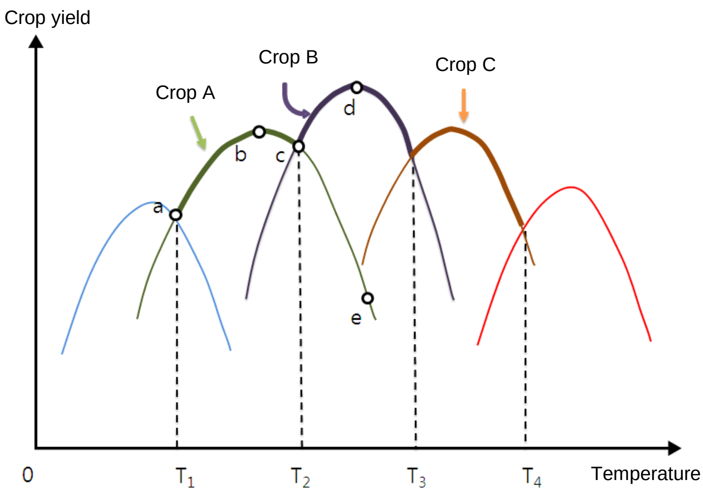
[19] The quasi-rent is a concept closely related to the economic rent, meaning that the profit from the elements fixed for short-period of time disappears in the long run. Calculated by deducting the opportunity cost or total variable cost from the total income, the quasi-rent is considered the same as producer surplus.

economic impact of climate change (C. G. Kim *et al*, 2008).

In order to compare and contrast between the agro-economic model and Ricardian model, the relationship between temperature change and three crop responses is examined. In <Figure 4-31>, the optimum temperature range for cultivation of Crop A is T_1~T_2. When temperature rises, farmers will select Crop B that can adapt itself to the temperature rise as an alternative to Crop A, since its optimum temperature range is T_2~T_3. If temperature rises further, they will convert from Crop B to Crop C whose optimum temperature range is T_3~T_4. Therefore, the substantial sensitivity of crop responses to temperature change has a form of value function, which is an envelope of individual crop responses as shown by bold solid lines in <Figure 4-31>.

According to the crop production function approach, which is an agro-economic model, Crop A is produced at *a* and reaches its peak yield at *b* as temperature rises. On the other hand, its yield decreases to *c* if temperature rises to T_2 and then drops to *e* if it keeps on rising. However, if farmers convert from Crop B when the yield of Crop A drops to *c*, the crop yield increases from *c* to *d*. In this way, the

Figure 4–31. Relationship between temperature change and crop yield response



Ricardian approach assumes the substitution of new crops according to temperature and thus reflects the process of potential adaptation through adjustment of input materials. Such adaptation to climate change is accompanies by a considerable cost, which can be considered as economic loss. Also, adaptation is voluntary, meaning that farmer will accommodate it only when it gives benefits or is expected to give benefits. As adaptation is considered in terms of cost and benefits, it depends on farmland value or capitalized net benefit, rather than simple productivity. Therefore, Ricardian model can be regarded as an approach that identifies the economic costs and benefits of the agricultural sector faced with climate change in terms of the change in farmland value.

5.3.2. Analysis data

To forecast climate, 27 cities and counties that are main production regions of Korean cabbage, radish, red pepper, garlic, apples, and pears were analyzed in addition to main rice production regions such as Gimje and Dangjin. On the assumption that climate information of all observatories affects the climate of each city and county, all observatories that had continued providing climate information between 1988~2007 were included in our analysis, which in this instance numbered 57 of the 79 observatories in Korea. To estimate the long-term impact of climate change on agriculture, the average of the 20-year data from each observatory was used. In order to investigate the seasonal impact of climate change on agriculture, climate data for January, April, July, and October was also applied. This was operating on the assumption that the temperature in January affects the occurrence of blights and pests in April and that temperature and precipitation levels in July had a significant impact on crop harvest in October.

To apply the Ricardian model, socioeconomic variables, soil and geographic data and climate variables were all used. For farmland price, internal data from Korea Rural Economic Institute was used. In order to prevent bias in farmland price, the average price of rice fields and dry fields only in the agricultural development regions was used. The agricultural gross income and crop income data was taken from KOSTAT data province by province, as there was no municipal data to draw upon. In addition, GDP per capita in each region was also taken from the provincial data provided by KOSTAT. Data about ratio of fields damaged by sea wind or water, the ratio of wet fields, inclination, and drainage grade was taken from Korean Soils Information.

5.3.3. Analytical Results

To arrive at an estimation using the Ricardian model, a regression analysis was carried out by setting the algebraic linear function for farmland price with the climate variable, the square of the climate variable, the socioeconomic variable, and the soil variable. The farmland price involves future investment value depending on its location in addition to future value of agricultural income from the farmland. Therefore, in order to differentiate the influences of farmland price in a specific region and of independent variables on the entire land price, a weighted regression analysis approach was applied that carried out a regression analysis by weighting all variables with farmland area or crop income. The regression analysis was carried out in three types: a regression analysis only for the farmland price weighted with farmland area, using climate variables (Model 1); a regression analysis including other variables as well (Model 2); and a regression analysis that weighted variables with crop income (Model 3). Though there might have been differences to some extent, it appeared that all three models produced similar results for climate variables. The analysis result showed that the rise of average annual temperature had a negative impact on farmland price but that the average annual/monthly precipitation had a positive impact. When climate variables and other independent variables were included, it appeared that both the result of weighting variables with farmland area and that of weighting them with crop income had a nonlinear relationship. When the quadratic term of climate variable had a positive value, it meant that there was the lowest climate condition for cultivation and thus the farmland value went up if the region was above that climate condition. On the contrary, when the quadratic term had a negative value, it meant that there was an optimum climate condition at which the farmland value was highest.

Other than climate variables, independent variables appeared to have the same sign consistently in both models. It was shown that both the per capita production and population growth rate of a region positively affected the farmland price. In other words, it can be interpreted that as income and population grows, the demand for farmlands increases, resulting in a rise in farmland price. On the other hand, soil erosion and inclination, both considered negative factors in agriculture appeared to have a negative impact on the farmland price. Contrary to expectations, the ratio of frequently damaged lands had a positive impact on the farmland price. This is likely because, though 53 out of 80 cities and counties appeared to have no damaged lands, most of cities and counties in metropolitan area where the farmland price was relatively high were included in the damaged areas and so the ratio was also high.

The result of estimation based on the algebraic linear model shows that, when temperature rose by 1℃ from the average annual temperature (12.4℃), the farmland price fell by approximately 14,550 thousand won/ha (Model 2) and by 19,240 thousand won/ha (Model 3). These prices correspond respectively to 5.7% and 7.5% of the average farmland price in 80 cities and counties. Meanwhile, increasing precipitation was found to have a positive impact on farmland price. If precipitation increased by 1mm from the average monthly/annual precipitation (110.8mm), that is if it increased 12mm a year, the farmland price appeared to rise by 330 thousand won/ha (Model 2) and 360 thousand won /ha (Model 3).

According to “A Case Study on Prediction of Climate Change

Impact on the Korean Peninsula” by the Ministry of Environment, temperature in 2020 in Korea will rise by 1.2℃ and precipitation will increase by 11%. Given this case, the temperature rise will result in a farmland price drop of 14,550~19,240 thousand won/ha while the additional precipitation will result in a farmland price rise of 4,030~ 4,400 thousand won/ha. Therefore, in this scenario the overall impact of climate change on farmland price would be a loss in farmland price in the range of 13,430~18,680 thousand won/ha.

In analyzing the economic impact of climate change, it is crucial for Ricardian approach to derive as correct a farmland price as possible under perfect competition. In a country like Korea where the total land area is small and the population is large, the demand for land utilization is very diverse and thus it is difficult to reflect a pure future value and there is a high possibility of overestimating it. For farmlands adjacent to a city, it becomes more difficult to calculate a proper land price if the demand for development increases or speculative demand arises. Also, in Korea where free trading of farmlands is restricted, the value of a farmland might be underestimated.

The reason why Ricardian approach is deemed useful despite the aforementioned limitations is because it is appropriate for the market economy theory and it estimates the equilibrium assuming that all elements, including the adaptation measures to climate change, are optimized. In other words, the Ricardian approach has more economic implications in comparison to other economic analyses as they assess the impact of climate change under the existing conditions using production function rather than assuming optimized conditions.

In analyzing the economic impact of climate change, however, the Ricardian analysis is subject to limitations to presenting accurate estimates due to the limited data available. According to the results of preceding studies, a rise in temperature has a negative impact on agriculture while an increase in precipitation has a positive impact. This study also produced similar results when presenting a quantitative measurement of climate change impact. One thing is certain however, when both temperature and precipitation are considered at the same time, the impact of climate change on agriculture is negative. Therefore, in order to minimize the impact of changing climate, positive countermeasures such as a change of crop and changes to cultivation methods are required.

Analysis of Farmers' Responses to Climate Change

Chapter 5

In formulating adaptation measures for the agricultural sector to climate change, an analysis of farmers' responses is necessary. For, it is farmers who will put those measures into practice in the field. Therefore an analysis of their response constitutes important part of the circumstantial analysis approach for the adaptation to climate change. Also, the assessment of the farmers' awareness of both climate change and of adaptation policies is an important factor to be considered when improving adaptation capacity. Chapter five presents the results of analyzing the farmers' awareness of climate change and their attitudes toward to adaptation measures against climate change, based on questionnaire research. For a quantitative analysis of the farmers' decision making in connection with adaptation measures, when faced with uncertainty and the risk of climate change, an attempt is made to estimate the probability of applying adaptation measures by combining the expected utility and the crop yield simulation model based on climate conditions. Lastly, this chapter presents some suggestions, drawn from the questionnaire research from farmers, to verify the appropriateness of the results of expected utility analysis.

1. Farmers' Awareness of Climate Change

1.1. Overview of Questionnaire Research

1.1.1. Purpose of research and sample composition

To understand the farmer's awareness of climate change and their responses to adaptation measures, a questionnaire research was carried out.[20] The questionnaire consisted of a series of questions asking the farmer how much they were aware of climate change, what they expected from climate change, how they will respond to climate change, how important adaptation policy was, whether they will participate in adaptation measures, and what plans they had for the future. It contained a total of 27 questions: five questions to identify the level of awareness of climate change and 22 questions to identify their responses to climate change <Appendix 1>.

The research was carried out during the period between August and September 2009 with a total of 482 participants including 388 local correspondents of Korea Rural Economic Institute (by mail) and 105 farmers (by interview). The respondents comprised of those from Jeolla Area (31.5%), Gyeongsang Area (29.6%), Gangwon Area (11.8%), Chungcheong Area (11.0%), Gyeonggi Area (10.6%), and Jeju Area (2.9%) in consideration of the level of their awareness of climate change and the farmland area.

1.1.2. Characteristics of respondents and analysis methods

A breakdown of the socioeconomic status of the 482 farmers who responded to the questionnaire reveals that, 82% of the respondents

[20] In order to understand the agricultural industry’s awareness of climate change, the first-year study carried out a questionnaire of farmers and the experts in climate change in the agricultural sector, regarding how much they were aware of climate change, how much they actually felt it, what changes they experienced in their life, the impact on agriculture, the significance of global warming, and the natural disasters they were worried about (C. G. Kim *et al*., 2008, pp.53-66).

were male and 17% were female, 49% were 60 years old or older and 31% were between 50 and 60 years old, together accounting for 80% of the entire subjects, by age; 58.6% had secondary or post-secondary school education and 41.4% had a lower level of education. Sixty-six percent had 30 years or more farming experience and 57% expected to continue farming for less than 10 years. On the other hand, only 22% responded that they had somebody to succeed them on the farm while 75% answered that they did not.

For the main cultivation crops the crop breakdown was as follows: rice and barley accounted for 52%, vegetable 19%, and fruit 18%. According to the area of residence, 41% lived in semi-mountain areas, 24% in plains areas, 20% in mountain areas, and 20% in suburban areas <Table 5-1>.

The surveyed data was statistically analyzed using the frequency and cross-tabulation on SPSS 12.0. For statistical significance of the cross-tabulation, χ^2 verification was used.

Table 5-1. Socioeconomic statuses of the subjects

Unit: Persons, %

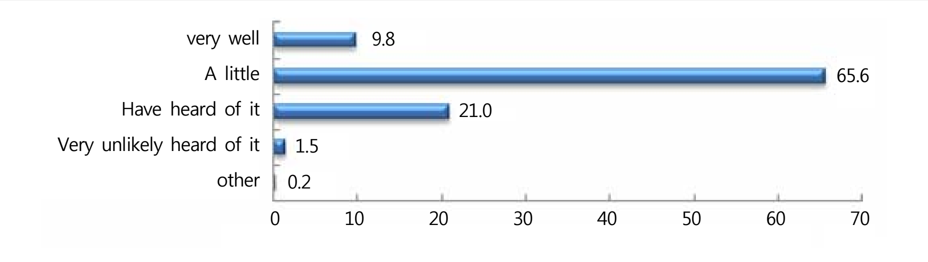
Items		No. of Answers	Percentage
Gender	Male	393	81.5
	Female	83	17.2
	No response	6	1.2
Age	~ 40 years old	20	4.1
	40~50 years old	71	14.7
	50~60 years old	150	31.1
	60~70 years old	120	24.9
	70 years old~	116	24.1
Education	Elementary school or lower	64	13.4
	Middle school graduate	134	28.0
	Secondary school graduate	207	43.2
	Post-secondary education or higher	74	15.4

Items		No. of Answers	Percentage
Experience	~ 20 years	67	13.9
	20~30 years	83	17.2
	30~40 years	127	26.3
	40~50 years	99	20.5
	50 years~	92	19.1
Main crops	Rice or barley	251	52.1
	Vegetable	91	18.9
	Fruit	85	17.6
	Others	40	8.3
	Missing value	15	3.1
Area of residence	Plain area	116	24.1
	Mountain area	95	19.7
	Semi-mountain area	197	40.9
	Suburban area	50	10.4
Successor to farming	Yes	107	22.2
	No	359	74.5
How many more years to continue	1~5 years	121	25.1
	6~10 years	153	31.7
	11~20 years	122	25.3
	21~30 years	33	6.8
	31~40 years	7	1.5
Total		482	100.0

1.2. Level of Awareness of Climate Change

Regarding the degree of awareness of climate change due to global warming, 65.6% answered that they were aware of it “a little” and 9.8% “very well,” showing that about 75.4% had varying degrees an awareness of climate change. However, considering the fact that 20.2% of the respondents answered that they “had heard of it,” this reveals

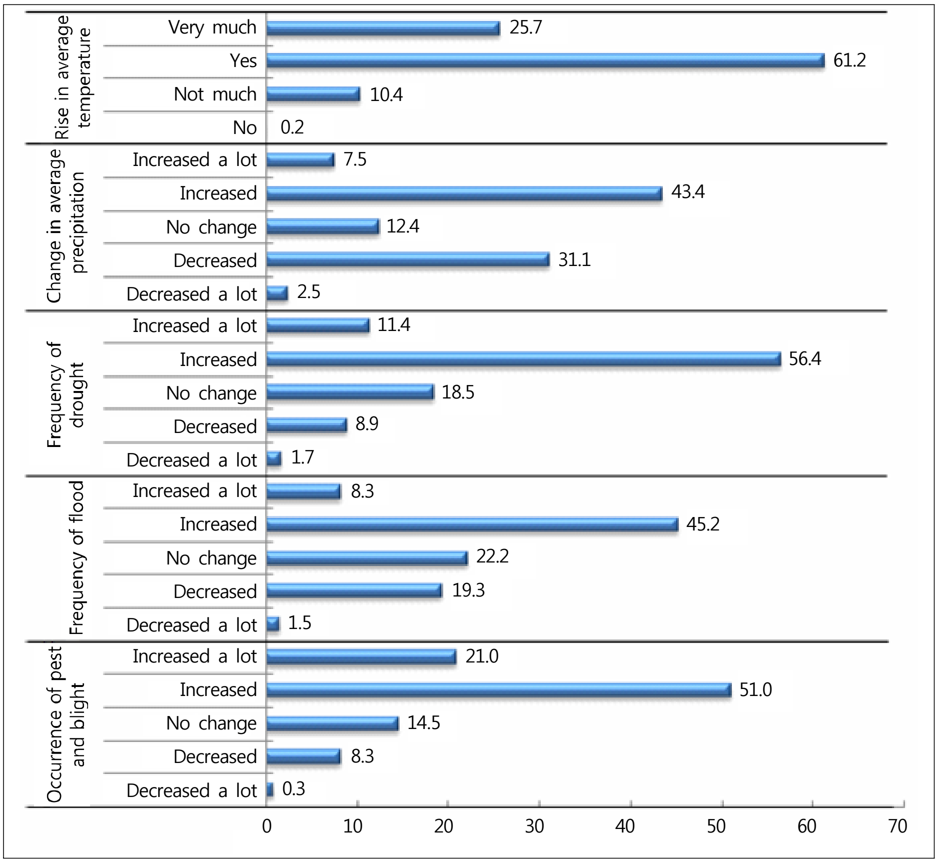
Figure 5-1. Level of awareness of climate change (n=482)



that almost all farmers had been aware of climate change. On the other hand, the respondents who answered that they had "never heard of it" accounted for 1.5%.

To the question asking about climate change they actually had felt, 86.9% of the respondents chose a "rise in average temperature" while 50.9% chose an "increase in average precipitation," showing that recognition of temperature rise was relatively high. To the question asking about abnormal meteorological phenomena caused by climate change, 67.8% answered an "'increase in the frequency of drought' while 53.5% answered an "increase in the frequency of flood," indicating that people reacted more to drought than to flood. The respondents who chose an "increase in the frequency of blights and pest" as a major impact of climate change on the agricultural ecosystem accounted for 72.0%, which indicates that they had actually felt an increase in the occurrence of blights and pest. In general, according to the farmers' responses to global warming, they had felt a temperature rise, an increase in the frequency of drought, and an increase in the occurrence of blights and pests more easily than other effects.

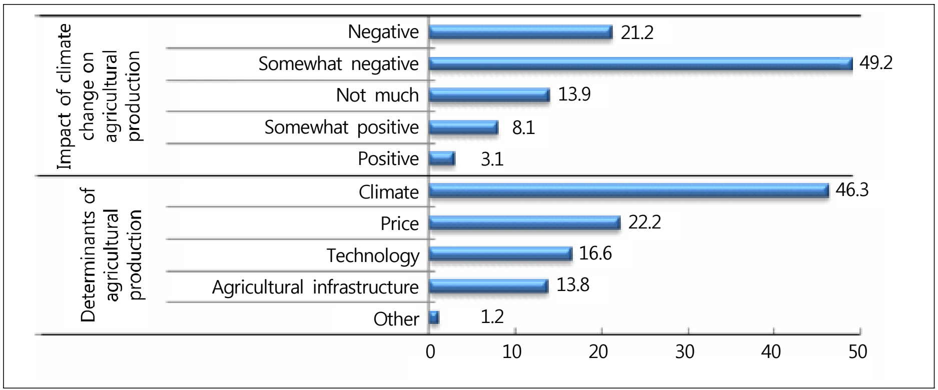
Figure 5-2. Responses to climate change (n=482)



The percentage of respondents who answered "negative" with regards to climate change's impact on agricultural production was 70.4%, much higher than 11.2% who answered "positive," showing that they thought of climate change negatively.

As for the determinants of agricultural production, 43.6% chose "climatic conditions," 22.2% "price of agricultural products," 16.6% "cultivation technology" and 13.8% "agricultural infrastructure," farmer, revealing that they recognize the climatic conditions as an important factor in agricultural production.

Figure 5-3. Response to the impact of climate change (n=482)

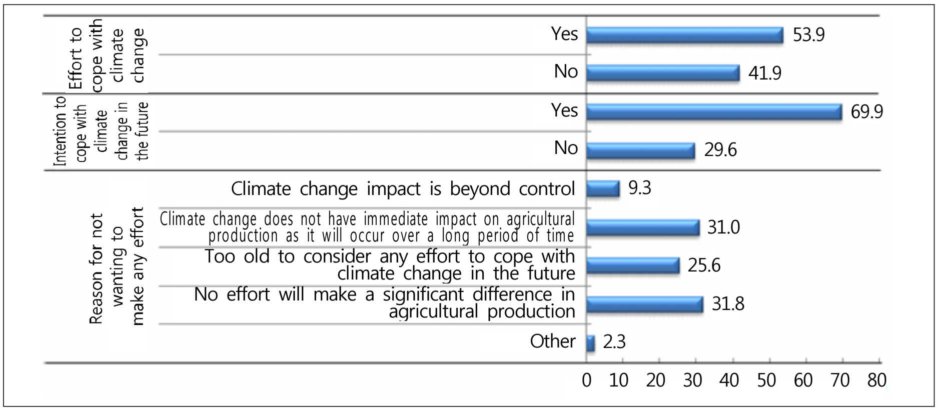


2. Farmers' Attitude to Coping with Climate Change

2.1. Responses to Coping with Climate Change

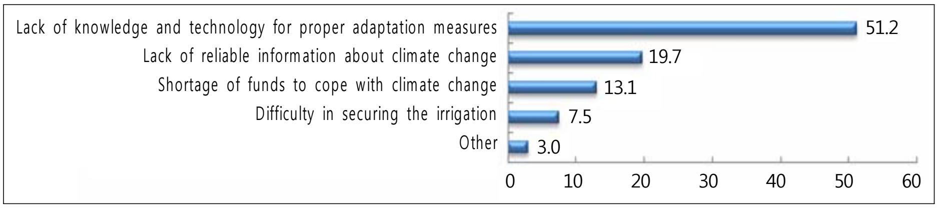
To the question asking whether they are making any effort cope with climate change, 53.9% responded "Yes" and 41.9% "No," indicating that a relatively greater proportion of people are trying to cope with climate change. Of those who answered "No," 69.9% responded that they will make efforts to cope with climate change in the near future, which shows that farmers had a high level of interest in coping with climate change. As for the reasons respondents gave for not wanting to make any effort to cope with climate change even in the future, 31.8% answered that it was because "an effort will make no significant difference on agricultural production"; 31.0% that "climate change does not have an immediate impact on agricultural production as it will occur over a long period of time"; and 25.6% that they were "too old to consider any efforts for coping with climate change in the future."

Figure 5-4. Efforts for coping with climate change



As for obstacles for the farmers to cope with climate change, 51.2% chose "lack of knowledge and technology for proper adaptation measures," 19.7% "lack of reliable information," 13.1% "shortage of funds to cope with climate change," and 7.5% "difficulty in securing irrigation" <Figure 5-5>. This reveals that a main obstacle for the farmer to cope with climate change is the lack of proper technology and information rather than a shortage of funds. Therefore, in seeking adaptation measures for the agricultural sector against climate change, it is desirable to develop policies that give considerable weight to the distribution of adaptation technologies and related knowledge that farmers can apply in the field and in offering reliable information.

Figure 5-5. Obstacles for the farmer to cope with climate change (n=482)



Regarding the adaptation measures against climate change that individual farm household can put into practice, 49.2% chose to change "varieties," 61.4% to change "seed/harvest time," 64.7% to control "the use of agricultural chemicals and/or fertilizers," and 39.0% to change 'cultivation crops" <Figure 5-6>. This result shows that, in adapting to climate change, farmers prefer controlling the use of agricultural chemicals and/or fertilizers and changing the seed/harvest time rather than changing the varieties or cultivation crops.

The reasons for not putting into practice any adaptation measures against climate change appeared to be mostly due to "lack of information" and a "shortage of labor force." Therefore, it is thought

Table 5-2. Adaptation measures for individual farm household against climate change (n=482)

Adaptation measures for individual farm household	Yes		No		If not, why?		
	No. of answers	Percentage	No. of answers	Percentage	Reason	No. of answers	Percentage
Variety change	237	49.2	192	39.8	Shortage of funds	41	21.4
	237	49.2	192	39.8	Lack of information	52	27.1
	237	49.2	192	39.8	Shortage of labor force	50	26.0
	237	49.2	192	39.8	Other	19	9.9
Seed time/harvest time change	296	61.4	133	27.6	Shortage of funds	9	6.8
	296	61.4	133	27.6	Lack of information	38	28.6
	296	61.4	133	27.6	Shortage of labor force	35	26.3
	296	61.4	133	27.6	Other	18	13.5
Controlled use of agricultural chemicals/fertilizers	312	64.7	115	23.9	Shortage of funds	11	9.6
	312	64.7	115	23.9	Lack of information	22	19.1
	312	64.7	115	23.9	Shortage of labor force	39	33.9
	312	64.7	115	23.9	Other	11	9.6
Cultivation crop change	188	39.0	236	49.0	Shortage of funds	26	11.0
	188	39.0	236	49.0	Lack of information	92	39.0
	188	39.0	236	49.0	Shortage of labor force	50	21.2
	188	39.0	236	49.0	Other	20	8.5

that adaptation measures for the agricultural sector against climate change should include proper measures to offer reliable information and compensate the additional labor needed for implementing adaptation measures.

2.2. Assessment of Adaptation Policies

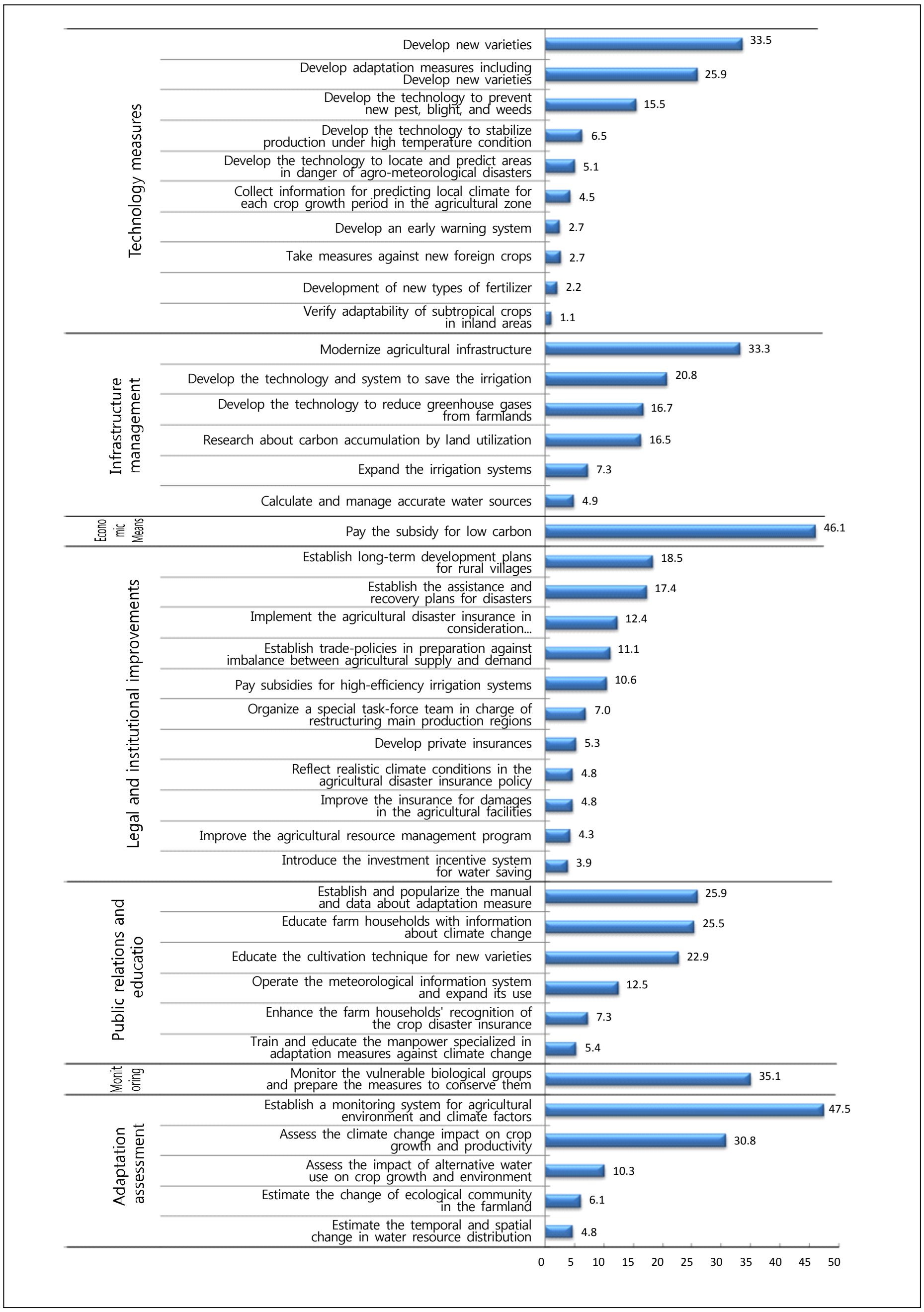
2.2.1. Assessment of importance of adaption policies and intention to participate

The governmental policies for adaptation to climate change were examined for such categories as technological measures, infrastructure management, economics, legal and institutional improvement, public relations and education, monitoring, and adaptation assessment <Figure 5-6>. "Development of new varieties" (33.5%) and "adaptation measures like seeding time and/or harvest time change" (25.9%) were assessed as the most important technological measures.

Regarding infrastructure management, it appeared that "modernization of agricultural infrastructure" was most needed (33.3%), followed by "development of technology and systems to improve the efficiency of irrigation systems and reduce water requirements" (20.8%), "development of technology to reduce greenhouse gas emission from farmlands" (16.7%), and 'research on accumulation of carbon by land utilization" (16.5%).

As for economic means, 46.1% of the respondents regarded "the payment of direct subsidy for the practice of low-carbon agricultural techniques" as important. Among the options for legal and institutional improvements, 18.5% chose "establishment of long-term development plan for agriculture/rural communities" and 17.4% "formulation of assistance plan for recovery from disasters."

Figure 5-6. Importance of adaptation measures by the government and the agriculture-related organizations against climate change (n=482)



For public relations and education, the breakdown of options showed that: 'buildup and distribution of adaptation measures manual and data" (25.9%), "education of farm households for climate change" (25.5%), and "education about cultivation techniques for new varieties" (22.9%) appeared to be important. Regarding adaptation assessment the breakdown of options showed that "construction of farming environment and climatic factors monitoring system" (47.5%) and "assessment of impact on crop growth and productivity" (30.8%) were assessed as being important.

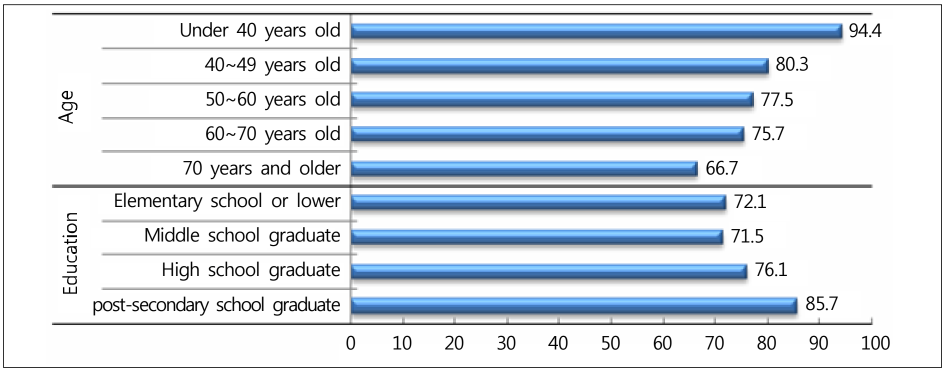
Sixty point six percent of the respondents answered "yes" to the question asking whether or not they would participate in the adaptation policy programs of the government, while 30.5% answered "no" or "do not know." As for the reasons for not participating, 29.3% answered that it is because "the governmental adaptation policies are uncertain as they have not yet been verified" while 24.5% responded that "the governmental adaptation policies do not seem to be of great help" <Table 5-3>.

Table 5-3. Intention to participate in the adaptation policy programs of the government (n=482)

Yes		No		Do not know		Reason for "No" or "Do not know"		
No. of answers	Percentage	No. of answers	Percentage	No. of answers	Percentage	Reason	No. of answers	Percentage
292	60.6	43	8.9	104	21.6	The governmental adaptation policies do not seem to be of great help.	36	24.5
292	60.6	43	8.9	104	21.6	Willing to deal with the risk, without participating in the adaptation policy	6	4.1
292	60.6	43	8.9	104	21.6	The governmental adaptation policies are uncertain as they have not yet verified	43	29.3
292	60.6	43	8.9	104	21.6	Other	9	6.1

The intention to participate in the governmental policies for adaptation to climate change appeared to be very high (94.4%) in the respondents aged 40 and under, but became smaller as the older the respondents' were. It also appeared that the more educated the respondents were, the higher their intention to participate in the governmental policies became.

Figure 5-7. Intention to participate in the governmental policies by ages and education level



2.2.2. Assessment of the government's role and education

The respondents, who answered "the government and related agencies" to the question asking who played the most important role in coping with climate change, accounted for 50.6%. On the other hand, 24.9% of the respondents chose "farmers" and 16.8%, "academic and research circles" <Figure 5-8>.

As for the best way to learn about adaptation measures against climate change, 68.7% of the respondents answered "take courses at the agricultural technology center," 13.1% "consult with the agricultural experts," 9.5% "group study," and 2.3% "self-study" <Figure 5-9>. Therefore, it is deemed that the education about climate change should be provided through municipal and/or agricultural technology centers.

Figure 5-8. Importance of the related subject in coping with climate change (n=482)

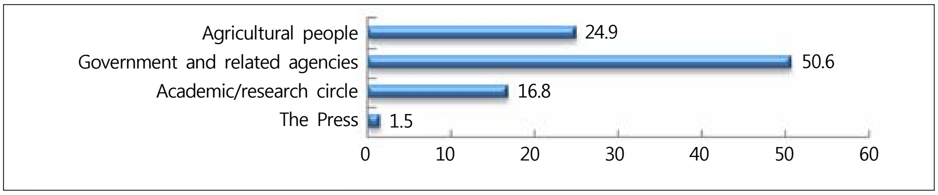
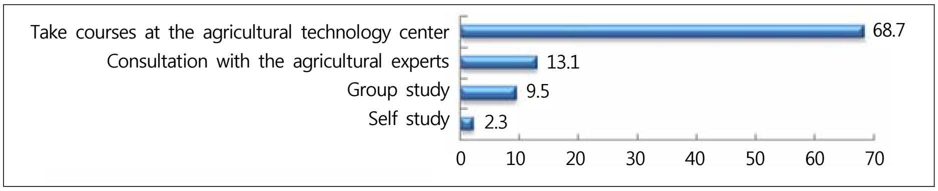


Figure 5-9. Proper ways of learning the adaptation measures against climate change climate (n=482)



2.2.3. Actual application of each adaptation measure and intention to apply

The respondents who actually had "crop disaster insurance" accounted for 14.9%, which broke down as follows: 47.1% for fruits, 36.8% for rice and barley, and 10.3% for vegetables and fruit-vegetables. The respondents who had "flood/storm damage insurance" accounted only for 5.0%. Overall, the percentage of respondents who had taken out crop disaster insurance and/or flood/storm damage insurance was very low <Table 5-4>.

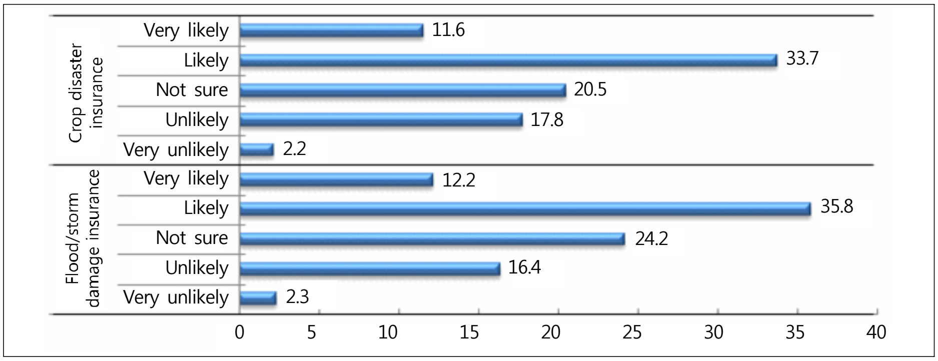
The respondents who had taken out crop disaster insurance and who responded that the premium was "high" accounted for 38.9% and those who answered "adequate" 40.3%. On the other hand, 33% of the subscribers of the flood/storm damage insurance answered it was "high" and 20.8% answered "adequate."

Table 5-4. Subscription to crop disaster insurance and flood/storm damage insurance (n=482)

Type	Subscription status and adequacy of insurance premium	Answer	No. of answers	Percentage
Crop disaster insurance	Subscription status	Yes	72	14.9
		No	385	79.9
	Subscribers by crops, and percentage of subscription	Rice and barley	25	36.8
		Vegetables and fruit vegetables	7	10.3
		Fruits	32	47.1
		Others	4	5.9
	Adequacy of insurance premium	Excessively high	4	5.6
		High	24	33.3
		Adequate	29	40.3
		Low	1	1.4
		Very low	1	1.4
Flood/storm damage insurance	Subscription status	Yes	24	5.0
		No	371	77.0
	Adequacy of insurance premium	Excessively high	2	8.3
		High	6	25.0
		Adequate	5	20.8
		Very low	1	4.2

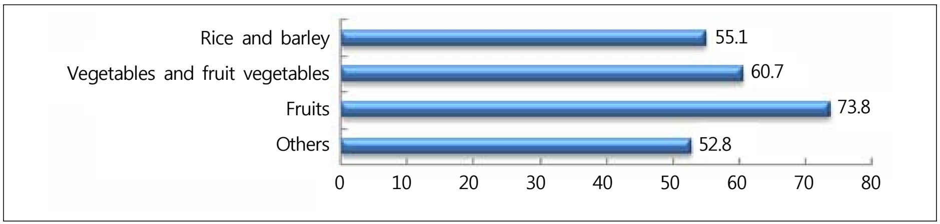
Of the respondents who had not taken out crop disaster insurance or the flood/storm damage insurance, 45.3% responded that they were "likely" to take out crop disaster insurance, whilst the 48.1% gave the same response to a query about flood/storm damage insurance, in order to cope with climate change, both totals not being very high. Therefore, it appeared that in order to encourage the farmer to subscribe to these insurance policies it will be necessary to both reflect realistic climate conditions in the insurance policy and to adjust the insurance premium <Figure 5-10>.

Figure 5-10. Intention to subscribe to the crop disaster insurance and/or flood/storm damage insurance



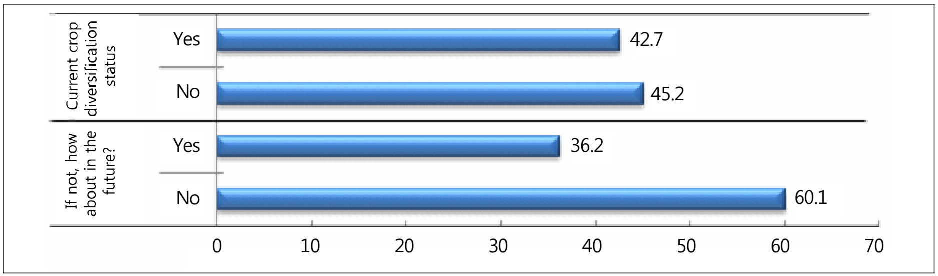
The future intention to subscribe to the crop disaster insurance could be broken down by major crops into 55.1% for rice and barley, 60.7% for vegetables and fruit vegetables, 73.8% for fruits, and 52.8% for others <Figure 5-11>. This can be explained by the reasoning that future changes in the agricultural sector due to climate change are most significantly recognizable in the fruit sector.

Figure 5-11. Intention to subscribe to the crop disaster insurance, by crop items



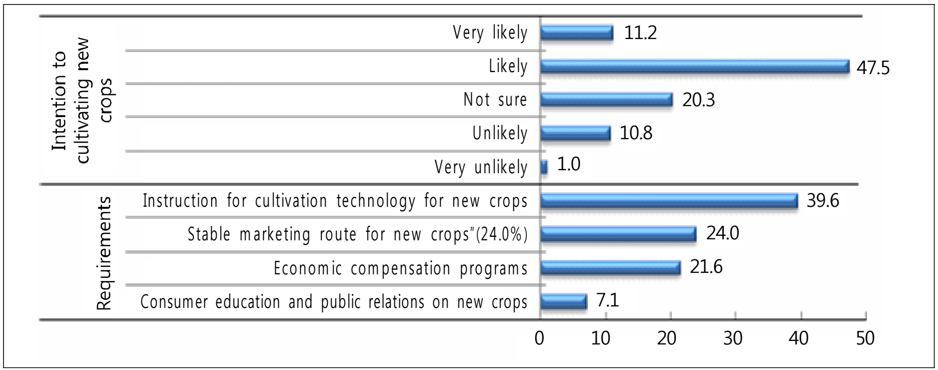
Forty-two point seven percent of the respondents answered "yes" to the current crop diversification status while 45.2% answered "no". Sixty point one percent of respondents who answered "no" when questioned about current diversification also answered "no" as to whether they had any future intention to pursue crop diversification while 36.2% answered "yes" <Figure 5-12>.

Figure 5-12. Crop diversification status (n=482)



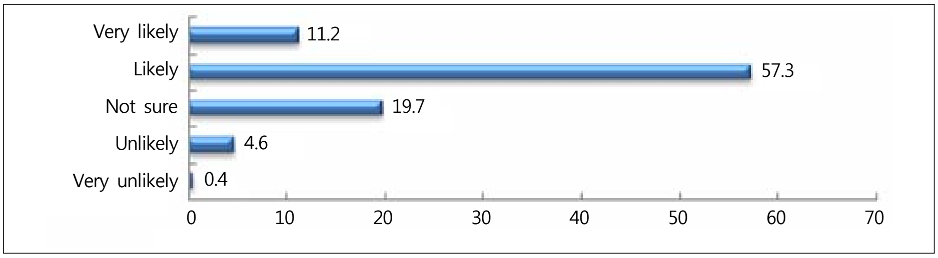
The respondents' intention to cultivate new varieties and/or subtropical crops was relatively high at 58.7%, Those who had the intention of diversifying were broken down by their requirements for doing so, which amounted to: "instruction for cultivation technology for new crops" (39.6%), "stable marketing route for new crops" (24.0%), "economic compensation programs (i.e. supplement for income decrease during the changeover period)" (21.6%), and "consumer education and public relations on new crops" (7%) <Figure 5-13>.

Figure 5-13. Intention to cultivate new varieties and/or subtropical crops, and requirements for changeover (n=482)



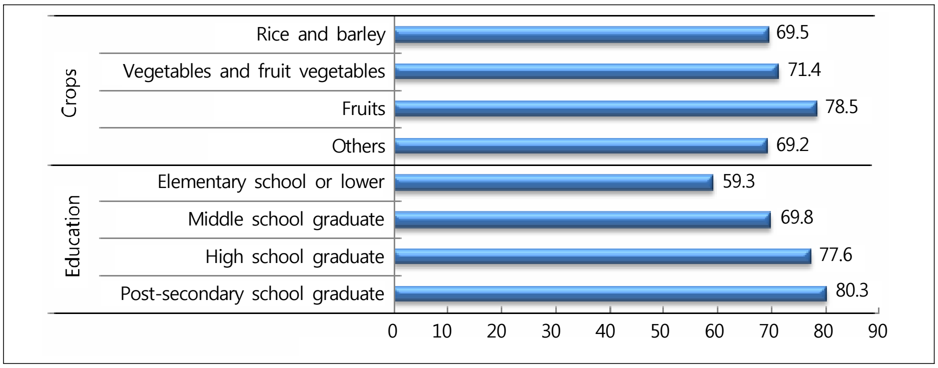
The respondents who answered that they were likely or very likely to participate in the future carbon reduction efforts accounted for 68.5%, while those who answered that they would not participate accounted for 5.0%. This reveals that the agricultural sector is very willing to participate in the carbon reduction <Figure 5-14>.

Figure 5-14. Intention to participate in the carbon reduction effort (n=482)



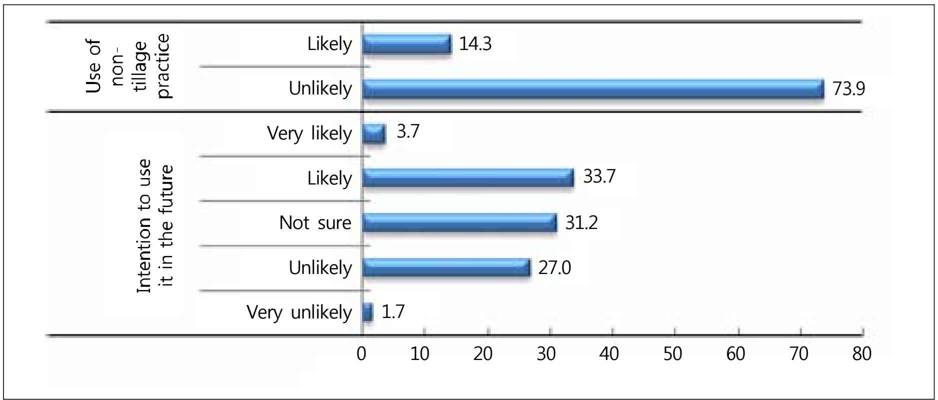
The intention to participate in the carbon reduction effort, broken down by major crop, appeared to be the highest in the fruit (78.5%) <Figure 5-15>. This implies that fruit is damaged most by climate change. In addition, it appeared that the higher educated respondents tended to be more willing to participate in the carbon reduction effort.

Figure 5-15. Intention to participate in the future carbon reduction efforts by crops and by education levels



The responses as to whether they were using non-tillage method as a means of carbon reduction was relatively low at 15.3%. However, responses as to whether they would put non-tillage method into practice saw 37.4% reply that it was "likely" or "very likely", implying that the intention to put non-tillage method into practice was not very low <Figure 5-16>.

Figure 5-16. Non-tillage practice and intention to use it (n=482)



2.3. Implications of the Results of Questionnaires for Farmers

The farmers' recognition of climate change appeared to be high and it was revealed that they had actually felt unusual changes in the weather and the increased occurrence of blights and pests due to climate change. They answered that they thought that climate change had a negative impact on agricultural production in general and of the several factors that might affect agricultural production that climate condition had the most significant impact.

It was shown that farmer were highly interested in the countermeasures against climate change and very willing to participate in adaptation measures for individual farm household units. However, it appeared that there were some obstacles in putting countermeasures into practice, such as lack of technology, knowledge, and information about adaptation measures and a shortage of labor force.

It appeared that the famers showed strong intention to participate in and an interest in the government's adaptation policies on climate change. They assessed the following adaptation measures as being the most important: development of new varieties, modernization of agricultural infrastructure, payment of a low carbon grant for the adoption of low-carbon agricultural techniques, the development and popularization of manuals and data about adaptation measures, the formulation of long-term development plan for rural villages, and the development of a monitoring system for the agricultural environment and meteorological factors.

As for who the main agent should be in coping with climate change, they answered that the government and related agencies played the most important role and as for the proper way of learning adaptation measures against climate change, they answered that it was best to take courses at the agricultural technology center and/or other related agencies.

The rate of subscription to crop disaster insurance and/or flood/ storm damage insurance appeared to be very low and the intention of subscribing in the future was also low. The farmer had a very high intention of participating in the future carbon reduction efforts and to put no-tillage technique into practice as a means of pursuing carbon reduction efforts.

Summing up the above results, this questionnaire research has the following implications:

First, in formulating the countermeasures against climate change, it is most important to popularize the adaptation technologies, information and knowledge that the farmer can then apply in the field. This is best achieved by giving the relevant courses at the agricultural technology center and/or related agencies.

Second, in order to encourage the farmers to subscribe to the crop disaster insurance and the flood/storm damage insurance, it is necessary to improve the existing insurance available through reflecting realistic climate conditions in those insurance policies and adjusting the insurance premium.

Third, if developed, proper incentive programs that can encourage carbon reduction will contribute to carbon reduction in the agricultural sector.

Lastly, in addition to the above-mentioned suggestions, it is necessary for the government to establish a step-by-step master plan in formulating the adaptation policies for climate change, which the farmer can trust and accommodate.

3. Analysis of Decision-making by the Farmers under Risk and Uncertainty

3.1. Theoretical Background of Decision-making using Expected Utility

Climate change gives rise to risk factors that may affect the productivity of agricultural crops. Thus many adaptation measures have been formulated to minimize its impact. The adaptation measures formulated by the government are assessed as to whether they can be applied by each household unit or not. At this time, the assessment can be done based on the expected utility of each measure.

In order to analyze whether the farm household applies adaptation measures when climate change brings forth any change (risk) in production, Finger and Schmid (2008) applied the expected utility decision-making model in which the eco-physical model of CropSyst and the economic analysis model are integrated. This method can resolve the shortcomings of both the production function estimation method, using past data, and the yield change estimation method, using the crop growth model. In other words, the production function estimation method may not estimate a correct future yield as it has to use an extrapolation yield and the crop growth model may underestimate the yield as it does not take adaptation to climate change into consideration. However, the expected utility decision-making model simulates the crop yield based on estimated future climate change and carries out a regression analysis based on the simulation result using and the production elements, so that the both the effects of climate change and the adaptation employed by farmers to it, are considered.

Theoretically, the expected utility decision-making model originated from the maximization of expected utility. For this, the expected utility is defined as follows. When utility is assumed to be the function of quasi rent which is a random variable, expected utility equals the product of integrating the multiple of density functions of utility and profit, which can be expressed as shown in the following equation:

$$E(U(\pi)) = \int_0^{\infty} U(\pi) f(\pi) d\pi \qquad (5\text{-}1)$$

where π indicates profit and $f(\pi)$ is a density function of profit.

When the utility function is assumed to be linear to profit, it can be expressed as the difference between the expected profit and the product of multiplying the standard deviation (σ_π) of profit due to risk and the risk avoidance coefficient (γ) (Hazell and Norton, 1986). Therefore, the producer's preference for risk varies with the preference coefficient (avoidance coefficient for the profit difference.

$$U(\pi) - E(\pi) - \gamma\sigma_\pi \qquad (5\text{-}2)$$

On the other hand, the expected profit is the value of the expected profit minus cost, which is expressed as follows:

$$E(\pi) = pE(Q(X)) - wX - IK \tag{5-3}$$

where Q is the yield expressed as a function of input factor, w the price of input factor (X), I the adaptation measure application status, and K the cost of applying the adaptation measure. The input factor includes adaptation measures; only the yield by climate change is considered as a random variable and the price as given.

On the other hand, the profit difference can be expressed as the difference of yield as shown below:

$$\begin{aligned}\sigma_\pi &= \left|E(\pi - E(\pi))\right| \\ &= \left|E(pQ(X) - E(pQ(X)))\right| \\ &= \left|E(p(Q(X) - E(Q(X))))\right| \\ &= p\left|E(Q(X) - E(Q(X)))\right| \\ &= p\sigma_Q\end{aligned} \tag{5-4}$$

Using the equations given above, the expected utility maximization problem can be expressed as the expected profit maximization problem through the following equation:

$$Max_X E(U(\pi)) = pE(Q(X)) - wX - IK - \gamma p\sigma_Q(X) \tag{5-5}$$

In order to solve this problem, the quantity response function (Q(X)) and the quantity deviation function (σ_Q(X)) should be estimated and substituted into the equation. At this time, the quantity response function and the quantity deviation function are functions of input factors and have the form of prime function. To find the optimized input factor level, Equation (5-5) can be integrated, which is expressed as follows:

$$\frac{\partial E(Q(X))}{\partial X} = \frac{w}{p} + \gamma \frac{\partial \sigma_Q(X)}{\partial X} \tag{5-6}$$

The marginal productivity of input factors equals the product of multiplying the ratio of input factor and product price (production factor price/product price), the risk avoidance coefficient and the value (estimation coefficient for the production deviation function) integrating the difference by the input factor. Therefore, if a risk avoidance coefficient is given, it is possible to calculate the optimized input factor level for the price and climate change scenario using Equation (5-6) and calculate the optimum deviation by substituting this value to the quantity response, optimum yield, and quantity deviation functions. By substituting it to Equation (5-5), it is possible to calculate the optimum expected utility.

When risk factors for production due to climate change are included, whether or not to apply adaptation measures is determined by comparing the difference in expected profits between when they are applied and when they are not applied and the expenses for applying the adaptation measures. Therefore, the adaptation measures will be applied only if the profit expected when they are applied minus the expense of application is greater than the profit expected when they are not applied, which is expressed by the following equation:

$$E(U(\pi_{I=1})) - K \succ E(U(\pi_{I=0})) \quad (5\text{-}7)$$

Using the above equation (5-7), it is possible to determine whether to or not to apply adaptation measures according to the expenses of application K and, when K has a constant probability distribution, it is possible to calculate the application rate of the corresponding scenario.

3.2. Actual Application of Expected Utility Model

Based on the above theories, the decision-making using expected utility is analyzed. This process is divided into three steps: the data generation step, the quantity response and quantity deviation function estimation step, and the optimization problem solving step.

3.2.1. Data generation[21]

Data generation refers to generating yield data through the simulation of production factor change on the assumption of the future climate condition expected, according to the climate change scenario. For future time frames, three periods of 2011~2040, 2041~2070, and 2071~2100 are assumed. Average climate conditions for each 30-year period are applied to the climate creation program to create a daily climate to use. In other words, such future climate conditions as temperature, precipitation, and carbon dioxide (CO_2) concentration are set using the climate change scenario (NMA, IPCC, etc.); adaptation measures are applied; and then adjustable production factors are randomly changed, to derive yield data. CO_2 change is given based on IPCC data and as for adaptation measures, seeding time change and irrigation system installation are considered.

For growth models appropriate for generating necessary data, ORYZA2000 and CERES-Rice are available. These models respond to climate, nature of soil, nature of crop, and production control. For ORYZA2000, it is easy to estimate the yield change by CO_2 change but it does not have its own program to create climate conditions and thus additional work is required. On the other hand, for CERES-Rice, it is easy to create climate conditions but difficult to effectively estimate the yield change by CO_2. In this study, ORYZA2000 is used to create the necessary data.

As for production factors to be applied for the simulation of a growth model, nitrogenous fertilizer and irrigation are selected, which

[21] This data was created through ORYZA2000 simulation analysis by Dr. C. G. Lee, National Institute of Crop Science, RDA.

are used as independent variables of quantity response and quantity deviation functions to be estimated later. The growth model is then applied to the mid-long maturing variety in such areas as Gwangju, Milyang, and Jeonju.

3.2.2. Measurement of quantity response function

Unlike general methods of estimating the yield based on past data, the quantity response function estimates it assuming nitrogenous fertilizer and irrigation as independent variables without including climate factors, which can be expressed as follows:

$$Q(X) = f(N, W)$$

where X is the production factor vector, N is the amount of nitrogenous fertilizer, and W is the amount of irrigation.

The quantity response function for the mid-long maturing variety in Gwangju area can expressed using the following equation. The marginal productivity is estimated using the quadratic function. The result of estimation using the function shows that the constant term decreases gradually, which implies that the yield decreases gradually as

Table 5-5. Estimation using the quantity response function for the mid-long maturing variety in Gwangju area (with fixed seeding time)

Variable	1971~2000	2011~2040	2041~2070	2071~2100
Constant	4360.1** (30.67)	4440.3** (22.94)	4379.3** (38.72)	2008** (6.02)
N	46.3** (23.98)	39.7** (12.56)	37.7** (24.37)	25.3** (25.3)
W	0.43 (0.33)	0.213 (0.11)	0.075 (0.05)	11.9** (4.68)
N2	-0.153** (-19.33)	-0.112** (-8.11)	-0.1** (-16.31)	-0.05** (-2.79)
W2	-0.002 (-0.55)	-0.0007 (-0.13)	-0.0005 (-0.09)	-0.015* (-2.65)
NW	0.006 (1.05)	0.0012 (0.16)	0.0015 (0.25)	0.006 (0.59)
R2	0.960	0.947	0.972	0.816

Note: ** and * indicate the significance of 1% and 5% respectively.

Table 5-6. Estimation using the quantity response function for the mid-long maturing variety in Gwangju area (with varied seeding time)

Variable	1971~2000	2011~2040	2041~2070	2071~2100
Constant	4360.1** (30.67)	4044.2** (21.21)	4161.5** (17.75)	4039.7** (17.02)
N	46.3** (23.98)	49.3** (18.13)	40.1** (12.31)	23.8** (7.07)
W	0.43 (0.33)	1.24 (0.57)	2.73 (1.54)	4.83** (3.78)
N2	-0.153** (-19.33)	-0.142** (-12.19)	-0.123** (-9.06)	-0.11** (-7.87)
W2	-0.002 (-0.55)	-0.004 (-0.69)	-0.01* (-2.40)	-0.01** (-4.55)
NW	0.006 (1.05)	0.006 (0.76)	0.032** (4.39)	0.053** (10.03)
R2	0.960	0.945	0.928	0.923

Note: ** and * indicate the significance of 1% and 5% respectively.

time passes if the seeding time is fixed or if both nitrogenous fertilizer and irrigation are not provided. In the estimated quantity response function, the amount of irrigation appears to have a statistical significance for the period of 2071~2100 but a relatively low significance for other periods.

The result of estimating the yield of mid-long maturing variety in Gwangju area using the quantity deviation function is given in <Table 5-7> and <Table 5-8>. The quantity deviation is a linear function, which shows that the nitrogenous fertilizer reduces the quantity deviation when the seeding time is fixed.[22] However, the irrigation does not show a constant pattern of change and has low statistic significance, so that it is difficult to conclude what impact it has on the quantity deviation. When the seeding time is changed, the nitrogenous fertilizer appears to reduce the quantity deviation while the irrigation increases it. Namely, as the amount of nitrogenous fertilizer applied

22 Like the quantity response function, it is proper to estimate the marginal deviation in the form of the quadratic function or square root function. However, it is difficult to solve the optimization problem. So, a linear function is used here to get a final solution.

increases, a stable yield can be expected but as the amount of irrigation increases, the uncertainty of yield also increases.

Table 5-7. Estimation using the quantity deviation function for the mid-long maturing variety in Gwangju area (with fixed seeding time)

Variable	1971~2000	2011~2040	2041~2070	2071~2100
Constant	320.9** (12.63)	373.8** (11.45)	291.4** (14.42)	536.8** (6.40)
N	-1.21** (-8.38)	-1.06** (-4.07)	-1.05** (-8.78)	-1.003* (-2.04)
W	0.167 (1.49)	-	-0.06 (-0.49)	-0.407 (-1.28)
Dummy	-	-	-	936** (8.62)
R2	0.547	0.355	0.558	0.570

Note: ** and * indicate the significance of 1% and 5% respectively.

Table 5-8. Estimation using the quantity deviation function for the mid-long maturing variety in Gwangju area (with varied seeding time)

Variable	1971~2000	2011~2040	2041~2070	2071~2100
Constant	320.9** (12.63)	406.8** (10.45)	333.4** (6.36)	237.0 (1.51)
N	-1.21** (-8.38)	-0.976** (-3.88)	-0.77* (-2.49)	-0.02 (-0.02)
W	0.167 (1.49)	0.253 (1.22)	0.68** (3.62)	0.46* (1.99)
Dummy	-	-	-	520** (2.83)
R2	0.547	0.217	0.240	0.496

Note: ** and * indicate the significance of 1% and 5% respectively.

3.2.3. Solving the optimization problem

Solving the optimization problem using Equation (5-5) gives the following result. At this time, exogenous variables are assumed as follows: Rice price -- 1,892 won/kg, nitrogenous fertilizer price – 723 won/kg, irrigation cost – 400 won/m^3, and risk avoidance coefficient (γ) -- 0.5.[23]

23 The rice price is based on the data from KOSTAT as of August 15, 2009, and

When the seeding time is fixed, the optimum rice yield appears to decrease as time passes and the expected utility is also reduced gradually. On the other hand, if the seeding time is changed, the optimum rice yield appears to gradually increase even though climate changes and accordingly the expected profit also increases. Difference between the expected profit when the seeding time is fixed and the one when it is changed is calculated to be about 790 thousand won/ha for the period of 2011~2040, 1,550 thousand won/ha for 2041~2070, and 5,000 thousand won/ha for 2071~2100. Therefore, if the expense incurred by changing the seeding time does not exceed 800 thousand won a year, it is profitable for the producers to change the seeding time according to the climate change.

Optimized solutions for Milyang and Jeonju calculated by applying the same method are given in the following table. Comparison of the expected profit between the fixed seeding time and the varied seeding time, with the average-year climate scenario of 2011~2040 applied, shows that Milyang area will have about 1.2 million won more profit with the varied seeding time. Jeonju area also will have about 1.4 million won more.

the nitrogenous fertilizer price from the international data of Nonghyup as of January 2009. The agricultural water price does not exist in reality. However, assuming that the common operation cost of agricultural water in the municipal or county management regions is 4,000 won per 10a (by making inquiries to cities and counties) and the amount of water required for rice farming is 1,000mm, the price of water for $100m^3$, the amount required for 10a, is calculated at 4,000 won. Therefore, if 1mm water is supplied to 1ha ($100m*100m*0.001m=10m^3$), the price is calculated at 400 won. The risk avoidance coefficient greater than zero (>0) indicates risk-averse, and the one smaller than zero (<0) indicates risk-love.

Table 5-9. Optimized solution for the mid-long maturing variety in Gwangju area

	Fixed seeding time				Varied seeding time			
	Expected profit (Thousand won)	Yield (kg/ha)	Nitrogenous fertilizer (kg/ha)	Irrigation (mm/ha)	Expected profit (Thousand won)	Yield (kg/ha)	Nitrogenous fertilizer (kg/ha)	Irrigation (mm/ha)
1971~2000	11,386	8,074	157	245	11,386	8,074	157	245
2011~2040	11,353	7,995	179	104	12,146	8,639	179	233
2041~2070	11,317	7,968	190	119	12,863	9,406	222	455
2071~2100	11,752	8,246	280	456	16,789	13,007	434	1,363

Table 5-10. Optimized solution for the mid-long maturing variety in Milyang area

	Fixed seeding time				Varied seeding time			
	Expected profit (Thousand won)	Yield (kg/ha)	Nitrogenous fertilizer (kg/ha)	Irrigation (mm/ha)	Expected profit (Thousand won)	Yield (kg/ha)	Nitrogenous fertilizer (kg/ha)	Irrigation (mm/ha)
1971~2000	12,529	9,353	232	794	12,529	9,353	232	794
2011~2040	13,161	9,563	301	741	14,358	10,585	308	845
2041~2070	-	-	-	-	16,743	12,785	448	1,531
2071~2100	11,395	8,129	249	30	18,509	14,139	499	1,362

Note: The optimum solution for the expected profit for the period of 2041~2070 is not calculated due to data problem.

Table 5-11. Optimized solution for the mid-long maturing variety in Jeonju area

	Fixed seeding time				Varied seeding time			
	Expected profit (Thousand won)	Yield (kg/ha)	Nitrogenous fertilizer (kg/ha)	Irrigation (mm/ha)	Expected profit (Thousand won)	Yield (kg/ha)	Nitrogenous fertilizer (kg/ha)	Irrigation (mm/ha)
1971~2000	10,774	7,946	160	574	10,774	7,946	160	574
2011~2040	11,020	7,787	164	179	12,432	8,966	193	470
2041~2070	10,583	7,628	172	430	12,921	9,343	215	440
2071~2100	10,578	7,554	177	421	14,413	10,543	287	427

3.2.4. Estimation of the probability of applying adaptation measures

Based on 0.8 million won, the difference in expected profit in Gwangju, it is possible to calculate the probability that the farmer will apply the adaptation measures. Unlike the above optimization problem where only the seeding time is changed, there is no additional expense and thus it is difficult for the current model to calculate the probability of applying adaptation measures. Given this, the double-bounded dichotomous choice model is applied.[24] In this model, a virtual situation is set without specific adaptation measures being suggested and the expected profit of 0.8 million is presented, so that the respondents can select additional expenses. Out of the farmers who responded to the previous questionnaire research, those who are willing to participate in the government's adaptation program are selected to estimate how much they are willing to pay for applying adaptation measures.

The respondents who are willing to participate are classified into four groups, and each group is asked whether they are willing to pay additional expenses of 100 thousand won, 300 thousand won, 500 thousand won, and 700 thousand won. If they are willing to pay additional expenses, they are asked whether they would pay 100 thousand won more than the amount they are willing to pay but if they are not willing, they are asked whether they would pay the amount if it is 100 hundred won less. For the choice of 100 thousand won, the respondent who is not willing to pay additional expenses is asked whether they would pay if the amount were 50 thousand won. The results of the questionnaire survey is listed in the following table, in which the 256 responses that answered all the questions in steps 1 and step 2 are used for analysis.

[24] When estimating the amount the farmer are willing to pay additional pay, double-bounded dichotomous choice model measures the probability of answering "Yes" on the assumption that the errors would follow the logistic distribution.

Table 5-12. Double-bounded questionnaire for the intention of paying the adaptation expenses

	100 thousand won	300 thousand won	50 thousand won	70 thousand won
Total no. of responses	77	64	61	54
YY	47	37	35	32
YN	20	10	10	4
NY	6	7	9	10
NN	4	10	7	8

Note: Y is for positive answer to the question and N for negative answer. The answers indicate the first answer and the second answer in order.

The payment function calculated using the above result is listed in the following table. The mean value for the amount they are willing to pay is 624,650 won. Based on this calculation, the probability of applying the adaptation measures when an amount less than 800 thousand won is suggested is calculated to be 64.8%.

Table 5-13. Calculation of the payment function for adaptation measures

Variable name		Coefficient	*t* value
Constant term		5.370	8.867***
ln(T): Suggested amount (won)		-1.512	-10.279***
Gender dummy		1.046	2.921***
Age		0.0234	0.1934
No. of samples		256	
Mean value (won)	WTP	624,650	
	95% confidence interval	523,331~770,961	

Note: 1) *** and * are significant at 1% and 10% respectively
2) 95% confidence interval is based on 1,000 times of Monte Carlo simulation, which Krinsky and Robb used (1989).

3.3. Expected Effect of Expected Utility Analysis

The difference between the expected profit when adaptation to climate using the expected utility is applied and when it is not, is estimated. When the climate scenario for 2011~2040 is applied, the difference will be about 790 thousand won for Gwangju, about 1,200 thousand won for Milyang, and about 1,400 thousand won for Jeonju. The reason for such differences among areas is because the climate change scenario is different and thus the seeding time is changed in suit. Though not directly proportional, the probability that the farmer will apply adaptation measures will be estimated to be about 65% based on the result of expected utility analysis.

The purpose of the expected utility analysis is to estimate the ratio of application of adaptation measures for each climate change scenario. The expected utility analysis estimates the probability that the farmer will apply the adaptation measures given in a certain climate change scenario, which is to say, the viability of the government policy. Therefore, the expected utility analysis can be used by the policy makers as basic data when formulating proper adaptation measures, whilst also taking productivity risk by climate change into consideration.

When the price change of production factors and products, which are processed as exogenous variables, is estimated and applied, it is also possible to analyze the optimum yield, optimum input factor levels, and the expected utility for the price change as well as for the climate change. In other words, it is possible to predict the optimum activity for the producer in consideration of both climate change and price change, which are uncertain future market variables. For example, let's assume that the rice price drops by 5% and the irrigation cost changes as given below. Then, the difference between the expected profit for varied seeding time and the one for the fixed seeding time becomes smaller than the previous estimation. Therefore, if the additional expenses for applying adaptation measures remain the same, the probability that the farmer will apply them will also be lowered.

Table 5-14. Result of optimization for mid-long maturing variety in Gwangju area, depending on rice price and irrigation cost

Period	Rice price	Irrigation cost	Difference of expected profit
1979~2000	1,892.0	400	0
2011~2040	1,797.4	600	714,013
2041~2070	1,702.8	1,000	1,115,780
2071~2100	1,608.2	1,500	-

Note: Difference of the expected profit for the period of 2071～2100 is not available as it is impossible to calculate an optimized solution for the expected profit for fixed seeding time.

Climate Change Impact on the Agricultural Sectors of Major Countries and Their Countermeasures

Chapter 6

Regarding the analysis of climate change impact on the agricultural sector and countermeasures to mitigate that impact, many countries have actively performed scientific and political research. Chapter six summarizes the climate change impact on the agricultural sector of major countries such as Japan, the European Union (EU), the United Kingdom (UK), Australia, and China as well the countermeasures.

With regards Japan, the results of scientific research carried out by the National Institute of Agriculture and Environmental Studies (NIAES) as well as the cases of climate change impact analyses used by the Ministry of Agriculture, Forestry and Fisheries (MAFF) of Japan for formulating the comprehensive strategies against global warming are both summed up.

With regards to the EU and UK, the comprehensive report by Commission of the European Communities on adaptation measures for the agricultural sector as well as research undertaken in the related fields are discussed.

With regards to Australia, the government document which concerns the agricultural sector's action plan for countermeasures against climate change as well as the reports prepared by research institutes are summarized.

With regards to China, the government document regarding countermeasures against climate change and the key content of a special report on the Ningshia area, prepared with assistance of the UK government, are summed up.

1. Japan

1.1. Impact of Climate Change

Japan, via NIAES for the most part, has carried out in-depth research studies with regards to impact assessment, in order to formulate countermeasures for the agricultural sector against climate change since the late 1980s.

The Japanese National Agriculture and Food Research Organization (NARO) carried out questionnaire research projects for 47 local government agricultural research institutes on the impact of global warming on agriculture – the first being fruit trees in 2003 and the second being rice, wheat, soybean, vegetables, flowering plants, and livestock farming in 2005. The result of the questionnaire research studies showed that global warming affected fruit trees in all areas, affected vegetables and flowering plants in 70% or more of the areas, and affected wheat/soybeans and livestock farming (livestock and forage crops) in about 40% of the areas. Of the 47 local governments, 37 reported an increase in the occurrence of white under-ripe kernels, which had lately become an issue in rice cultivation, and of this number, more than half of them (22 local governments) perceived global warming as being the cause.[25] With regards problems other than white underripe kernels, the occurrence of cracked kernels accounted for the bulk of the reported problems and six local governments perceived global warming as being the cause.

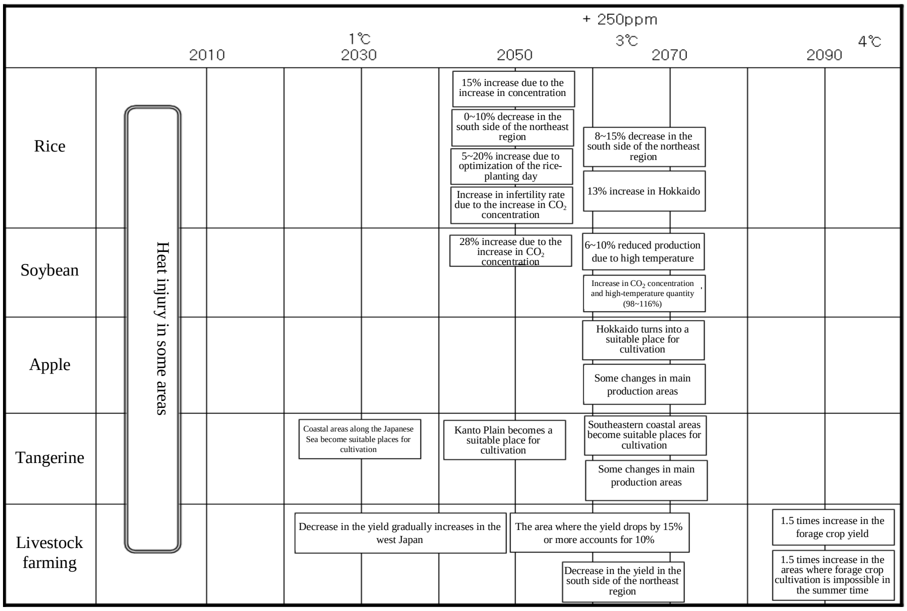
In formulating the comprehensive counterstrategy against global

25 White under-ripe kernels of rice is the symptom caused as all or some of brown rice turns to milk white when the average temperature during the maturing period (the period between the earing/blossoming and the harvesting) exceeds 27℃, which shows a rising trend.

warming (2007), MAFF of Japan utilized the results of NIAES's analysis of climate change impact on crops, based on the result of global warming impact simulation (4~5℃ rise in 100 years) <Figure 6-1>.

When analyzed using the CERES-Rice model, the potential rice yield was estimated to increase by 13% in Hokkaido while decreasing by 8~15% in the southern portions of northeastern areas if the average temperature across the country rose by about 3℃ (2060). On the other hand, it was estimated that if the carbon dioxide concentration rose by 200ppm from the current level, the rice yield will increase by about 15% in Hokkaido.

Figure 6-1. Impact of temperature rise on the agriculture and livestock farming in Japan



Note: For mid/long-term estimates for temperature rise, an average temperature rise of 1℃ by the 2030s, 3℃ by the 2060s (250ppm rise in CO_2 concentration), and 4℃ by the 2090s are assumed, based on the result of impact analysis according to the "World of Very Rapid Economic Growth" scenario.

Source: JMAFF (2008)

For apples, areas suitable for cultivation (i.e. with an annual average temperature of 7～13℃) are gradually shifting north and thus it is estimated that the Hokkaido area will become a place suitable for cultivating apples by 2060 whilst apple cultivation in the present main production areas (Aomori, Nagano, etc) will decrease considerably. Degradation of apple, such as poor coloration due to heat injury, was also expected.

For tangerines, the areas suitable for cultivation (i.e. with an annual average temperature of 15～18℃) was gradually shifting north and was estimated to extend to the Nigita Plain by the 2030s, the Kanto Plain by the 2040s, and the south portions of northeastern areas by the 2060s. In the 2060s, most of the current main production areas (Shizuoka, Wakayama, and the coastal area of Minamikysu) will become unsuitable for cultivating tangerines as the average temperature in those areas will exceed 18℃.

For livestock farming, meat production started decreasing especially in the poultry farming in the west region of Japan. So, by 2060, the number of areas experiencing more than a 15% decrease will increase by 10%, furthermore the affected area will extend to the southern portions of northeastern areas. However, it is expected that forage crop yield will increase as will the production area devoted to it.

Global warming will also affect water resources, with the potential amount of water resources by August 2030 estimated to be about 30mm less than at present (due to a 20% increase in the evapotranspiration from the present amount). As about 60% of the water resources available are used for irrigation, it is estimated that the use of irrigation water will be significantly limited in some areas. In addition to these problems, it is expected that global warming will result in an increase in the incidence and severity of blights and pests in rice, vegetables and fruits and also allow foreign insects to settle in the southern areas.

1.2. Adaptation Measures against Global Warming

Japanese Ministry of Agriculture, Forestry and Fisheries (JMAFF) announced "MAFF's Comprehensive Counterstrategy against Global Warming" by consolidating the results of researches completed by March 2008. The Comprehensive Counterstrategy consists of three parts: global warming prevention measures, global warming adaptation measures, and international cooperation in the agriculture, forestry and farming sector. The global warming adaptation measures are subdivided into implementation of global warming adaptation measures and technology development for global warming adaptation measures. Major items for the implementation of global warming adaptation measures, being urgent adaptation measures or future response policies are documented in "Report and Schedule for Adaptation Measures by Items," which is based on the results of nationwide surveys and of technology development by research institutes. As for technology for adaptation measures, the Comprehensive Strategy suggests the early development of crop varieties that are resistant to high temperature or the development of stable cultivation control technologies that are applicable to the production field.

The production bureau of MAFF published the "Report on Countermeasures against Global Warming Measures" in June 2007, which suggests the adaptation measures applicable to the agricultural production field and the short-, mid-, and long-term research and development tasks. The research and development tasks are approached in three phases: short-term (2008-2010), mid-term (2010-2030), long-term (2030~) <Table 6-1>.

The adaptation report deals with such items as rice, various kinds of barley, beans, and tomatoes and covers the current production situation, urgent adaptation measures, and future adaptation measures <Table 6-2>. Major adaptation measures for rice are divided into urgent measures and future measures. Urgent measures to be taken against the

Table 6-1. Japan's phased research plan for adaptation to global warming

Short-term (2008~2010)	Mid-term (2010~2030)	Long-term (2030~)
· Urgent tasks (project researches,) - Develop technology to reduce the occurrence of green-kerned rice - Develop rind puffing control technology for tangerines using the plant growth control agent. - Develop efficient dimming methods to inhibit the occurrence of defective tomatoes	- Research to formulate well-designed adaptation measures - Develop production stabilization technology - Develop new varieties resistant to stresses including high temperature, so as to adapt to global warming - Cope with new blights/pests	· Review fundamental issues concerning with adaptation measures - Develop production stabilization technology via a thorough review of cultivation technologies - Develop new varieties that can adapt well to global warming, using genome information - Switch over crops based on the global warming impact assessment
· Mid/long-term tasks including the development of new varieties (using the grant) - Develop new rice varieties resistant to high temperatures - Develop new fruit varieties that are not easily coloured even at high temperature	· Develop the crop switchover assessment system - Review conditions for crop switchover	

Source: JMAFF (2008).

occurrence of white underripe kernels and/or cracked kernels include the introduction of delayed rice-planting, proper fertilizer application, and a switchover to varieties resistant to high temperatures. Future counterstrategies include verifying the feasibility of lengthening the earing time through direct sowing, establishing the technology development systems, and popularizing the cultivation control systems.

Adaptation measures for beans are focused on thorough irrigation between furrows in order to reduce crop damage due to undergrowth and poor fruiting caused by high temperatures and precipitation. To prevent the frequent and extended occurrence of blights and pests and the occurrence of sub-tropical blights and pest, such adaptation measures as timely and adequate pesticide application and a switchover to resistant varieties have been prepared. For tangerines, strict observance

Table 6-2. Current problems caused by global warming, and adaptation measures against them

Items	Main problems	Urgent adaptation measures	Future counterstrategies
Rice	White underripe kernel	· Introduce delayed rice planting. · Apply proper amount of fertilizer and irrigation control · Switch over to new varieties resistant to high temperatures	· Verify the feasibility of lengthening the earing time through direct sowing. · Establish the technology development system and popularize the cultivation control system
	Cracked kernel		
	Frequent occurrence of *Pheropsophus jessoensis*	· Remove weeds along the raised borders between rice fields before earing time · Remove the damaged kernels using the color screening machine	· Develop advanced technology to estimate the occurrence of pest and to control its population, using pheromones
Beans	Lack of growth due to high temperature and precipitation, Underripe roots	· Thoroughly irrigated between furrows.	· Establish and popularize the systematized water control system to balance between draining and irrigation. · Develop new varieties that are resistant against blights and pests and moisture as well. · Estimate the occurrence of pest and prevent damages, using pheromones.
	Frequent and extended occurrence of blights and pest, Occurrence of sub-tropical blights and pest	· Thorough prevention of pest through timely and adequate pesticide application · Switch over to pest-resistant varieties	
	Yield drop due to high precipitation, Lowered quality due to high temperature and precipitation	· Introduce thorough draining measures and no-tillage seeding technology.	
Tangerines	Poor coloration	· Strictly observe the proper crop load · Introduce the seat mulching cultivation technology	· Develop the cultivation technology making the best use of materials. · Review variety switchover, using high-precision estimation models.
	Puffiness	· Strictly observe the proper crop load · Apply calcium supplement	

Source: JMAFF (2008).

of proper crop load against poor coloration, introduction of the seat mulching cultivation technique, and the application of calcium supplements to combat fruit puffing have been considered as adaptation measures.

The report suggests the adaptation measures for each item by summing up the research results on climate change and then focussing on popularizing the technologies that farm households can apply in their fields <Table 6-3>. For rice, such adaptation measures included the development of high-temperature resistant varieties, inhibition or induction measures to produce the proper number of grains, cultivation density control, and the improvement of fertilizer application. These measures have been formulated in order to cope with the occurrence of white underripe kernels, cracked kernels, and infertility due to heat injury. For coloring season, the selection of varieties with good coloration and the introduction of light-receiving apples have been considered so as to prevent poor coloration due to heat injury during the technology using reflection film.

To prevent the browning of peach flesh from heat injury during the ripening period, a variety of adaptation measures have been formulated, including a switchover to mixed-color varieties, the observance of proper crop load and harvesting, and soil and weed management. In order to cope with poor coloration of grapes due to heat injury, a number of adaptation measures have been developed including using ABA (Abscisic acid) treatment and girdling treatment. For tangerines a variety of adaptation have been prepared including improved light-receiving technology using reflective mulching materials to prevent poor coloration due to heat injury, measures to minimize the bearing of bulky fruits, and control the bearing of large fruits due to fruit drop, the development of new varieties that greatly inhibit the bearing of bulky fruits. For beans, the development of an underground water-level control system has been considered as an adaptation measure to prevent drought damage due to high temperatures in summer and fall.

Table 6-3. Adaptation measures for each item against global warming

Item	Climate	Impact	Adaptation measures
Rice	Heat injury	White underripe kernel Cracked kernel Infertility due to high temperature	· Develop high-temperature resistant varieties - Develop high-temperature resistant and early- ripening varieties · Delay rice-planting time, inhibit or induce a proper number of kernels, control the cultivation density, and improve the fertilizer application
	Blights and pest	*Pheropsophus jessoensis*	· Estimate occurrence of pest using the sex-pheromone trap - Review the pest control methods including new pesticides
Apples	High temperature during the coloring season	Poor coloration (softened flesh, reduced storability)	· Select good coloration system from Tsugaru and Fuji - Improve the light-receiving technology using the reflective film.
Peaches	High temperature during the growing season	Browning of the flesh	- Switch over to mixed-color varieties. - Strictly observe proper crop load and/or crop harvesting. - Soil and weed management
Grapes	High temperature during the coloring season	Poor coloration	· ABA(abscisic acid) treatment and girdling treatment - Strictly observe the bearing of proper crops
Tangerines	High temperature during the coloring season	Poor coloration and bulky fruits	- Improve light-receiving by using reflective mulching materials - Prevent bearing of bulky fruits by fruit drop - Develop varieties that will rarely bear bulky fruits · Reduce bulky fruits using plant control agents
	High temperature in summer	Falling of fruits	· Prevent natural falling of fruits through Gibberellin treatment
	Blights and pest	Tangerine green disease	· Prompt diagnosis using LAMP method - Prevent vectors
Beans	High temperature in summer and fall	Drought injury	· Develop underground water-level control system

Source: JMAFF (2008).

2. EU

2.1. Climate Change Impact on EU: Case of the Mid-Atlantic Coastal Area

In the European agricultural climate zone, the mid-Atlantic coastal area includes the UK, Netherlands, Belgium, Luxemburg, north France, west Germany, Denmark and west Sweden. In this area, it is expected that temperatures will rise by 2.5~4℃ by 2080 and that precipitation will decrease annually but increase seasonally in winter. It is also expected that winter precipitation and temperatures will increase, resulting in an increase in the frequency of storms and floods, while summer will become drier and hotter.

In this climate zone, climate change might be of benefit to agriculture. An average 12% increase in the crop yield is estimated by 2080 due to the lengthened cultivation period, a rise in temperature and an increase in CO_2 concentration in the atmosphere (Atkinson *et al*., 2005). In the northern area where soybeans and sunflowers can be cultivated, there is a possibility that the yield might increase. This area has the highest agricultural productivity in Europe and if the agricultural climate conditions are extended to southern Norway, mid-southern Sweden, southwest Finland, it will result in a potential increase in Europe's food production.

On the other hand, the mid-Atlantic agricultural zone may also face significant risks because of climate change. A rise in the sea level will submerge a large amount of the farmland in the lowlands of the east UK, Belgium, Netherlands, and northern coastal areas of Germany. An increase in the amount of winter precipitation will increase the danger of flood (Reynard et al., 2001), which will have a serious impact on a large amount of low farmlands around major rivers. Additionally, extreme weather events will become more frequent.

An increase in severe rainstorms, where precipitation exceeds the soil's absorption rate will result in an increase in the occurrence of point-source pollution in areas where livestock excrements are put into the soil. If the precipitation is reduced or temperatures rise too much during the ripening period of major crops, it will not be possible for the crops to produce their potential yields. In this agricultural zone, the risk of yield drop in some areas will offset the aforementioned potential increase in the yield and thus there is a greater likelihood of a yield drop than a yield increase. Hotter and drier summer weather will have different influences on different crops. In this agricultural zone, potatoes and sugar beets are sensitive to dry soil conditions and thus require irrigation for sowing in spring and for reaching the potential yield. In the future, demand for irrigation will increase, resulting in a drop in the productivity of potatoes and sugar beets.

Temperature rise increases the risk of new blights and pests and this risk will likely lead to an increased use of agricultural chemical pesticide, which would lead to a deterioration in water quality. A large amount of the soil resources in this zone is composed of brown soil that can better endure the pressure of drought than shallow or coarse soil. However, production in this soil will not be able to reach the potential yield if the pressure of drought gets worse.

2.2. EU's Adaptation Strategies against Climate Change

2.2.1. Objectives of adaptation strategies

The Commission of the European Communities has established improving resilience as an objective of its adaptation strategies against climate change. The resilience improvement strategy supports the EU's goal for sustainable development while respecting the subsidiarity principle at the same time. The strategy will be implemented over two phases -- Phase I (2009~2012) and Phase II (2013~) with Phase I serving as the preparatory stage for the adaptation strategies to be carried out in Phase II.

As for the main tasks to be implemented in Phase I, the Commission suggests establishing a solid knowledge base about the impact of climate change on the EU, consolidating adaptation strategies in major policy fields of EU, coordinating various policy measures (market-drive devices, guidelines, public-private partnerships, etc.). This will in turn allow for the effective implementation of adaptation measures, and consolidating international cooperation. The tasks to be put into practice by 2011 are to develop the indices for monitoring the impact of climate change, to analyze and assess the cost-effectiveness of each adaptation measure, to enhance the resilience of agricultural policies, and to enhance the resilience of policies regarding bio-diversity, ecosystem and water. The EU's greenhouse gas reduction efforts for mitigating climate change, have limitations and thus supplementary measures, that is adaptation efforts, against the impact of climate change are required. Acting on this understanding the Commission emphasizes the need for measures to increase the resilience of mankind and nature against climate change. Deeming it is necessary to take adaptation to climate change into consideration for agricultural policies, water management policies, energy policies, and finance and insurance policies. Among the EU nations, Denmark, Finland, France, Germany, Hungary, Netherlands, Spain and UK have adopted National Adaptation Strategy.

2.2.2. Adaptation plan

The Commission analyzed in detail the potential adaptation measures against climate change in relation to the agricultural sector across the entire EU. According to the analysis, climate change will increase the risk of drought, water shortage, reduced crop productivity, deteriorated crop quality, increased blight, pest and weeds, flooding, reduced water quality, and sea-level rise. The adaptation options for each risk are summarized in <Table 6-4>.

Table 6−4. EU's major adaptation options against climate change

Risks	Adaptation options
Drought and water shortage	· Increase irrigation availability and improve water efficiency. · Increase the use of compost to reduce the damage caused by blights and pests, and maintain yields. · Switch the variety to new crops that use water less intensively. · Select and develop new crops like beans that are resistant to heat. · Take measures to increase the water storage capability of soil. · Take measures to increase the storage of rainwater during the winter time.
Reduced crop productivity	· Cultivate heat-resistant varieties to mitigate productivity reductions due to heat pressure. · Sow beans in early fall or early spring so as that they ripen prior to temperature rises in summer. · Research into breeding with a focus on crop production.
Deteriorated crop quality	· Increase in CO_2 concentration and direct sunlight affect the quality of crops. Use of protection and monitoring devices such as heat shields and thermometer prevent deterioration of crops quality
Increase in blight, pest and weeds	· Diversify the varieties with less resistors and damages. · Install thermometer and modern ventilation systems in greenhouses, to reduce damage by blights and pests. · Administer vaccinations to livestock to prevent diseases. · Research into the measurement of potential risks of blights and pests and cures for them, then collect and build up the corresponding information.
Increase in the risk of floods	· Improve soil drainage to reduce the damages by flood. · Disseminate information about flooding to minimize the unwanted impact of flood. · Provide proper farm insurances to prevent the loss of buildings and equipment. · Improve the soil structure and plow the outer blocks, to enhance the soil's water absorption rate. · Develop forests that will act as buffers during torrential rain. · Provide government grants and aid for farm household adaptation activities.
Deteriorated water quality	· Improve the efficiency of composting and its application methods, to prevent pollution by torrential rain from expanding.
Sea-level rise	· Support farmers who have lost their land due to sea-level rise. · Preferentially protect crowded and coastal areas.

Source: AEA Energy & Environment (2007).

Among the major adaptation options, adaptation to drought and water shortage is given the highest priority. There are a variety of adaptation options to mitigate the problem of water shortage caused by temperature rise, such as increase of irrigation, improvement of water efficiency and a switch to crops that use less water. Though the emphasis is on building the infrastructure to mitigate the problem of water shortage, the adaptation options also address how to efficiently use and save water. They even take into consideration the risk of reduced crop productivity and that of deteriorated crop quality.

The socioeconomic conditions and environmental conditions of the nations of the European Community are very diverse. Their income and education levels and cultural norms are also different. As such diversity and differences may affect the development of adaptation strategies, adaptation measures are analyzed in consideration of specific environment of a certain area or farm before they are formulated into an adaptation strategy for that area or farm.

3. UK

3.1. Climate Change Impact

For the UK, extreme precipitation and an increase in river flow are expected. It is estimated that the water flow will increase by up to 20% over the coming 50 years (MAFF, 2001) and the inundation of rivers during the winter time will increase across the entire UK (West and Gawith, 2005).

According to the Research Report on Future Drought Risk by the UK Environment Agency (Wade, 2004), the phenomenon of a slight increase in the incidence and severity of drought will be detected even under a low carbon dioxide emission scenario in the early 2020s. More research is required to verify whether the expected drought level change is beyond the range of natural variability. By the 2080s, such drought conditions will mean that droughts, such as the one which occurred in 1995, will be more severe and occur at ever shorter interval, the interval will decrease from once every 9 years to twice every 15 years (under low carbon dioxide emission scenario) or once every 3 years (under high carbon dioxide emission scenario) (West and Gawith, 2005).

3.2. Adaptation Strategies to Climate Change

3.2.1. Objectives of adaptation policies

The UK has already started taking action to adapt itself to climate change. Many governmental policies including flood control, water resource management, urban planning, building regulations, medical services, agriculture, and international development have been consolidated in terms of climate change. The UK government has provided funds for the UK Climate Impacts Programme (UKCIP), to improve the knowledge base on climate change and help those subject to the effects of climate change impact, including the farmer, adapt themselves to climate change.

The objectives of the adaptation policies for the UK agricultural sector consist of the following four strawman objectives <Table 6-5>, which have been set in consideration of the sectional, cross-sectional, and regional issues after the climate risk assessment[26]. The first two objectives have taken into consideration the prevention of climate change impact by financial support, the resilience to climate change,

[26] Defra (2005), p.50.

Table 6-5. Strawman objectives for the agricultural sector

· Help the farm households and market make the best use of new opportunities and cope with the changes and risks of climate resources. · Estimate climate change and ensure that national adaptation strategies be securely incorporated into the agricultural environment planning and regulation. · Develop specific plans for regions which have become suitable for cultivating certain crops, and estimate the need for agricultural processing in those regions. · Estimate new conditions required for cultivating crops under conditions of rising temperatures and drought in the summer, using the crop breeding program.

Table 6-6. Objectives to utilize new opportunities and cope with risks

	Present (2010-2015)	Future (2015～)
Policies and planning	· Financing: Long-term contracts from purchasers promote rural village development by financing climate adaptation. · Related regional agencies improve the percentage of production of vulnerable crops.	· Mid-term objectives have not yet been set due to the difficulty in estimating the future conditions. · Modify objectives over time.
Functions	· Implement transition to new climate resources/risks through the industrialization of farm management, change of crop types and sowing time, and diversification based on research and information.	
Standard and regulations	· Introduce climate adaptation to the regional planning and the surveys by the regional development agencies.	
Research and monitoring	· Apply research and monitoring tools to determine whether or not to assist land utilization and adaptation to climate change.	
Education and training	· Improve awareness of climate change through farm-connection service and consultation provided for adaptation to climate change, for a diversity of adaptation methods.	
Partnership	· Include supply chain, in addition to regional development.	

Source: Defra (2005).

and the minimum resilience to climate change through the existing policies, and thus they are practically feasible. These practical objectives are presented respectively for the present and the future, with regard to policy, function, regulation, research and monitoring, education and training, and partnerships <Table 6-6>. These objectives are mainly aimed at ensuring the provision of financing, improving the yields of vulnerable crops, and implementing adaptation measures appropriate for new climate resources/risks, including diversification. Of the four objectives, the other two objectives focus on clusters within the sector rather than on individual risks for crops or livestock and thus their scope is wider than the first two objectives. They are aimed at solving issues in connection with certain risks, including adaption control for livestock feeds, irrigation, and investment in farm reservoirs or new livestock stables.

3.2.2. Adaptation strategies

The UK agricultural sector's adaptation to climate change is characterized by a lack of initial adaptation measures despite a high-level of awareness among people. It appears that it was much easier to adapt directly without any plan than to adapt according to a certain plan and thus adaptation under most plans has changed from "implementation of adaptation" to the "cultivation of adaptation capacity." The percentage of trickle irrigation, which reduces the water use, has been increased up to 5% in the irrigated regions of England and Wales and it appears that more than 50% of the farmer living in those regions schedule irrigation according to the seasonal water availability.

Recently, the UK prepared adaptation strategies against water shortage, an increase in winter precipitation, and increases in blights and pest in the agricultural sector <Table 6-7>. The strategies to solve the water shortage issue include controlling the water use level by storing water and introducing drought-resistant crops. The strategy to counter the increase in winter precipitation takes into consideration the fact that the farmland plays an important role in flood control and the agricultural techniques may help reduce the impact of precipitation increase. The strategies for markets, processing, and consumers include taking advantage of climate change as an opportunity for increasing the demand for new types of farming machinery and investing in removable processing factories.

Table 6-7. Adaptation strategies for the UK agricultural sector

	Adaptation strategies
Water shortage	· Install small water reservoirs in farmlands. · Encourage efficient water use (technically and bio-technically) · Enforce the water-responsibility/trade permits to promote efficient water use. · Trade water that farmer have stored. · Select technologies to control soil erosion. · Select highly adaptable crop varieties and livestock breeds. · Install a system for preserving moisture on the land surface, for water use in summer.
Increase in winter precipitation	· Convert the farmers into the caretakers of the areas vulnerable to flood and carbon storage managers in the highlands, through appropriate compensation. · Improve plant breeding technology to reduce the danger of landslide during torrential rain. · Add organic matter to muddy soil to increase soil fertility.
Blight and pest	· Formulate a sustainable integrated weed control strategy to counter new crop blights and pests. · Formulate to control seeds, blight, and pests.
Market, processing, and consumer	· Make the best use of the opportunity generated from the potential demand for new types of farming machines for irrigation, seeding, and harvesting. · Invest in building removable processing factories that can be installed and easily removed within a short period of time, as the places for crop cultivation shift north
Others	· Introduce creative ideas to crop cultivation to cope with climate change. · Encourage flexible approaches to the sowing time.

Source: Defra (2006).

4. Australia

4.1. Climate Change Impact

The Australian climate has changed over the time, which has been shown through precipitation, temperature, and extreme climate events. According to the estimation of future greenhouse gas emission by the IPCC (IPCC, 2000), the average temperature of Australia will rise by 1~5℃ (CSIRO & BoM, 2007) from that of 1990, though this will vary by area, that is, inlands and coasts. <Table 6-8>.

It is estimated that in comparison with the level of precipitation in 1990 the precipitation in 2070 will rarely change in the northern Australia but will decrease by about 10% in the southern regions (CSIRO & BoM, 2007). Such changes in precipitation are expected to vary widely both by region and by season.

The number of dry months in 2030 will increase by 20% or more in most regions of Australia, in comparison to the 1990 level and, for extreme cases, the frequency of rainfall events will increase in the northern regions and decrease in the southern regions. It is also expected that rainfall events will become more intense across Australia and that rainfall events following long dry seasons will become frequent, resulting in flooding and soil erosion.

Table 6-8. Estimated rise in the average temperature of Australia (in comparison to 1990)

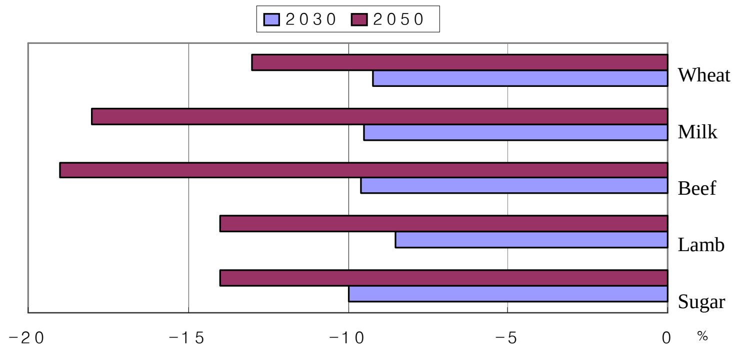
Unit: ℃

	2030	2050	2070
Australia	1	0.8-2.8	1.0-5.0
- Coasts	0.7-0.9	-	-
- Inlands	1.0-1.2	-	-

Source: CSIRO & BoM (2007).

Potential changes in the major climate variables of Australia will cause agricultural productivity and crop yield to decrease. According to an analysis by Gunasekera, the decrease in agricultural productivity and global economic activities caused by future climate change will have an impact on the major crop production of Australia and of the entire world. The potential climate change will result in a decrease in the production of major agricultural products of Australia; wheat production will decrease by 9.2% in 2030 and by 13% in 2050, beef by 9.6% and 19% respectively, lamb by 8.5% and 14%, milk by 9.5%, and 18%, and sugar by 10% and 14% <Figure 6-2>.

Figure 6−2. Change in the production of major agricultural products of Australia due to climate change



Source: Gunasegera D., et al (2007).

4.2. Climate Change Strategies

4.2.1. Climate change response programs

Australia’s Farming Future (AFF) is a Australian government climate change initiative for the primary industry, which helps the primary producers adapt themselves to climate change by providing financial supports over four years. The AFF is comprised of the Climate Change Research Program, FarmReady, and Climate Change Adjustment Program.

The Climate Change Research Program provides funds for research projects and farm experiments that will help the agricultural sector adapt itself to climate change and so prepare for the future. The program includes the projects to develop viable management solutions for the agriculture and farm households. Projects focus on greenhouse gas reduction, soil management improvement, and adaptation to climate change. It supports large-scale joint projects that involve many organizations such as research providers, industrial groups, universities and provincial governments. The program promotes the development of individual methods that will substantially improve producers' adaptability and resilience to climate change.

The FarmReady program aims at supporting primary producers and indigenous land managers with the opportunity for training. It also encourages industrial, the agricultural, and the natural resource management organizations to develop strategies to cope with and adapt themselves to climate change impact. The grants available through this program include the FarmReady Reimbursement Grants and the FarmReady Industry Grants.

The Climate Change Adjustment Program is designed to help agricultural producers adapt themselves to the climate change impact. The program comprises training activity support, adaptation consulting support, and support for those farm households that decide to leave the farm. The training activity support is available via authorized agencies and focuses on entire farm planning, business and risk management, and understanding the implications of climate change. Adaptation consulting support is available for qualified primary producers who are negatively impacted, or likely to be negatively impacted, by climate change, and includes those who have experienced damage due to drought. Expert recommendations and training delivered under this program are customized to help farms adapt their management to climate change and set objectives and develop action plans to improve their financial situation.

4.2.2. Climate change action plan

Australia's National Agriculture and Climate Change Action Plan 2006-2009 constitutes an important framework for the climate change policies of the government and the agricultural sector. The Action Plan was established by means of cooperative and coordinated efforts between the federal, provincial, and local governments of Australia, and completed in consultation with farms, local communities and climatologists.

The Action Plan is composed of four major parts: adaptation, mitigation, research and development and awareness and communication. The adaptation strategy manages the various risks facing sustainable agriculture under changing climate conditions and strengthens the agricultural system's resilience. The mitigation strategy is concerned with reducing greenhouse gas emissions. Research and development pursues ways and means to enhance the agricultural sector's capacity to cope with climate change. Awareness and communication seeks to inform the decision-making of primary producers and rural communities.

Australia's government policies and scientific research places a high value on flexible long-term strategic adaptation plans. In particular, farmers demand the action plans and tools that will allow them to cope with climate change. In response, the Action Plan suggests such adaptation strategies as improving the agricultural system's resilience to cope with climate change by integrating the adaptation policy and the local development plan; supplementing the existing program to train natural resource managers' and improve the system's capacities; minimizing the invasion of foreign varieties, blight, and pests and their adverse influences on indigenous varieties; and utilizing the advantages of any market opportunities provided by climate change <Table 6-9>.

The Action Plan also includes an strategy to develop the agricultural management technology needed to improve the agricultural system's resilience, technology to manage climate change and variability management tools, and tools that would allow the agricultural system to mitigate greenhouse gases. Another action plan is to promote diversification and industrial restructuring in consideration of the risks and vulnerability of climate change and to grow both the natural resource managers' and the system's capacities. The Australian government evaluates the agriculture as being a means of finding new market

Table 6-9. Actions for the detailed adaptation strategies

4 major actions	Actions require for detailed strategies
Cultivate the agricultural system's resilience.	· Develop dynamic agricultural management technologies to integrate the risks of climate change into the existing and new management systems. · Develop the climate change and variability management tools. · Development agricultural systems to promote adaptation and to mitigate adverse impacts on the environment such as greenhouse gas emission. · Improve adaptation strategies that were successful and develop the agricultural environment management system.
Cultivate the natural resource managers' and system's capacities.	· Integrate risk and vulnerability of climate change into the natural resource management plan and investment.
Minimize the adverse influences of invasion of blight pests.	· Assess whether blight, pests, and weeds have any relation to climate change. · Determine priorities and define the potential impact of climate change regarding those priorities.
Utilize the advantage of market opportunity.	· Strengthen socioeconomic and market researches that explain climate issues. · Ensure research results to be satisfactorily delivered to the farmers and the resource managers. · Evaluate agriculture as a means of finding new market strategies for the industrial viability under climate change.

Source: www.daff.gov.au.

strategies that will maintain industrial viability under climate change. This illustrates that various policy directions are possible, including those that perceive climate change not only as a risk but also as an opportunity.

4.2.3. Adaptation measures for farm households

Most of Australia's adaptation measures for farm households were to expand or improve existing actions for dealing with the climate change. Therefore, it was necessary to develop diverse cultivation and adaptation plans for large scale agriculture, and make them available for use (Howden et al., 2003). To that end, various research and development project have been carried out to formulate adaptation measures applicable to the Australian farm houses (Kingwell R., 2006). In order for farm households to adapt themselves to climate change, the use of advanced technologies such as a weather forecast system, satellite image technology and the technological improvements connected with weather and season forecasts is required. Major adaptation measures are to develop a portfolio of resources, techniques and processes suitable for climate change scenarios including the breeding of varieties resistant to new or more toxic blights and pests, improving the weather forecast technology and the season forecast technology so as to estimate the extent and duration of drought more accurately, change the way how to determine cultivation methods and crops to be cultivated, and to use the satellite image technology and other expert systems <Table 6-10>.

Table 6-10. Adaptation measures applicable at the farm household level

Adaptation measures	Examples
· Develop a variety portfolio suitable for the increased weather change: Develop varieties that are more resistant to new or more toxic blights and pests.	-
· Reduce down-side risk in crop production.	Staggered planting machine, erosion control infrastructure, minimum soil disturbance crop facility, crop byproduct maintenance, crop portfolio
· Cultivate crops based on the improved weather forecast technology.	Sowing, pest control, weed control, harvesting
· Decide cultivation method, varieties to be cultivated, and crop investment level, based on the improved season forecast technology.	-
· Opportunism in cultivation method and cultivation decision.	Sowing season, extent of sowing, planting density, technical application of nitrogen fertilizer
· Forage production and crop administration decision support system, based on the consultation service using satellite image technology and other expert systems	-
· Decision about inventory and liquidation through the improved weather forecast system that can estimate the extent and duration of drought.	-
· Research into the impact of the prolonged dry season and high temperature on the blight and pest ecosystem, and utilize the research results.	-
· Develop low-cost desalinization system that uses salty underground water, in order to supply water for irrigation.	-

Source: Kingwell (2006).

5. China

5.1. Climate Change Impact on the Chinese Agriculture

Climate change impacts on Chinese agriculture and stock farming include an increase in unstable factors for agricultural production; severe drought and heat injuries in some regions, and a worsening of freezing injuries in early spring due to the accelerated crop growth period brought about by global warming. Forage has decreased in both yield and quality and losses to agriculture and stock farming from meteorological disasters has increased.

The climate change impact on agriculture and stock farming is expected to continue into the future. It is expected that, due to climate change, the yield of the three major crops of China; wheat, rice, and corn, will decrease and the productivity of Chinese agriculture will have dropped 5~10% by 2030. In the late 21st century, the yields of these three major crops of china will decrease by up to 37%, affecting long-term food security. The irrigated area in China accounts for 47% of the entire cultivated acreage and two thirds of China's food production comes from the irrigated area. When moisture is reduced by 1%, the irrigated area is reduced by more than one percent which will seriously impact China's future food production. The yield of frigid crops in most of the northern regions will also decrease considerably and the forage growth in drought or semi-drought areas will be reduced as well.

Climate change will change the production distribution and structure of the Chinese agriculture. Global warming will bring about the rise in average annual temperature of China, the rise in suitable temperature for agriculture, and the extension of growth period, shifting the cultivation areas further north. Taking wheat as an example, the northern limit for cultivation, which is now the Great Wall, will shift to Shimyang. By

2050, the global warming will turn most of present double crop farming areas into triple crop farming areas and shift the present triple crop farming areas in the Long River valley about 500km north to the Yellow River valley. The double crop farming areas will shift to the middle of the present single crop farming areas and the single crop farming areas will be reduced by 23.1% (LI C. et al.). The climate change mainly characterized by temperature rise will definitely accelerate the increase in gross food production in the northeastern region, restrain the gross food production in Huabei, the northwestern and southwestern regions to some extent, but rarely affect the gross food production in the Huadong and Jungnam regions.

Climate change will significantly increase the production cost of Chinese agriculture. Extreme climate change in China will bring about increases in torrential rain and precipitation. Notably, in the 1990s, the level of precipitation and the incidence of torrential rainstorms had increased in the Long River valley and the southern region of the Long River. The frequency of heavy rain and flood also increased in the Yellow River and the Hoehwa valleys. The frequency of heat waves in the summer time increased as well. The increase in such extreme weather conditions will increase the frequency of disasters, resulting in insecurity of food production and an increase in production costs.

Climate change in China is also expected to affect crop blights and pests. According to the statistics, agricultural production of China will experience a loss of 20~25% of the gross agricultural production due to blights and pests. Global warming will expand the range of blights and pests that had been limited to low temperature conditions, resulting in an adverse impact on crop growth. At the same time, the greenhouse effect will lengthen the lifecycle of some blights and pests, aggravating crop damage.

Many research studies have suggested counterstrategies for the Chinese agricultural sector against climate change. Examples of these counterstrategies include Consolidation of Agricultural Infrastructure, Agricultural Restructuring and Improvement of the Tillage System, Increasing the Technology Investment in Agriculture and Consolidating the Innovation in Science and Technology System, Strengthening the Construction of the Ecological Environment and its Management, Consolidation of Weather Forecast and Warming and Assessment of its Impact on Agriculture.

5.2. Counterstrategies against Climate Change

5.2.1. Counterstrategies and actions to cope with climate change

The Chinese government takes the following four principles in coping with climate change: 1) Cope with climate change to ensure a sustainable development; 2) Attach equal importance to mitigation of, and adaptation to, climate change; 3) Convert the traditional production method and consumption pattern to cope with climate change; and 4) Ensure the whole country is involved.

The Chinese government's countermeasures for the agricultural sector against climate change are largely divided into greenhouse gas mitigation measures and adaptation measures to climate change. The greenhouse gas mitigation measures are to continue popularizing the low-emitting multi-harvesting rice varieties and half-drought type cultivation techniques; adopt scientific irrigation methods and soil-verified fertilization techniques; research and develop high-quality ruminant breeding technology and stockbreeding management technology of scale; strengthen the management of animal excrement, wastewater and solid wastes; enhance the efficiency of methane utilization; and control methane emissions.

Adaptation measures to climate change are as follows: strengthen the measured forecast level for the extreme meteorological disasters by supplementing the measured forecast emergency action mechanism, the multi-department decision-making mechanism, and ensure comprehensive community involvement mechanism in provision against various disasters; establish a meteorological disaster defense process by 2010 that can play a fundamental but essential role in securing the economic society; improve the comprehensive measured forecast level, defense level, and disaster mitigation capacity to cope with extreme meteorological disasters; and form 24 million ha of new grassland and 55 million ha of degraded, desertificated, and/or alkali grasslands by 2010, by strengthening such adaptation measures farmland construction, cultivation system adjustment, resistant variety selection and development, and biotechnology development.

As climate change adaption policies and actions, the Chinese government has enacted and enforced “The Agriculture Act,” “The Grassland Act,” “The Fisheries Act,” “The Land Management Act,” “An Ordnance on Emergency Measures against Sudden Critical Animal Epidemic,” “An Ordinance on Pasture Fire Prevention”. It has also made efforts to establish and supplement the political and regulatory system for the agricultural sector’s adaptation to climate change. In addition, they have strengthened the agricultural infrastructure construction, promoted the construction of farmland irrigation systems, expanded the irrigated agricultural area, and improved the irrigation efficiency and improved the amount of water piping in farmlands. Furthermore, they have popularized water-saving technology for hardy crops, enhanced the agricultural disaster ‘prevention and reduction’ capacity and the generation production capacity, and developed some plant varieties that can endure high temperatures, blights, and pests.

In the future, China is planning to further expand the popularization of high-quality varieties and increase the land cover rate of high-quality varieties. Also, it will strengthen critical animal epidemic prevention measures, establish and supplement the anti-epidemic measures for animals, and improve the forecast accuracy level for animal epidemics.

5.2.2. Ningxia Region's adaptation strategies to climate change

Ningxia Region, one of five self-governing regions located in the northwestern China, is the poorest region in China. Its weather is characterized by dry and distinctive seasons, an average annual temperature of 5-9℃, and precipitation of 262mm. In the Ningxia Region, all three characteristic agricultural systems of China are present: 1) utilization of rainwater; 2) utilization of rainwater and irrigation water; and 3) utilization of irrigation water. The region suffers from a high level of poverty, has often been ravaged suffered from meteorological disasters, and is vulnerable to climate change. The Ningxia Region's climate had been stable but its average temperature has risen by about 0.6~1.2℃ over the past 10 years and the drought became worse in 2004~2006.

The northern Ningxia Region is irrigated from the river flows in from the Yellow Sea. This region cultivates corn, spring wheat, rice, and potatoes through intercropping, and its main livestock are chickens. The central Ningxia region is a dry region with a vast pasture that uses both irrigation water and rainwater. Due to the dryness of the growing conditions only corn, spring wheat, and potatoes can be cultivated and some cows and sheep are raised. The southern mountain area is by Ningxia standards a humid area, though still very dry. Cultivation here uses rainwater to grow mainly potatoes, while the livestock reared include beef cattle, sheep, pigs, and poultry. Because of these differing regional characteristics, the Ningxia Region formulates adaptation objectives taking into consideration how climate risk will affect each area. Furthermore, it pursues policies that integrate its main development objectives and the objectives for adaptation to climate change. This has the following implications: when considering the adaptation policy by the unit of region, in-depth research about the Ningxia region, including its natural conditions, climate system and crops cultivated in the region should be undertaken; the different policies for each region should be formulated based on the research results whilst taking into consideration existing policies.

In response to climate change, the farming households in Ningxia Region have taken some adaptation measures. First of all, as a provision against dry weather and drought, they harrow their fields and uses film covering and/or sand cover to maintain the moisture content of the soil. Harrowing is the most widely used measure in the Ningxia Region, especially in the southern area and Huinong and Helan districts in the northern area. Film covering is used in Huinong, and this has different effects, depending on the crop type. For potatoes, it contributes to an increase in yield of 30%. Sand covering, which is known to be effective against drought, is only used in Haiyuan.

In order to secure water, various rainwater collection measures are taken and the three areas use very different methods. To save water, water saving irrigation is used as well. This applies mostly in the northern irrigated areas. It would be difficult to expand water saving irrigation to other areas as without irrigation facilities this would mean supplying water directly to furrows. Ningxia Region has a high non-farming income rate of about 50%. Not being entirely dependent on farming income the area has a relatively low income vulnerability to climate change. A large number of residents move to other areas with better environmental conditions, and they evaluate moving as a successful adaptation measure <Table 6-11>.

6. Implications of Major Countries' Adaptation Measures

To examine how major countries' agricultural sectors cope with climate change, the cases of Japan, UK, Australia, China and the EU bloc, were reviewed. The result of reviewing their adaptation measures

Table 6-11. Adaptation measures for the farmers in Ningxia Region

Type of adaptation	Description
Measures to maintain the moisture content of the soil against dry weather and drought	· Use various methods to increase the moisture content of the soil. · Harrow the fields and use film covering and/or sand cover.
Rainwater collection	· Use different rainwater collection methods - The northern area rarely collects water as it has rich water resources. - The central area collects rainwater in the underground reservoir. - Jinyuan in the southern area collects rainwater in the underground reservoir.
Water-saving irrigation measures	· Water-saving irrigation is used mostly in the northern area.
Non-farming income	· All three areas have a high non-farming income rate of about 50%.
Moving	· Ningxia residents often move to areas with a better environment.

against climate change shows that, with some minor differences, they mostly adopted similar adaptation strategies. <Table 6-12>.

Japan has divided the global warming adaptation measures into the implementation of global warming adaptation measures and the technology development for global warming adaptation measures, and formulated the adaptation measures based on the research results or the technology development for each item.

The EU has prepared adaptation plans to cope with the various risks of climate change in the agricultural sector.

The UK has adopted various strategies to cope with water shortage such as the installation of water reservoirs and the trading of stored water. The UK has also prepared adaptation strategies connected with markets, processing, and consumers.

Australia, in addition to establishing the climate change action plan for the agricultural sector, pays grants to help agricultural producers adapt themselves to the impact of climate change,

As shown by the detailed plan for adaptation to climate change in

Table 6-12. Comparison of major countries' strategies for adaptation to climate change

		Japan	EU	UK	Australia	China
Adaptation strategy Objective		· Impact mitigation and adaptation	· Improve resilience	· Utilize opportunity and cope with risk	· Build up agricultural system resilience	· Sustainable development
Main strategies (plans)	Agricultural production	· Countermeasures for each item: Adaptation by farm households	· Cultivate heat-resistant new varieties · Maintain the yield and increase the compost use · Intercropping	· Select highly adaptable varieties · Flexible approach to the sowing season	· Develop a varied portfolio · Reduce down-side risk in the crop production	· Harrowing and film covering · Allocate water to each region · Improve the early warning system for disasters
	Farmland, water, and irrigation facilities	· Identify the cases of climate change impact, and review adaptation measures	· Improve efficiency of composting to remove the pollution sources. · Prepare soil protection plans in preparation against sea level rise	· Install the water reservoirs · Trade stored water · Select technologies to cope with the soil erosion	· Take climate change into consideration when investing in the natural resource management · Formulate strategy to increase the efficiency of water management	· Rainwater collection measures · Water-saving irrigation measures · Anti-desertification strategy
	Development of adaptation technology	· Breeding · Improve the cultivation technology	· Researches to improve the crop varieties	· Improve plant breeding technology to cope with the risk of landslide	· Develop cost-efficient crops · Develop low-cost desalination facilities	· Develop high-yield heat-resistant varieties
Policy measures or means		· Support for research and development	· Market-drive devices · Guidelines · Public-private partnership	· Water responsibility/trade permits · Grants for agricultural restructuring	· Farm ready, adaption programs	· Enact and enforce laws and regulations such as "Agriculture Act" and "Grassland Act"

Ningxia Region, China has suggested different strategies for adaptation to climate change, based on the unique characteristics of the agricultural systems in specific regions.

Through the analysis of major countries' strategies for adaptation to climate change in the agricultural sector, the following recommendations have been devised.

First, for the agricultural sector to properly cope with climate change, it is necessary to formulate specific adaptation strategies for each item, for which nation-wide or region-wide surveys about the items impacted by climate change, should be carried out.

Second, the most important thing in minimizing the negative impacts of climate change on the agricultural sector is the research and development of proper varieties and cultivation management technologies for adaptation.

Third, adaptation strategies inevitably involve cost. Therefore, to make the adaptation strategies cost-efficient, it must be ensured that adaptation strategies are differentiated according to the characteristics of the agricultural environments and the agricultural systems of specific regions.

Fourth, as damage to the agricultural sector due to climate change affect not only the present generation but also future generations, it is necessary for a nation to actively support the agricultural producers' efforts to adapt themselves to climate change through the provision of grant programs. Fifth, it is necessary to establish or improve the legal and/or institutional systems to support the climate change counterstrategies so that the agricultural sector's climate change counterstrategies can be smoothly implemented.

Sixth, proper water-saving strategies must be prepared in provision against water shortage in the future, such as introduction of efficient irrigation system, installation of water reservoirs, and trading of stored water.

Lastly, it is necessary to prepare the adaptation strategies regarding markets, processing and consumers including the utilization of opportunity for new market demand following climate change and the mobility of processing facilities as the suitable areas for cultivation shift.

Korean Agriculture Sector Counterstrategies to Climate Change

Chapter 7

In order to minimize the impacts of climate change on the agricultural sector, systematic and phased-out counterstrategies should be established. Chapter seven analyzes the impacts of climate change on the agricultural sector and proposes a master plan and adaptation strategies for the agricultural sector to cope with climate change, based on the examples of foreign countries' counterstrategies. To formulate counterstrategies, it sets basic directions on the basis of which strategic analysis, strategic selection and strategic implementation are examined. An Analytic Hierarchy Process (AHP), using expert questionnaires to decide priorities of adaptation measures against climate change, is applied. Implementation strategies to cope with climate change are presented as key tasks in the following eight categories: technology development, infrastructure management, economic incentives, legal and institutional improvement, education and training, monitoring, technology and administration applicable to farm households, and integrated management system.

1. Basic Directions for Strategy Formulation

Strategy formulation for the agricultural sector in response to climate change is a comprehensive action plan for setting the future vision and corresponding targets from the national perspective and achieving them. The future vision for the agricultural sector's adaptation to climate change is to "establish a stable agricultural production system through adaptation to climate change." The short-term target to achieve this vision is to comprehensively strengthen the systematic capacity for adaptation to climate change. The long-term target is to reduce the risks associated with climate change while realizing the opportunities that arise from climate change. To achieve these targets, the proper policies, including governmental supports, environmental regulations and compensations systems, should be efficiently integrated and implemented consistently through positive policy committment.

Basic directions for formulating the strategies that can establish a stable agricultural production system, by means of strengthening the capacity for turning risks of climate change into opportunities climate change are as follows:

First, viable adaptation measures should be formulated based on the analysis of the impacts of global warming on the agricultural sector and that of the farmers' capacity to deal with those changes. As discussed in Chapter three 'Theories about Countermeasures for the Agricultural Sector against Climate Change', the decision-making analysis stage which throws light on the impacts of climate change on each field of the agricultural sector and the extent of the farmers' capacity for adaptation measures is very important when seeking viable adaptation measures against climate change. Therefore, in formulating the strategies for adaptation to climate change, the following factors must be examined: the climate change impacts on the agricultural ecosystem, crop production, meteorological disasters, and the farm household economy. In addition, the results of analyzing the decision-making and questionnaire surveys regarding the farmers and the extent to which they can adopt adaptation measures in their farming practices should be properly reflected in the adaptation strategies.

Second, implementing the action programs for effective adaptation to climate change takes a considerable amount of time, and so it should be approached phase by phase. As discussed in the chapter on actual conditions and prospect of climate change, climate change refers to the climate system's gradual but continuous change by both natural and artificial factors. This in turn brings about the changes in temperature and precipitation over a considerable period of time, which causes frequent meteorological events, though the changes vary according to location. Therefore, when formulating adaptation measures against climate change, detailed programs for each sector should be prepared that deal with both the short-term (several years ahead) to the long-term (several decades in the future). The period can be divided into several phases in consideration of domestic and international conditions. Here, in order to formulate the adaptation measures to climate change, the period is divided into three phases with 2030 being the target year. The first phase, the information system establishment phase (2009~2013), is followed by the take-off phase (2014~2019) which leads to the settlement phase (2020~2030).

Third, the adaptation measures for the agricultural sector should be approached multilaterally in terms of technology, policy, and management. Chapter three discussed the considerations, which should be reflected in the adaptation measures to climate change. These considerations were the economic and sectional variability, the adaptation barrier, sufficient support, communication, and improvement of adaptive capacity. The adaptation measures themselves should therefore be formulated for different categories which include: research and development (R&D) and infrastructure management in terms of technology development; the economic means, legal and institutional improvement, public relations and education, monitoring in terms of policy planning; and management technology and know how applicable to farm households.

Fourth, adaptation measures for the agricultural sector should be implemented by customizing adaptation programs to reflect the characteristics of each region. As the impact and/or risk of climate change varies from region to region and the capacity to cope with climate change also varies, it is essential to formulate and implement adaptation measures customized to the agricultural sector of each region. In particular, the development of adaptation technologies for climate change should be carried out in consideration of the regional characteristics of Gyeonggi, Gyeongsang, Jeolla, Chungcheong, Gangwon, and Jeju zones respectively.

Fifth, the viable implementation of adaptation measures requires proper role division among the relevant subjects by central government, local governments, agencies concerned, and farmers. Like general agricultural policies, the policies for adaptation to climate change also need appropriate role division among concerned parties in relation to policy making, execution, and policy targets so as to achieve the intended policy objectives. The central government should formulate a master plan for adaptation policies for each sector. The central government should also establish and execute the action programs after taking into consideration the conditions of the corresponding region and with regard to the central government's policies. The Rural Development Administration and its subject organizations (National Academy of Agricultural Science, National Institute of Crop Science, and National Institute of Horticultural and Herbal Science) shall research , develop, and popularize the technologies for adaptation to climate change at the national level. The Agricultural Research & Extension Service of each province shall develop and popularize the adaptation technologies taking into account the provincial characteristics. The government research institutes such as Korea Rural Economic Institute and Korea Environment Institute shall develop the adaptation policies and evaluate the policies before and after implementation. Lastly, the farmer shall attend the related education and training programs to properly cope with climate change, monitor the developed adaptation measures and technologies, and suggest useful ideas.

2. Determining the Priorities of Adaptation Measures to Climate Change

2.1. Use of AHP for Determining the Priorities and Analysis Procedure

To prioritize adaptation measures to climate change, the Analytic Hierarchy Process (AHP) was applied.[27] Solving decision problems using AHP generally involves four steps: decision hierarchy setting, pair-wise comparison of assessment criteria, weight estimation, and weight aggregation.

2.1.1. Decision hierarchy setting (Step I)

The decision hierarchy setting is a step to set decision hierarchies for matters to be determined. Each element of the matters at hand is subdivided into final objectives, assessment criteria, and options. The highest hierarchy is set as the most comprehensive objective of the decision-making. The next hierarchy consists of various comparable attributes that affect the objective of the decision-making. The lowest hierarchy is composed of options to choose.

To set the assessment criteria, the independence of each option from other options of AHP (mutual exclusiveness) should be ensured; the

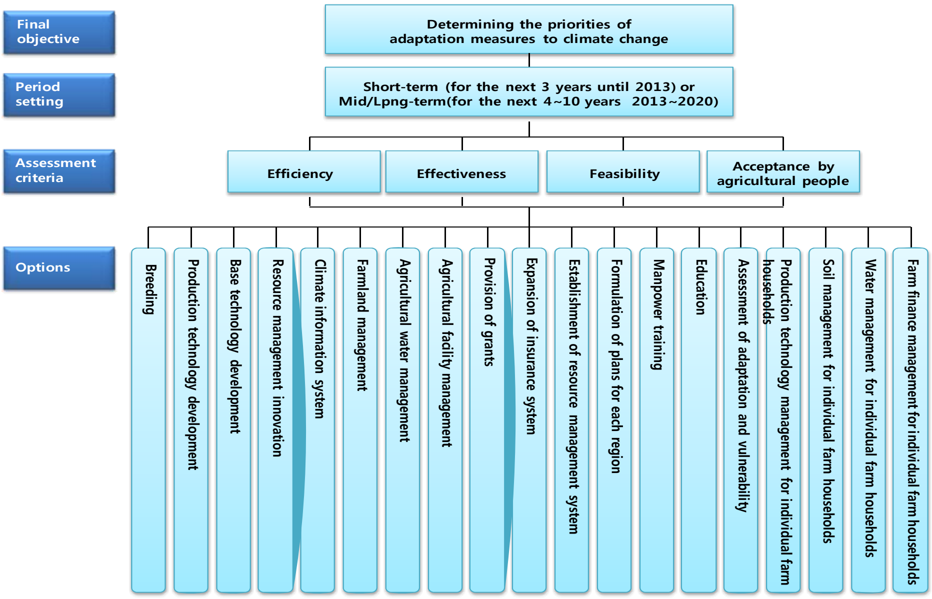
[27] AHP is a decision-making methodology developed by Saaty in the 1970s, which is useful for decision-making for problems or uncertainties that cannot be quantificated through pair-wise comparison of elements of the hierarchy. It identifies the weight of each objective hierarchically to compare the priority of each option, so that not only the quantitative data but also the qualitative data can be considered at the same time. For more information about the determination of priorities of policy programs for the agricultural sector using AHP, see the article by C. G. Kim et al (2004, pp.156-163).

dependence of higher item on the lower elements (complete integrity) should be secured; and the number of items to be processed (processing capacity) should be maintained.

This study has established a three-stage hierarchy for determining the priorities of adaptation measures to climate change <Figure 7-1>.

To determine the priorities of adaptation measures to climate change-efficiency, effectiveness, feasibility, and acceptance by farmers are set as assessment criteria. Efficiency compares the cost and benefit of an adaptation policy. Effectiveness assesses the extent of achievement of the adaptation policy objective. Feasibility assesses whether the policy-making authorities can actually enforce the adaptation poliy. Acceptance by farmers assesses whether the farmer would readily accept the adaption policy.

Figure 7−1. Hierarchy of adaptation measures to determine their priorities



A total of 19 items have been selected as adaptation measure options for the agricultural sector in the face of climate change. They are: R&D (breeding, production technology development, base technology development, resource management innovation, and climate information system); infrastructure management (farmland management, agricultural water management, agricultural facility management); economic means (provision of grants); legal and institutional improvement (insurance system expansion, resource management system setup, formulation of plans for each region); manpower training and education (manpower training, education/public relations); monitoring (assessment of adaptation and vulnerability); technology and management applicable to farm households (production technology management, soil management, water management, farm household finance management).

2.1.2. Comparing assessment criteria (Step II)

The assessment criteria can be compared using two methods, absolute comparison and pair-wise comparison, so as to determine the importance of each criterion and that of each option. The absolute comparison is to assess an option based on the standard obtained from experiences, while the pair-wise comparison is to compare options in pairs based on their common attributes (Saaty, 1990).

As there are 19 options in this study, it is difficult to apply the pair-wise comparison to the options. So, the pair-wise comparison is applied only to the assessment criteria. The assessment criteria are given respective weights using the pair-wise comparison marks out of a nine-point scale, and the options are evaluated using the absolute comparison method[28].

[28] AHP uses relative measurement that compares the elements of each hierarchy in one to one pairs. However, when there are more than ten options, it is not easy to apply pair-wise comparison.

The pollees for the expert questionnaire survey were selected from experts involved in the research on climate change in research institutes or universities. For this study, they were asked to evaluate the importance of assessment criteria for selecting adaptation measures respectively for the short-term (base buildup phase, 2009~2013) and for the long-term (take-off phase and settlement phase, 2014~2030). The questionnaires were completed either by e-mail or by interview and the answers from 56 experts were collected.

Only the pollees whose consistency index was evaluated to be 1.0 or less were included in the analysis, so the questionnaire results of 20 of the 56 experts were used to evaluate the importance of the short-term adaptation measures against climate change and the questionnaire results of 24 experts were used for evaluating the mid/long-term adaptation measures.

2.1.3. Weight estimation (Step III)

To obtain the relative weight and the absolute weight of each decision-making element, Satty's weight calculation method was used. The relative weight obtained from pair-wise comparison was examined to see whether it was logically consistent or not using the consistency index and consistency ratio.[29] In this study, the consistency ratio of 0.1 or less (10% or less) proposed by Satty was selected as the consistency decision criterion.[30]

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[29] Consistency index is measured by (λmax-N)/(N-1), which is 0 when the pair-wise comparison matrix is completely consistent. The lower the consistency is, the bigger the consistency index becomes. Consistency ratio is measured by (CI/R), which is calculated by dividing CI of the pair-wise comparison matrix by random consistency zero (R).

[30] Regarding the consistency decision criteria, a certain pair-wise comparison matrix is considered to be consistent to the corresponding weight when the values of both consistency index and consistency ratio are less than 0.15 according to Tone (1986) or 0.1 (10%) according to Satty (1990).

2.1.4. Weight aggregation (Step IV)

In the last step, the weight of the assessment criterion obtained in Step III was multiplied by the weight of the option to aggregate the relative weights of the decision-making matters. Through this step, the overall priorities of the options were determined.

2.2. Results of the Measurement of Priorities of Adaptation Measures

2.2.1. Result of the pair-wise comparison of assessment criteria

A numeric integration method was used to aggregate the points given by the experts to evaluate the adaptation measures. The points given by the entire pollees for the elements of the pair-wise comparison matrix prepared by the experts were aggregated using the geometric mean, and then a single pair-wise comparison matrix that had the geometric mean as an element was obtained.

The weights obtained by aggregating using the geometric mean, a pair-wise comparison matrices evaluated by 20 experts from the long-term point of view, appear to be 0.11 for efficiency, 0.29 for effectiveness, 0.30 for feasibility, and 0.30 for acceptance level. This implies that effectiveness, feasibility, and acceptance level are important criteria in accessing the priorities of adaptation measures.

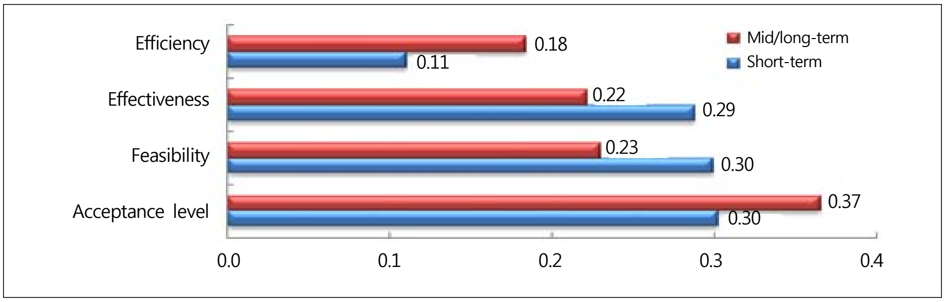
The weights evaluated by 24 experts from the long-term point of view appear to be 0.18 for efficiency, 0.22 for effectiveness, 0.23 for feasibility, and 0.37 for acceptance level, implying that the acceptance level is the most important criterion for assessment.

Comparison between the weights of assessment criteria from the short-term point of view and those of mid/long-term point of view shows that, though similar in the short-term point of view, the weights of efficiency and acceptance level become bigger while those of effectiveness and feasibility become smaller.

Table 7-1. Aggregation of the weights of assessment criteria

Overall (Geometric mean)	Short-term				Mid/long-term			
	Efficiency	Effectiveness	Feasibility	Acceptance level	Efficiency	Effectiveness	Feasibility	Acceptance level
Efficiency	1.00	0.35	0.35	0.42	1.00	0.88	0.74	0.52
Effectiveness	-	1.00	1.03	0.82	-	1.00	0.99	0.62
Feasibility	-	-	1.00	1.00	-	-	1.00	0.60
Acceptance level	-	-	-	1.00	-	-	-	1.00
Weight	0.11	0.29	0.30	0.30	0.18	0.22	0.23	0.37

Figure 7-2. Weights of assessment criteria from short-term and mid/long-term points of view



2.2.2. Result of comparison of adaptation measures to climate change

From the short-term point of view, breeding and climate information system appear to be important in terms of efficiency; breeding and agricultural water management in terms of effectiveness of policy; breeding and agricultural water development in terms of feasibility of the policy; and breeding and provision of grants in terms of acceptance level <Table 7-2>. In all four assessment criteria, breeding appears to have the greatest importance.

From the mid/long-term point of view, breeding, management of agricultural water as infrastructure, and water management for individual farm household appear to be important in terms of efficiency of the policy; development of production technology and climate information system in terms of effectiveness of the policy; breeding and agricultural water management in terms of feasibility of the policy; and breeding and management of production technologies in terms of acceptance level. Breeding appears to be important even from the long-term point of view.

2.2.3. Overall result of the assessment of adaptation measures to climate change

A. Short-term point of view

The overall result of the AHP-based evaluation of the priorities of assessment criteria for the adaptation measures shows that effectiveness, feasibility, and acceptance level have higher importance than efficiency from the short-term point view.

The aggregate weight obtained by aggregating the weight of each assessment criterion and that of each adaptation measure appears to be the highest for breeding (0.059), followed by agricultural water management and production technology development which have almost the same aggregate weight, insurance system expansion, production technology management, education, and climate information system in order. In other words, it is analyzed that these measures should be taken preferentially from the short-term point of view. Breeding and production technology development are selected as the high priority measures in the R&D category, and the following adaptation measures

Table 7-2. Result of the absolute comparison of adaptation measures to climate change for each assessment criterion

Adaptation plans		Short-term				Mid/long-term			
		Efficiency	Effectiveness	Feasibility	Acceptance by farmers	Efficiency	Effectiveness	Feasibility	Acceptance by farmers
R&D	Breeding	0.057	0.057	0.060	0.061	0.058	0.056	0.058	0.059
	Production technology development	0.055	0.057	0.058	0.055	0.057	0.059	0.057	0.056
	Base technology development	0.051	0.054	0.053	0.048	0.052	0.055	0.054	0.048
	Resource management innovation	0.049	0.050	0.047	0.047	0.049	0.050	0.049	0.045
	Climate information system	0.057	0.055	0.056	0.048	0.056	0.057	0.054	0.048
Infrastructure management	Farmland management	0.051	0.050	0.050	0.054	0.051	0.051	0.050	0.052
	Agricultural water management	0.056	0.057	0.058	0.057	0.058	0.056	0.058	0.058
	Agricultural facility management	0.047	0.047	0.051	0.059	0.047	0.049	0.054	0.057
Economic means	Provision of grants	0.048	0.049	0.047	0.061	0.046	0.046	0.047	0.058
Legal & institutional improvement	Insurance system expansion	0.053	0.052	0.054	0.058	0.054	0.052	0.055	0.056
	Resource management system buildup	0.052	0.052	0.050	0.048	0.052	0.050	0.049	0.045
	Formulation of specific measures for each region	0.054	0.054	0.053	0.046	0.054	0.053	0.053	0.045
Manpower training and education	Manpower training	0.052	0.052	0.050	0.046	0.051	0.051	0.049	0.047
	Education	0.053	0.057	0.054	0.051	0.052	0.055	0.051	0.053
Monitoring	Assessment of adaptation and vulnerability	0.054	0.052	0.055	0.043	0.053	0.054	0.056	0.046
Technology & management applicable to farm households	Production technology management	0.053	0.054	0.052	0.057	0.054	0.054	0.054	0.059
	Soil management	0.051	0.051	0.050	0.051	0.052	0.053	0.052	0.055
	Water management	0.054	0.053	0.052	0.053	0.058	0.055	0.054	0.056
	Farm household finance management	0.052	0.048	0.047	0.057	0.046	0.045	0.047	0.056

Table 7-3. Result of the overall assessment of adaptation measures to climate change (Short-term)

Assessment criteria and weight of each adaptation measure							Aggregate Weight	Priority
Adaptation measures \ Assessment criteria		Efficiency	Effectiveness	Feasibility	Acceptance level			
		0.11	0.29	0.30	0.30			
R&D	Breeding	0.057	0.057	0.060	0.061		0.059	1
	Production technology development	0.055	0.057	0.058	0.055		0.057	3
	Base technology development	0.051	0.054	0.053	0.048		0.052	11
	Resource management innovation	0.049	0.050	0.047	0.047		0.048	19
	Climate information system	0.057	0.055	0.056	0.048		0.053	7
Infrastructure management	Farmland management	0.051	0.050	0.050	0.054		0.051	12
	Agricultural water management	0.056	0.057	0.058	0.057		0.058	2
	Agricultural facility management	0.047	0.047	0.051	0.059		0.052	9
Economic means	Provision of grants	0.048	0.049	0.047	0.061		0.052	10
Legal & institutional improvement	Insurance system expansion	0.053	0.052	0.054	0.058		0.056	4
	Resource management system buildup	0.052	0.052	0.050	0.048		0.050	17
	Formulation of specific measures for each region	0.054	0.054	0.053	0.046		0.051	13
Manpower training & education	Manpower training	0.052	0.052	0.050	0.046		0.049	18
	Education	0.053	0.057	0.054	0.051		0.054	6
Monitoring	Assessment of adaptation and vulnerability	0.054	0.052	0.055	0.043		0.050	16
Technology & management applicable to farm households	Production technology management	0.053	0.054	0.052	0.057		0.055	5
	Soil management	0.051	0.051	0.050	0.051		0.051	14
	Water management	0.054	0.053	0.052	0.053		0.053	8
	Farm household finance management	0.052	0.048	0.047	0.057		0.051	15

are given the highest priority in each category: agricultural water management in the infrastructure management category; insurance system expansion in the legal and institutional improvement category; education in the public relations and education category; production technology management and water management in the technology and management applicable to farm household category. Applying all possible measures in a short period would be difficult due to constraints on budget, human resources, and technology. Therefore, if adaptation policies and programs that address these high-priority measures are established and implemented, the efficiency and effectiveness of the policies would be improved and the level of acceptance of adaptation policies by the farmer would also be increased.

B. Mid/long-term point of view

According to the overall result of the AHP-based evaluation of the priorities of assessment criteria for the adaptation measures, it appears that the level of acceptance by farmers must be given the highest priority from the short-term point view.

The aggregate weight obtained by aggregating the weight of each assessment criterion and that of each adaptation measure appears to be the highest for breeding, followed by agricultural water management, production technology development, water management, insurance system expansion, and soil management in this order. This suggests that these measures should be executed in the same order.

Table 7-4. Result of the overall assessment of adaptation measures to climate change (Mid/long-term)

Assessment criteria and weight of each adaptation measure							Aggregate weight	Priority
Adaptation measures \ Assessment criteria		Efficiency	Effectiveness	Feasibility	Acceptance level			
		0.18	0.22	0.23	0.37			
R&D	Breeding	0.058	0.056	0.058	0.059		0.058	1
	Production technology development	0.057	0.059	0.057	0.056		0.057	3
	Base technology development	0.052	0.055	0.054	0.048		0.051	13
	Resource management innovation	0.049	0.050	0.049	0.045		0.048	19
	Climate information system	0.056	0.057	0.054	0.048		0.053	8
Infrastructure management	Farmland management	0.051	0.051	0.050	0.052		0.051	11
	Agricultural water management	0.058	0.056	0.058	0.058		0.058	2
	Agricultural facility management	0.047	0.049	0.054	0.057		0.053	10
Economic means	Provision of grants	0.046	0.046	0.047	0.058		0.051	14
Legal & institutional improvement	Insurance system expansion	0.054	0.052	0.055	0.056		0.055	6
	Resource management system buildup	0.052	0.050	0.049	0.045		0.048	18
	Formulation of specific measures for each region	0.054	0.053	0.053	0.045		0.050	15
Public relations & education	Manpower training	0.051	0.051	0.049	0.047		0.049	17
	Education	0.052	0.055	0.051	0.053		0.053	9
monitoring	Assessment of adaptation and vulnerability	0.053	0.054	0.056	0.046		0.051	12
Technology & management applicable to farm households	Production technology management	0.054	0.054	0.054	0.059		0.056	4
	Soil management	0.052	0.053	0.052	0.055		0.053	7
	Water management	0.058	0.055	0.054	0.056		0.056	5
	Farm household finance management	0.046	0.045	0.047	0.056		0.050	16

C. Comparison between short-term and long-term points of view

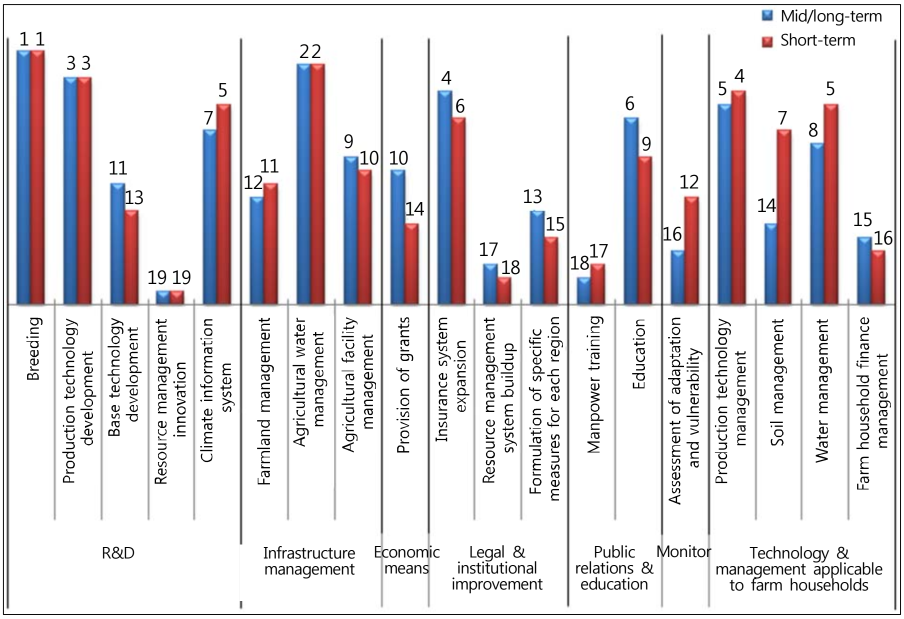
A comparison of the priority of each adaptation measure between the short-term and the long-term points of view shows that breeding, agricultural water management, and, development of production technology development rank first, second and third respectively both from short-term and the long-term points of view, implying that these three measures are to be considered the most important.

Climate information system, insurance system expansion, and education have high priorities from the short-term point of view. While adaptation measures related to the technology and management applicable to individual farm households, such as water management and soil management, have a low priorities from a short-term point of view, they have higher priorities from the long-term point of view.

Table 7-5. Comparison of the priorities of adaptation measures between the short-term and the long-term points of view

Adaptation measures		Short-term	Mid/long-term	Change
R&D	Breeding	1	1	-
	Production technology development	3	3	-
	Base technology development	11	13	▽2
	Resource management innovation	19	19	-
	Climate information system	7	8	▽1
Infrastructure management	Farmland management	12	11	△1
	Agricultural water management	2	2	-
	Agricultural facility management	9	10	▽1
Economic means	Provision of grants	10	14	▽4
Legal & institutional improvement	Insurance system expansion	4	6	▽2
	Resource management system buildup	17	18	▽1
	Formulation of specific measures for each region	13	15	▽2
Public relations & education	Manpower training	18	17	△1
	Education	6	9	▽3
Monitor	Assessment of adaptation and vulnerability	16	12	△4
Technology & management applicable to farm households	Production technology management	5	4	△1
	Soil management	14	7	△7
	Water management	8	5	△3
	Farm household finance management	15	16	▽1

Figure 7-3. Comparison of the priorities of adaptation measures between the short-term and the long-term points of view



3. Strategies for Implementing Adaptation Measures against Climate Change

3.1. Roadmap for Adaptation to Climate Change

As climate change would occur over an extended period of time, the roadmap for adaptation was drawn with 2030 being the target year. The period was divided into three phases: the short-term base buildup phase (2009~2013), the mid-term take-off phase (2014~2019), and the long-term settlement phase (2020~2030). The roadmap is presented for each phase, covering seven major categories such as R&D, infrastructure management, economic means, legal and institutional improvement, public relations and education, monitoring, and technology & management applicable for individual farm households <Table 7-6>.

Table 7−6. Roadmap for implementing the adaptation measures against global warming in the agricultural sector

Adaptation measures	Base buildup phase (2009-2013)	Take-off phase (2014-2019)	Settlement phase (2020-2030)
R&D	- Develop new breeds that are in great demand and resistant to heat. - Popularize new cultivation technologies for fertilization and sowing. - Prepare maps for suitable places for cultivation and crop distribution. - Research to identify physiological effects of global warming. - Develop forecast models to prevent blights, pest and weeds. - Develop and utilize early warning systems. - Develop water resource management systems to prevent natural disasters, including drought and flood.	- Popularize breeds adapted to global warming. - Provide information about adaptation to global warming and build up the training system. - Promote crop transformation evaluation studies. - Add sophistication to the early warning system. - Promote facilities to optimize the efficiency of water utilization. - Promote water resource management system as prevention against natural disasters such as drought and flood.	- Build up adaptation system to global warming. - Convert to agricultural production system that makes the most of global warming. - Build up a crop transformation evaluation system. - Build up an early warning system - Popularize the farming simulator - Promote water resource management system in prevention against natural disasters such as drought and flood.
Infrastructure management	- Popularize technologies to reduce carbon emission from rice fields and dry fields. - Popularize no-tillage farming methods. - Establish standard for water-saving irrigation. - Modernize agricultural infrastructure. - Popularize energy-saving technology for the protected horticulture.	- Promote the reduction of carbon emission from rice fields and dry fields. - Expand no-tillage farming methods. - Popularize standard for water-saving irrigation. - Build up automated agricultural water management. - Expand energy-saving technology for protected horticulture.	- Promote the reduction of carbon emission from rice fields and dry fields. - Settle no-tillage farming methods. - Build up TMTC systems. - Expand energy-saving fusion technology for protected horticulture.

Adaptation measures	Base buildup phase (2009-2013)	Take-off phase (2014-2019)	Settlement phase (2020-2030)
Economic means	- Consider paying carbon grants to the farmers who practice low-carbon farming methods. - Introduce investment incentive for water saving. - Support high-efficiency irrigation systems	- Expand the carbon grant for the low-carbon adaptation menu methods. - Promote the investment incentive for water saving. - Consider charging the use of agricultural water	- Promote the carbon grant for the low-carbon farming methods.
Legal & institutional improvement	- Expand the insurance system for agricultural disasters. - Expand the insurance system for damages by flood and storm. - Operate a farm household income stabilization program. - Establish a global warming adaptation committee. - Introduce a system for calculating crop damage. - Formulate a long-term development plan for rural villages. - Operate a special task force team for main areas of production.	- Promote the insurance system for agricultural disasters. - Promote the insurance system for damages by flood and storm. - Settle down the programs to help farm households have stable income. - Operate the global warming adaptation committee. - Build up the system for calculating the crop damage. - Settle down the long-term development plan for rural villages.	- Promote the insurance system for agricultural disasters. - Promote the insurance system for damages by flood and storm. - Settle down the programs to help farm households have stable income. - Operate the global warming adaptation committee. - Settle down the system for calculating the crop damage and the support system.
Public relations & education	- Train farmers specialized in risk management. - Train consultants specialized in risk management. - Expand education of farm households with regards insurance for crop disasters and also risk management.	- Train farmers specialized in risk management. - Utilize the consultants specialized in risk management. - Popularize the manual about adaptation to global warming. - Build up the adaptation education system.	- Train farmers specialized in risk management. - Complement the manual about adaptation to global warming. - Build up a systematic education system for each subject related, for their adaptation to global warming.
Monitoring	- Introduce an impact assessment model for productivity forecast and biological changes. - Build up the agricultural ecosystem monitoring system.	- Utilize the impact assessment model for productivity forecast and biological changes. - Operate the system for assessing the environmental impact on crop growth. - Make mid/long-term forecasts of the world food demand and supply.	- Build up the system for assessing the environmental impact of alternative water use on crop growth. - Make mid/long-term forecasts of the world food demand and supply.

Adaptation measures	Base buildup phase (2009-2013)	Take-off phase (2014-2019)	Settlement phase (2020-2030)
Technology & management applicable to farm households	- Control the crop growth rate, greenhouse cultivation, agricultural chemicals, and weeds. - Cultivate the crops adapted to climate change. - Fertilize the soil by improving the alkali soil. - Install the water management for individual farm households. - Utilize the risk avoidance crop insurance.	- Fertilize the soil by improving the alkali soil. - Prepare the irrigation schedule to enhance the efficiency of water use. - Participate in the income stabilization program - Diversify the farm household revenues through crop diversification.	- Change the places of cultivation to proper climate. - Fertilize the soil by improving the alkali soil. - Prepare the irrigation schedule to enhance the efficiency of water use.

Among the major tasks for each phase, those which have to be implemented continuously are not easily placed in a certain phase.

The development of adaptation technologies to climate change is one such task that has to be implemented continuously in all phases, so as to prevent and/minimize the damages caused by climate change. Most especially, the requirement to develop breeds that are in great demand, resistant to disasters and heat is an urgent task that should be continuously carried out to ensure the developed breeds can be popularized to individual farm households.

In the infrastructure management category, farmland management, agricultural water management, and agricultural facility management are the allotted main tasks for each phase. In particular, the popularization of no-tillage farming method is an important task for mitigating and adapting to climate change, thus it too has to be carried out continuously.

In the economic means category, the introduction of the low-carbon grant is a key task that needs to be introduced in the base buildup phase, but must then be carried on afterwards.

In the legal and institutional improvement category, the agricultural disaster insurance system needs to be carried on a continuous basis so that it can be securely settled down. Public relations and education should also be carried on with special interest being taken to form a consensus about the need for adaptation to climate change and the form it will take.

In the monitoring category, the tasks for developing a model to make mid/long-term forecasts of the world food demand and supply should be carried out in each phase.

In the category of technology and management applicable to individual farm households, effective programs should be developed in each phase in relation to R&D so that the developed adaptation technologies can actually be popularized to individual farm households.

For the R&D category, the roadmap is drawn separately for crop farming, horticulture, and tropical and subtropical farming <Table 7-7>.

For example, the Rural Development Administration has established the climate change agenda for three phases being: short-term (2009~ 2011), mid-term (2012~2016), and long-term (2017~) and has carried out research projects for such categories as policy support for climate change, assessment and estimation of the climate change impact, and development of low-carbon green-growth technologies (Rural Development Administration, 2009).[31] The RDA has not classified adaptation to climate change as a separate category but included it in two categories - the assessment and estimate of the climate change impact and the development of low-carbon green-growth technologies. The main tasks for the adaptation to climate change, as carried out by the RDA, can be summarized as breeding for crop farming, evaluation of the shift in suitable places for horticulture, and research into the adaptability of

[31] The budget for the 2009 climate change agenda being carried out by RDA is made up of 958 million won for 18 detailed tasks in the category of policy support for climate change, 3,866 million won for 94 detailed tasks in the category of assessment and forecast of climate change impact, and 3,962 million won for 76 detailed tasks in the category of low-carbon green-growth technology development (RDA, 2009).

new breeds of tropical/subtropical vegetables and fruit vegetables <Table 7-7>.

Table 7−7. Roadmap for the R&D in each phase to adapt to global warming

	Base buildup phase (2009~2013)	Take-off phase (2014~2019)	Settlement phase (2020~2030)
Crop farming	- Research on changes in agricultural characteristics by climate change and the superior genetic resources for climate change - Assess the impact of global warming on cultivation periods, crop types, and crop quality and develop new cultivation technologies. - Develop technologies to monitor and forecast new blights and pests. - Develop technologies to forecast and mitigates food crop disasters by abnormal climate conditions	- Develop new breeds that can adapt to high temperature, and technologies to maintain the crop quality. - Develop cultivation technologies for each phase of adaptation to global warming. - Identify characteristics of meteorological disasters and develop technologies to mitigate such disasters.	- Popularize new breeds adaptable to global warming to individual farm households, and promote the industrialization of each crop. - Demonstrate the effectiveness of cultivation technologies adaptable to global warming and the blight and pest control technologies, and popularize them. - Develop technologies to reduce damages to rice by abnormal climate conditions.
Horticulture	- Assess resources for developing new breeds resistant to high temperature and disasters. - Collect and evaluate the genetic resources, and consolidate joint research internationally - Establish research methods to assess the impact of global warming on horticulture crop, and set up zones for cultivating horticulture crops. - Prepare distribution maps of suitable places for cultivating vegetables and fruit vegetables.	- Carry out adaptation test in each region for cultivation of prospective breeds that can adapt to high temperature and are resistant to disasters. - Develop cultivation management technology for each phase of adaptation to global warming. - Evaluate shifts in suitable places for cultivating major vegetable crops and vegetable fruit crops.	- Popularize new breeds resistant to high temperature and disasters to individual farm households and promote the industrialization of the breeds. - Research into the environmental and physiological responses of main horticulture crops to assess the impact of climate change on horticulture. - Make low-cost high-efficiency cultivation technologies fit for practical use by using new renewable energy to cope with global warming

	Base buildup phase (2009~2013)	Take-off phase (2014~2019)	Settlement phase (2020~2030)
Tropical/ subtropical farming	- Build up bases for developing new income-generating crops using tropical/subtropical genetic resources. - Collect tropical/subtropical crops and establish the international cooperation system (Okinawa, Myanmar, etc.). - Establish impact assessment researches and methods for crop cultivation zones. - Analyze optimum cultivation locations and evaluate climate change including maps of suitable locations for cultivation of specific crops.	- Review the adaptability of genetic resources collected from the tropical/subtropical zones, and select suitable crops. - Perform regional adaptation tests for selected crops, and develop cultivation management technologies. - Classify places suitable for cultivating tropical/subtropical crops.	- Cultivate pilot projects and brand building businesses to expand the cultivation of new revenue-earning crops. - Prepare maps of crop vulnerability to climate change and crop disaster prevention plans. - Prepare and popularize a manual about cultivation and management technologies to cope with global warming. - Educate experts from developing countries in tropical/subtropical farming and arrange academic and training exchanges
Research infrastructure	- Consider building a climate change research center.	- Build and operate a climate change research center.	- Establish a climate change research center as an advance base for researches into adaptation

Note: Compiled with data from the reports and publications by Rural Development Administration (2007b), Agricultural Research Center for Global Warming under Rural Development Administration (2009), and Agricultural Research & Extension Service of each province

In order for research into the agricultural sector's adaptation to climate change to continue, support by policies and the public interest should be provided, to ensure that the research infrastructure (including the related facilities and manpower) can be secured in the base buildup phase. In the take-off phase, it is desirable that the climate change research center is in operation and prepared for use as an advance base for future climate change research. This is essential in order to firstly, formulate the long-term agricultural sector adaptation measures for the agricultural sector in response to climate change, and secondly, to scientifically assess the climate change impact on the crop productivity and quality as well as the shift in suitable places for cultivation. For this, an integrated "climate change research center (tentative)" should be built as soon as possible. The center should allow for the complete control of the cultivation environment (including temperature and the carbon dioxide concentration). In advanced nations, such as Japan, the USA and Germany, climate change research centers have been established under the national agricultural research institutes and the agriculture-related universities. These climate change research centers are actively carrying out adaptation research. It should be considered that the results of research into adaptation significantly contributes to effective policymaking and policy enforcement due to the fact that it provides reliable information to both the farmer and the policymakers (Ministry of Agriculture, Forestry and Fisheries of Japan. 2008; RDA Agricultural Research Center for Global Warming, 2009).

The roadmap for R&D for adaptation to climate change in each phase may vary according to time and contents of implementation, depending on the standpoints of the concerned agencies and experts.

3.2. Main Tasks for Implementing the Strategies for Each Category

3.2.1. R&D

The highest priority task in developing implementation strategies for the agricultural sector's adaptation to climate change is breeding (including the development of new breeds). This is true both from the short-term and the long-term point of view, as shown by the prioritization of adaptation measures determined by experts. Most important is the development of new breeds (including the introduction of foreign breeds) in consideration of the changes facing the agricultural ecosystem and the shift in main production places due to climate change. This is the main concern of the farmer as equally important to the future of farming. To ensure effective breeding for adaptation to climate change, the following matters should be taken into consideration:

First, new breeds should be developed, taking into consideration the unique breed characteristics of agricultural products. Taking rice as an example, those varieties that are highly resistant to disasters, can ripen at high temperature, and are able to adapt to their regional environment should be developed after taking into consideration the climate conditions and soil of the corresponding region. For apples, the varieties that are insensitive to low temperatures and which will color easily at high temperatures should be developed.

Second, when it is necessary to introduce a new breed to a certain region as the main production area shifts, the breed should be selected after overall consideration has been given to regional adaptability, consumers' preference, and domestic and international competitiveness. For example, when a tropical or subtropical crop is introduced, the crop has to be the one that can readily adapt itself to the new environment, is easy to cultivate, meets the preferences of consumers, is difficult to import from overseas, and is highly profitable.[32]

Third, breeding requirements should be in accordance with the unique characteristics of each zone <Appendix 6>. As shown in <Table 7-8>, Gyeonggi zone needs the development of new rice varieties and major fruit varieties (such as apples and peaches), that are adaptable to high temperature. For the Gyeongsang zone, researches should be undertaken to develop an apple breed suitable for high temperatures

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32 Regarding the standard for selecting new crops for Jeju of which climate has changed to tropical/subtropical climate, crops should be taken into consideration which have the competitiveness over imported agricultural products, can bring about diversity to wintering crops, can strengthen the competitiveness of related industries, and can contribute to maintaining the diverse functions of agriculture including environmental preservation and ecosystem conservation (K. C. Sung, 2009, pp.91-92).

Table 7-8. Tasks to be implemented for R&D for adaptation to climate change in each zone

Zone	R & D
Gyeonggi	- Improve rice varieties and cultivation technologies adaptable to high temperature under climate change. - Improve apple varieties in consideration that the northern Gyeonggi region is becoming the main production area for apples, and develop proper extension strategies. - Improve peach varieties and the cultivation technologies to cope with climate change.
Gyeongsang	- Research on changes in rice yield and its quality due to climate change. - Popularize machine transplantation technology for rice in the soil of low-carbon no-tillage milk vetch cultivation. - Develop barley cultivation method to cope with global warming in Gyeongsang region. - Develop cultivation technologies for new fruit varieties to cope with climate change. - Popularize the adaptation and cultivation technologies for such fruits as tangerines, Halla oranges, figs. - Improve apple varieties adaptable to high temperature and develop the technology for cultivating apples in high-latitude areas, highlands, and mountains. - Review adaptability of subtropical fruits to a new cultivation environment.
Jeolla	- Develop and popularize the technology to expand rice double-cropping. - Develop technology for estimating the rate of damages by blights and pest due to abnormally high temperature. - Develop and popularize fruit varieties to cope with global warming. - Popularize cultivation technologies for subtropical fruits such as tangerines and Halla oranges. - Develop adaptation and cultivation technologies for subtropical fruits such as avocado, mango, passion fruit, cherimoya, pitaya, noni, and cantaloupe. - Develop revenue-generating crops to cope with global warming - Research into the adaptation of subtropical vegetables such as artichoke, tropical spinach, okra, and asparagus. - Develop new breeds and popularize the cultivation technologies, regarding that the highlands in Jeonbuk are becoming main apple production areas.
Chungcheong	- Select high-quality early-ripening rice varieties that ripen at high temperature to cope with climate change. - Develop and popularize adaptation technologies including early transplantation of early-ripening rice varieties and setting of appropriate transplantation intervals. - Research into the technologies to improve the bean quality and ensure safe cultivation. - Improve fruit varieties such as peaches and grapes and popularize the cultivation technologies.

Zone	R & D
Gangwon	- Research into new high-quality rice varieties resistant to disasters. - Improve fruit varieties and popularize the cultivation technology, to cope with global warming. - Popularize adaptation and cultivation technologies for major fruit varieties such as apples, grapes, and pears. - Research the possibility of cultivating subtropical fruits in Yongdong district. - Develop new peach varieties that are very sweet and resistant to the cold.
Jeju	- Research into the change in blight and pest occurrence due to global warming. - Research and develop tropical/subtropical crops to cope with global warming. - Evaluate adaptability of tropical fruits such as mango and passion fruit. - Introduce fruit varieties, including twelve varieties of eight fruit types such as mango, avocado, passion fruit, pitaya, macadamia, atemoya, cherimoya, and guava - Subtropical vegetables: okra, artichoke, tropical spinach, chyote, tropical tomatoes, lpomoea aquatic, and Yambean

Source: The above table is a compiled excerpt of the result of analysis of the shift in main production regions of major crops, the adaptation measures against climate change which have been carried out by Agricultural Research and Extension Service of each province, and the in-depth interviews with the agricultural experts of each zone.

and high latitudes and to improve the adaptability of such subtropical fruit varieties as tangerines, Halla oranges and figs. For Jeolla zone, research should focus on improving the adaptability of subtropical fruits such as tangerines and Halla oranges and that of subtropical vegetables and developing new apple breeds suitable for highland growing. Chungcheong zone needs to select an early-maturing high-quality rice variety which is adaptable to high temperatures. It also needs improved varieties of beans, peaches and grapes which can adapt to high temperatures.

Gangwon province needs to select proper varieties of fruit (such as apple, pear and grape) as their main production locations shift, and to develop a new breed of peach which is very sweet and resistant to the cold.

The Jeju zone needs to improve tangerine and Halla orange varieties in order to adapt them to high temperatures Research is also needed into the adaptability of new varieties of tropical and subtropical fruits and vegetables. For Jeju in particular, the RDA Agricultural Research Center for Global Warming has actively performed research into tropical and subtropical fruit cultivation since the mid 1990s.[33] The research into breeding and adaptation of new breeds is a field study that takes into climate change and agricultural conditions of each region into consideration and thus requires a considerable length of time.

With regards the role of R&D in the agricultural sector's adaptation to climate change, the category of production technology development is especially important. Production technology is a generic term that applies to firstly, the pest-control technology to cope with new blights, pest and weeds; secondly, the cultivation technologies for developing new forecast models, fertilizers, new sowing and harvesting seasons, and thirdly, the technology to adjust the shift in suitable cultivation areas, so as to stabilize fruit-bearing, and verify the adaptability of subtropical crops to the inland areas. For rice, as suggested in the analysis of the impact of adaptation measures on crop cultivation, it is possible to significantly mitigate a climate related decrease in rice yield by adjusting the cultivation period of each variety, the amount of nitrogenous fertilizer, and the irrigation. Therefore, development of the adaptive cultivation technologies for each variety, and for each region can be considered a cost-effective adaptation measure. In particular, the adjustment of sowing season and shift in suitable cultivation areas are every effective production technologies that can be applied by individual

[33] RDA Agricultural Research Center for Global Warming researches into the adaptability of 12 varieties of 8 fruit types such as mango, avocado, passion fruit, pitaya, macadamia, atemoya, cherimoya, and guava, regarding the introduction of new tropical and subtropical crops (RDA Agricultural Research Center for Global Warming, 2009).

farm households as adaptation measures against global warming.

To ensure effective adaptation to climate change, it is necessary to undertake in-depth scientific research so as to build up a climate information system for the agricultural sector. Necessary research tasks for building up the climate information system include: the development of an early-warning system to provide necessary climate information before disasters hit, the construction of a meteorological disaster monitoring and agricultural/meteorological disasters database that will allow the development of technology to forecast, and locate in detail, the areas in danger of agricultural/ meteorological disasters, the construction of a detailed climatic map for each agricultural climate factor, and the development of technologies to cope with agricultural/ meteorological disasters. Most crucial is the construction of a detailed climatic map for each agricultural/meteorological factor. This digital climatic map will be able to provide the climate and agriculture information required for farm management to cope with global warming.[34]

The R&D tasks for the category of 'agricultural resource management innovation for adaptation to climate change' are firstly, the development of a system to analyze the relation between the agricultural environment information and the agricultural policies; secondly, research into agricultural resource management systems such as water resource

[34] The digital climatic map can be considered as a microclimate digital climatic map, which enables to analyze the climate by overlapping the map with other spatial information and of which high resolution makes it possible to see the climate information about each lot. The climatic map analyzed using the digital climatic map and the agricultural simulation models (growth, quality, and environment) can provide information to support decision-making regarding agricultural management such as selection of suitable cultivation region (J. I. Yun, 2009). At present, a pilot service is in force in which the digital climatic map built into a spatial database is operated as a decision-making support system for farm households (www.affis.net/peotal/weather/new/sub2.jsp).

management systems (which prevent natural disasters like drought and flood), agricultural resource management systems as well as alternative cultivation and drainage systems.

R&D tasks for the category of base technology development are to develop the technology to reduce greenhouse gas emission from farmland, the facilitate the optimization of water use efficiency, to develop technology that will reduce water losses during irrigation, and the water-saving irrigation materials in consideration of soil infiltration. Most especially, as the shortage of water resources due to climate

Table 7–9. Development of technologies for the agricultural infrastructure, in preparation against the sea–level rise

Technology		Description
Estimation of sea-level rise		- Utilize IPCC's sea-level rise scenarios and the results of domestic estimations.
Impact assessment	Development of the target area analysis technique	- Develop target area analysis technique using GIS/ GPS. - Analyze the target areas and facilities.
	Development of the assessment techniques	- Develop impact assessment techniques for each IPCC scenario. - Develop techniques for assessing the impact on farming villages and irrigation facilities.
	Preparation of the hazard map	- Prepare hazard maps for each scenario.
	Impact assessment for each scenario	- Assess impacts on agricultural zones, for each scenario. - Assess impacts on agricultural facilities, for each scenario. - Assess the impact on such facilities as tide embankment and pumping stations.
Buildup of adaptation bases	Development of techniques	- Build up adaptation base for each facility. - Build up adaptation base for swales in the southwest coastal district.
	Buildup of adaptation bases.	- Develop projects to build up the adaptation bases in the farming villages. - Carry out adaptation base buildup projects.

Source: Supplementation of what is presented in p.93 of the article by Kim Yeong Hwa (2007).

change worsens over time, it is necessary to carry out in-depth research into the agricultural water management system, including the modernization of water management. Research into agricultural infrastructure preparatory measures against climate induced sea-level rise is an important mid/ long-term task. This will involve the development of the necessary technologies in each phase and for each category, based on the results a review of sea level rise scenarios, an identification of the target areas, and analysis and assessment of the agricultural infrastructure <Table 7-9>.

3.2.2. Infrastructure management

Infrastructure management to ensure the agricultural sector’s successful adaptation to climate change is largely divided into three sections: farmland management, agricultural water management, and agricultural infrastructure management. Of these three, agricultural water management appeared to have the second-highest priority in the AHP priority-decision, both from the short-term and the mid/long-term points of view. As climate induced water resource shortages are expected to become worse, it is important to continue complementing the agricultural water management system, including the modernization of water management. Detailed tasks for agricultural water management are as follows: firstly, to establish the standard for water-saving irrigation for the protected cultivation; secondly, to establish customized water management appropriate for each cultivation environment; thirdly; to construct and maintain the pipes and watercourses so as to improve the pumping system for agricultural water, and fourthly, to expand the use of sprinkler and drip irrigation as well as automated agricultural water management (TMTC).

The category of agricultural facility management, which had a middle ranking among the priorities determined for each adaptation measure by the experts, is related to the installation of facilities that can reduce the damage caused by climate change. Implementation programs for this category are: to firstly, install a windbreak fence to minimize the damage caused by meteorological disasters such as typhoons; secondly, to install the devices to shield crops from heat damage; thirdly, to install the modernized facilities for the greenhouses; fourthly, to install plastic film to prevent the evapotranspiration of moisture; fifthly, to use machines to reduce the period of preparation for cultivation, and finally to modernize crop storage facilities.

Detailed tasks for the 'farmland management for the agricultural sector's adaptation to climate change' component are, firstly, to enforce the direct-sowing of rice to dry fields and the use of simplified irrigation to reduce methane emission; secondly, to reduce the amount of nitrogenous fertilizers applied to the fields so as to reduce nitrous oxide emissions; thirdly, to expand the no-tillage cultivation techniques, and finally to maintain vegetation cover to prevent soil erosion.

3.2.3. Economic means

In order to facilitate the agricultural sector's adaptation to climate change, it is desirable to provide individual farm households with proper incentives that will compensate them for the additional expenses or effort caused by the introduction of adaptation measures. At present, many countries have introduced and put into practice the environmental cross compliance (ECC) program by which individual farm households can take environmental protection measures. To ensure that the agricultural sector can effectively cope with climate change an ideal measure would be to introduce an ECC-based menu-driven debit payment system. As an example, it is necessary to consider introducing the debit system for the low-carbon cultivation method. This debit system compensates to a certain degree, per cultivation area, and only after proper monitoring, to farm households that put into practice low-carbon cultivation methods into practice. Low-carbon cultivation methods include the organic chemical-free, environment-friendly, agricultural technique, the no-tillage milk-vetch covering method, and fallow. To introduce the debit payment system for low-carbon agricultural techniques, it is necessary to verify how effective the low-carbon agricultural techniques are, in comparison to conventional agricultural methods, calculate the proper incentives in consideration of the difference of production costs and income between the low-carbon agricultural technique and the conventional agricultural technique, and continue monitoring based on scientific methodology.

As water shortage worsen due to climate change, it is necessary for the agricultural sector to consider introducing investment incentives for water-saving and to pay a grant for high-efficiency irrigation systems by bench-marking UK cases. For example, should a farm that uses a large amount of water install water-saving facilities, such as water-saving systems and wastewater reclamation and reuse systems, the government shall provide some incentives such as financing the installation cost, reducing the water rate, and reducing or exempting the environmental improvement fee. By adopting such measures the government would persuade other farms to install similar water-saving systems. In addition, for the farms that install a high-efficiency irrigation system which requires a high initial investment, the government should pay the grant.

Due to climate change, an increase in natural disasters (such as floods, droughts, and abnormal temperatures) is expected, which could result in the bankruptcy of farm households. If large numbers of farm households become bankrupt simultaneously, it could lead to the collapse of the agricultural base. In this case, the government should actively intervene to properly compensate the losses sustained by farm households[35]. In the case of such a risk, it is important to prevent it

[35] The supplementary measures against natural disasters, as a macro-risk factor for farm households and about the disaster insurance system as a means of risk man-

from arising by operating risk management programs like disaster insurance, or by paying the farm household support fund under the name of a disaster assistance program. In addition to this, there are other compensation programs to manage the risks with regard to adaptation to climate change. For example, when a farm introduces a new crop as a means to adapt to climate change, the farm has to bear a considerable risk until the cultivation technology is stabilized and the production reaches a certain level. Therefore, it is necessary to offer a certain level of debit payment to mitigate the risk of decrease in production and income due to the introduction of a new crop.

The economic means is to use the effect of offsetting the additional expenses by paying the incentive. Its success depends largely on how the incentive level is decided. The above-mentioned analysis of decision-making by the farmer people can be a useful tool to determine a proper level of economic means. For example, how the debit payment for low-carbon agricultural technique works is that an amount corresponding to the additional cost for carbon reduction is paid from the government budget. In this case, if the government estimates the relationship between the additional cost to be paid by the farmer and the probability of them applying the low-carbon agricultural techniques using the decision-making analysis method and decides a proper budget and a carbon-reduction target, it would be able to effectively enforce the debit payment system for low-carbon agricultural technique.

3.2.4. Legal and institutional improvement

For adaptation programs to be implemented effectively and continuously, legal and institutional systems are needed. Among the options for the category of legal and institutional improvement for the

agement are explained in detail in the article by E. S. Hwang and Y. H. Lee (2008, pp.120-124).

agricultural sector's adaptation to climate change, the insurance system expansion appeared to have the fourth priority from the short-term point of view and sixth from the mid/long-term point of view. However, no law or regulation that specifies the agricultural sector's adaptation to climate change has been enacted so far.[36] Only the regulations that provide a relevant framework for the disaster insurance system such as the crop disaster insurance act and the flood/storm damage insurance act have been in force.[37] For the agricultural sector's adaptation to climate change, it is necessary to consider enacting proper laws and regulations that can mitigate the impact of climate change on the agricultural sector and ensure its adaption to climate change. This can be achieved by bench marking China that has enacted and enforced the laws and regulations for the agricultural sector's adaptation to climate change.

For individual farm households to properly adapt to the risks of climate change, insurance systems have been in force. At present, the only policy insurance related to natural disasters in the agricultural sector are crop disaster insurance and flood/storm damage insurance. As listed in <Table 7-10>, the rate of farm households' subscription to

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[36] The regulation that prescribes the agricultural sector's countermeasures against climate change is "Environment-friendly Agricultural Cultivation Method," which only deals with climate change mitigation, the implementation measure for minimizing the emission of greenhouse gases from the agricultural sector (Article 10) but does not prescribe anything about adaptation to climate change. The current situation of legislation for climate change and the future tasks about it are explained in detail in the article by J. Y. Kim (2007, pp.64-70).

[37] The crop disaster insurance system was enacted in January 2001 for the purpose of striving for stabilizing the farm households' income and management and supporting the agricultural production activities by raveling out the uncertainty in agricultural management due to natural disasters, and has been governed by the Ministry of Food, Agriculture, Forestry, Fisheries (MIFAFF). The flood/crop damage insurance system was enacted by the Flood/Storm Damage Insurance Act in March 2006, and has been governed by National Emergency Management Agency (NEMA) and administered by a private insurance company.

these insurances is low. In order to build up a comprehensive risk management system by promoting the insurance system, it is planned to bring into existence agriculture/fishery disaster insurance by consolidating crop disaster insurance, livestock mutual aid, marine-farming/ fishery product disaster insurance, all of which cover the hazards in agriculture and fisheries at large, from January 1, 2010. The eligibility for disaster insurance will also be extended from crops to include livestock and also agricultural/ fishery facilities. The scope of disasters will also be expanded to include damages by blights, pests, wild animals, and wire as well as from natural disasters. However, in order to expand the insurance system for the agricultural sector in preparation for climate change, there are certain tasks that need to be carried out, such as expansion of the agricultural disaster insurance that takes into consideration the conditions of each region and item, establishment of the agricultural disaster insurance that reflect realistic climate conditions, development of personal insurance for risk management, and improvement of the flood/storm insurance to prevention losses due to damage to agricultural base facilities.

In order to ensure effective operation of the agricultural/fishery disaster insurance, realistic climate conditions should be reflected in the insurance policy in consideration of the regional/variety conditions and the level of farmers' participation. Also, another requirement is to improve flood/storm damage insurance as preparation against damage to the agricultural infrastructure and to develop personal insurance for the management of farm household risks.

Detailed tasks for formulating the adaptation plan for each region, an important option within the category of legal and institutional improvement for the agricultural sector's climate change adaptation, include organizing a special task force team for the shift in main production areas, formulating the long-term rural village development plan for each region, and to formulating the climate change adaptation measures for each region.

Table 7-10. Current situation of the operation of crop disaster insurance and flood/storm damage insurance

		Crop disaster insurance (MIFAFF)	Flood/storm damage insurance (NEMA)
Eligibility		· Confirmed: seven varieties such as apple, pear, tangerine, peach, grape, sweet persimmon, bitter persimmon · Trial: thirteen varieties such as plum, kiwi, chestnut, potato, bean, onion, pepper, watermelon, rice, garlic, sweet potato, Japanese apricot, and corn	· Houses · Greenhouses (including vinyl houses) · Barns
Coverage	Prime contract (Mandatory)	· Typhoon (strong wind) · Hail	· Typhoon · Torrential Rain · Strong wind · Wind and waves · Hail · Heavy snow · Flood
	Special contract (Optional)	· Cold damage · Torrential rain · Compensation for fruit trees	· Barn excrement facilities · Vinyl houses on riverbed (Heavy snow)
Subscription method		Voluntary subscription	
Compensation level		· 70% · 80%	· 50~90% of the cost of recovery
Government subsidy	Net premium	· 50% of the premium calculated for each farmland	· Prime contract: 50% (Central government subsidy: local government subsidy: 20: 10 for houses and 25:10 for barns and greenhouses), Special contract: None
	Operation cost	· 100%	· 100%
	Rate of government subsidy (total)	· About 68%	· 49~65% depending on the insurance amount
Rate of subscription to insurance (%)		· 28.5%	· Houses: 0.7% · Greenhouses: 0.2% · Barns: 0.1%
Administering agency		· Nonghyup(Business administration)	· Private insurance company (Commissioned administration)

Source: Internal data from MIFAFF and NEMA

Though the buildup of the agricultural resource management system for adaption to climate change appeared to have a low ranking in prioritization as determined by the experts, it is still important in ensuring effective and continuous adaptation to climate change. Detailed tasks for building up the resource management system are two-fold. Firstly, to build up a system to calculate the amount of crop damage and support the recovery; secondly, to change the land utilization plan so as to prevent disasters and thirdly to strengthen the standard for the disaster prevention facilities. Agriculture is sensitive to climate change and agricultural production is affected not only by climate but also by water resources and irrigation facilities. Therefore, it should be examined whether laws can be enacted to ensure the effective use and management of agricultural resources, which can also consolidate the management of related areas. In addition to this, it is also necessary to consider establishing legal devices to manage saving, reclaiming, and reusing agricultural water.

3.2.5. Manpower training and education

Manpower training and education in the agricultural sector will be necessary to cope with climate change. Programs will be needed to train expert manpower specialized in adaptation measures and to educate the farmer who will lead climate change adaptation. As adaptation to climate change in the agricultural field is carried according to the instructions received from the municipal agricultural research and extension centers and the leading farmers, it is necessary to provide systematic training for these institutes and leaders.

In forming a consensus about adaptation to climate change and prompting the public awareness, it is necessary to develop effective education programs and invest a considerable amount of budget. Using Australia's Climate Change Adjustment Program as a model, the government needs to provide assist the people who passed specific qualification tests with the educational grants and assist them to help themin getting necessary training from the nationally-attested training institutions or agencies. This would enhance the farm household's awareness of the utilization of the agricultural climate information system, crop disaster insurance and the risk management. In particular, training on how to use the digital soil maps and digital climatic maps for each lot, should help the farm households adapt themselves to climate change on their own by selecting crops appropriate for their regions or coping with natural disasters.

It is necessary to develop and popularize the manual of adaptation measures for each plant variety, both present and future, based on the analysis of the climate change impact on each region/variety, so that the farmer can apply these measures to their fields and so minimize the negative impact of climate change.

It is necessary to build up a system that can provide accurate climate information and meteorological disaster information, based on the results of assessing the impact of climate change and vulnerability to it, since this will to help the farmer to cope with the impact of climate change. It is also necessary needed to educate the farm households in cultivation technologies for new varieties and/or subtropical crops. This will be facilitated by developing and implementing programs for them to visit farms or other countries where new cultivation technologies have successfully been put into practice.

3.2.6. Monitoring

The category of monitoring for the agricultural sector's adaptation to climate change appeared to have a very low priority of ranking 16 (out of 19) from the short-term point of view and a ranking 12 from the mid/long-term point of view. Nevertheless, monitoring is still important for technology development and vulnerability assessment. To actively cope with climate change, it is necessary to build up the early-warning system that can detect climate change in early stages and provide reliable estimates. When building an early-warning system, building up a system that can monitor the environmental and climatic factors of the farmland is key. To build up a monitoring system for the agricultural ecosystem change is also an important task in the category of monitoring. To monitor the change in water resources in the rice cultivation area and the change in crop growth and productivity due to climate change is also important.

It is essential for monitoring to develop a mid/long-term estimation model for world food demand/supply based on the climate change scenario. Climate change has negative impacts on the agricultural production of developing countries, due to the fact they weak adaptability to climate change, and this in turn will affect the international crop market. The IPCC has estimated that significant changes in temperature and precipitation would have a considerably adverse impact on agricultural production in countries that do not use developed agricultural technologies. It also suggested that the frequent occurrence of unusual climate events, such as high temperatures, drought and a decrease in water resources would significantly affect regional food production. It analyzed that a temperature rise of 3℃ would seriously affect crop production across the world (IPCC, 2008). A decrease in national and or regional crop production due to intense global warming will act as a factor that will raise the international grain rice.[38]

For such grains as wheat, corn and bean that are highly dependant on foreign trade, it is possible to estimate the yields by using satellite data and meteorological observation data concerning the planted area and the growth conditions of major producing countries for the concerned

[38] Due to climate change, the international grain price by 2025 is expected to be significantly affected by the change in production and demand. According to the analysis of grain price based on IPCC's scenarios, the international rice price as of 2025 will rise by 23%, 79% for wheat from current prices.

year, and applying the growth modeling technique based on the mid/long-term weather information and forecast data.

It is analyzed that inappropriate countermeasures against global warming will undermine the world economy and reduce food demand. In such a way, global warming will seriously affect food production that depends on climatic conditions such as temperature, precipitation and sunlight and thus will affect the world's food demand and supply. Therefore, if a mid/long-term estimation model for world's food supply and demand, in consideration of climate change, were to be developed, it would become a useful tool for estimating the mid/long-term domestic food demand and supply.

3.2.7. Technology and management applicable to farm households

To formulate adaptation strategies for individual farm households against climate change, the impact of climate change on each region/plant variety should be analyzed and the technologies to cope with the impact should be developed. In particular, in-depth research into formulating differentiated adaptation strategies for the characteristics of each regional agricultural system should be carried out.

Key tasks for the category of technology and management applicable to individual farm households include production technology management, soil management, water management, and farm finance management.

According to the priorities determined by the experts' questionnaires, production technology management ranked fifth and water management eighth from the short-term point of view but fourth and fifth respectively from the mid/long-term point of view. The production technologies that the farm households can put into practice include crop growth rate control, greenhouse cultivation, control of the use of agricultural chemicals, weed control, diversification of crop varieties, adjustment of transplantation date, and switchover of cultivation regions to suitable climate zone. For Japan, the adaptation measures that individual farm households can apply to each crop item are suggested in detail in the guidelines for major agricultural businesses. The adaptation measures for each crop item based on those guidelines are outlined below <Table 7-11>.

Table 7-11. Adaptation measures for each crop item against climate change

Item	Climate	Impact	Adaptation measures
Rice	Meteorological disaster	Overhead flooding damage	· Designate disaster hazard zone, select the variety immune to diseases, and control the amount of fertilizer.
		Wind damage	· Control cultivation period, select a variety resistant to wind, and install a windbreak facility.
		Lodging	· Select a lodging-tolerant variety , use a proper amount of fertilizer at a proper time, manage water use, and treat the rice with materials for lodging resistance
		viviparous germination	· Select variety with high dormancy, and treat with a growth control agent.
	Heat injury	White under ripe kernel	· Develop early-maturing varieties resistant to high temperature. · Postpone transplantation time, suppress or induce to produce the appropriate number of kernels, and control the cultivation density. · Balanced fertilizer between nitrogen, phosphorous, and potassium.
		Cracked kernels	
		Infertility due to high temperature	
	Blight and pest	*Pheropsophus jessoensis*	· Estimate its occurrence using sex pheromone trap.
Fruits	Damage by high temperature	Damage by heat wave	· Perform drip irrigation at a regular interval when the precipitation during 7-16days is less than 30mm.
	Blight and pest	-	· Close observation is preferred.

Item		Climate	Impact	Adaptation measures
	Apple	High temperature during coloring season	Poor coloring (softening of flesh, reduced storage time)	· Select good coloration system from Tsugaru and Fuji: Improve the light-receiving technology using the reflective film.
	Peach	High temperature during ripening period	Water core～Browning of flesh	· Switch over to mixed-color varieties; Strictly observe proper crop load and/or crop harvesting; and soil and weed management
	Grape	High temperature during coloring season	Poor coloration	· ABA(abscisic acid) treatment and girdling treatment - Strictly observe the bearing of proper crops
	Tangerine	High temperature during coloring season	Poor coloration and bulky fruit	· Improve light-receiving by using reflective mulching materials · Prevent bearing of bulky fruits by fruit drop · Reduce bulky fruits using the plant control agent
			Falling of fruits	· Prevent natural falling of fruits through Gibberellin treatment
		Blight and pest	Tangerine green disease	· LAM Prompt diagnosis using LAMP method: Prevent vectors
Vegetable & flowering plants		Climate change	-	· Decision-making support system to select suitable areas and suitable varieties.
		Measures for reducing heat	-	· Spray-mode cooling, to control temperature rise · Select zucchini stalk resistant to heat. · Develop eggplant variety that bears fruits by each unit. · Reduce problem of not proper tomato fruits at high temperature.
		Blight and pest	*Spodoptera litura*	· Introduce insect screens and sex pheromone traps.
Beans		High temperature during summer and fall	Drought damage	· Develop an underground water-level control system

Source: Compiled with the data from MAFF of Japan (2008), RDA (2007b), and RDA Agricultural Research Center for Global Warming (2009).

Detailed programs for soil management include subdivision of dry fields, fallow, and surrounding vegetation control to prevent soil erosion, and change and/or diversification of the cultivation system (i.e. crop rotation and intercropping).

Implementation programs for water management include sprinkler irrigation, drip irrigation, use of a piped ditch, use of the irrigation scheduling system to enhance the efficiency of water use, and installation of water reservoirs for individual farm households.

Programs, which can be applied by individual farm households in the category of financial management for farm households, include utilization of crop insurance to avoid the risk of income reduction, participation in the income stabilization program, diversification of revenues for farm households through crop diversification and participation in the future's market for agricultural crops. Individual farm households can select appropriate programs in consideration of their unique conditions. In particular, when introducing a new crop, farm households may worry about a drop in crop yield and their income, until cultivation is stabilized technologically. Therefore, an income stabilization program that takes into consideration the conditions of each region should be prepared. Also, when the new crop is put on the market, it is important to advertise and secure its market, so proper distribution programs should be prepared. In order for the farm households to properly cope with climate change in terms of technology and policy, it is important to popularize the user-oriented manual not only from the short-term but also from the mid/long-term points of view.

Detailed tasks for the category of technology and management applicable to individual farm households must be preceded by the analysis of decision-making by the farmer people before the tasks into practice. Most especially, detailed tasks for water management such as sprinkler irrigation, drip irrigation, use of piped ditches, and installation of water reservoirs for individual farms, will incur additional expenses. This may result in a waste of money, time, and facilities if they are put into force without estimating to what degree farmer would accept them.

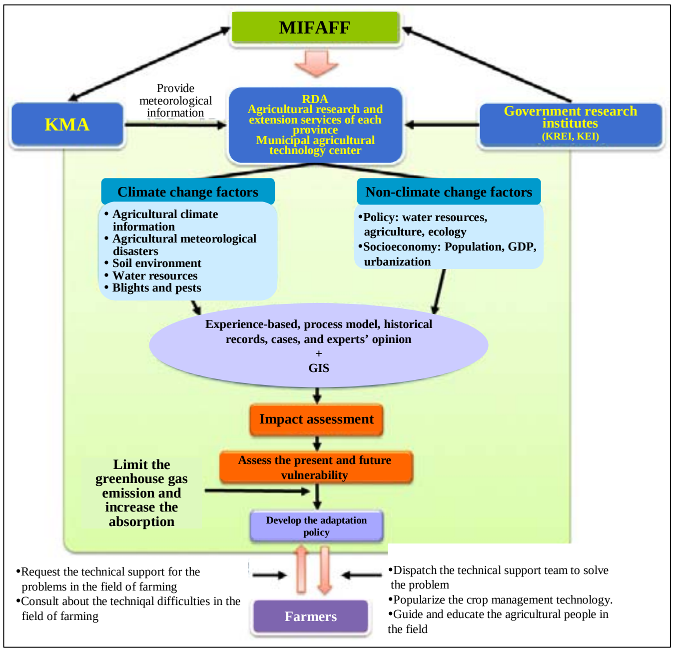
3.2.8. Buildup of an integrated management system for adaptation to climate change

The main body that will actually put the agricultural sector's climate change adaptation measures into practice is the farmer. Therefore, field technology support and proper training for them is very important. In order to ensure proper training, the impact of climate change on each region and crop item, (both present and future vulnerability), must be assessed in consideration of climatic and non-climatic factors. At the same time, the adaptation policy program should be developed based on the farm household's capacity to accept the adaptation measures.

In building up the integrated management system, it is important to secure the manpower in the related organizations, including Ministry for Food, Agriculture, Forestry and Fisheries (MIFAFF) who are in exclusive charge of the system. In addition, founding a separate organization that will ensure proper role division among the related parties should also be considered from the mod/long-term point of view. For the environment-related matters, the "National Climate Change Adaptation Center" has been created within the purview of the installed under Korea Environment Institute (KEI), as a non-legal organization of the Ministry of Environment in July 2009, in according to the "National Climate Change Adaptation Programme" and which has supervised the climate change adaptation affairs. As the National Climate Change Adaptation Center requires interdisciplinary researches and cooperation, 17 organizations including the Korea Meteorological Agency (KMA), the National Institute of Environmental Research, Korea Rural Economic Institute (KREI), and the National Fisheries Research and Development Institute are involved with in the Center as collaborating agencies.

For effective implementation of the climate change adaptation strategies for the agricultural sector, the integrated management system should be established to ensure proper role division among the related bodies and the farmer centering on the MIFAFF. The MIFAFF (Green Future Strategy Division) will take in general charge of adaptation to climate change; KMA will monitor climate change and provide the information about long-term forecast; and KREI and KEI, the government research institutes, will provide the inventory of adaptation policy measures and the information about economic and environmental impact analysis for each measure. As the key to success in adaptation to climate change is development and popularization of technologies, the Rural Development Agency, the municipal agricultural research and extension services, and the municipal agricultural technology centers should organically cooperate with each other <Figure 7-4>.

Figure 7-4. Integrated system for the agricultural sector's adaptation to climate change (Draft)



Summary and Conclusion

Chapter 8

It is analyzed that due to the impact of global warming, the average temperature has risen by 1.5℃ (1.9℃ in winter, 0.3℃ in summer) over the past 100 years and the flowering season in spring has started ever earlier. As a result, the crop cultivation zone has shifted north and the damage caused by wintering blight and pests have increased, resulting in a decrease in agricultural productivity. Scientific diagnosis and assessment of the impact of climate change on the agricultural sector is essential for formulating the vision of future agriculture and the direction of agricultural administration. Most especially, scientific diagnosis can provide useful information for formulating long-term agricultural development plan for each region and adaptive measures for farm households.

This study was carried out in order to suggest scientific and phase-by-phase counterstrategies against climate change through diagnosis of the climate change phenomena and in-depth analysis of climate change impact on the agricultural sector. To achieve these study purposes, the study was carried out as a two year project. In 2008, the actual conditions and prospect of climate change were analyzed; the trend of agricultural production was analyzed; the agricultural production with regard to climate change was diagnosed; and the case study for major countries' adaptation measures against climate change in the agricultural sector was completed; and the impact of climate change on the agricultural economy was analyzed. In 2009, the impact of climate change was analyzed in general. In addition, the master plan to cope with climate change in the agricultural sector was suggested, including the phase-by-phase adaptation programs, based on the analysis of the shift in main production regions of major crops, the farm household's capacity to accept the adaptation measures, and the evaluation of the priorities of adaptation measures.

This report is a general report on the first-year and the second-year studies. Chapter one, The Introduction, presented the need for the study, preceding studies, and study methods. Chapter two described the actual conditions and prospect of domestic and overseas climate change. Chapter three dealt with the theoretical approaches, including the approaches to cope with climate change in the agricultural sector, the methodologies for impact analysis, and approaches to climate change adaptation. Chapter four presented a general impact analysis covering the impact of climate change on the agricultural ecosystem, the impact of each climatic factor, the impact of adaptation measures on the crop cultivation, the shift in main production regions of major crops, and the economic impact of climate change on the agricultural sector. Chapter five described the results of questionnaire research undertaken to discover the farmers' response to climate change, their awareness of climate change, and their attitude to adaptation measures, and then analyzed to discover farmers' decision making under conditions of risk and uncertainty. Chapter six reviewed the impacts of climate change on the agricultural sectors of major countries such as Japan, EU, UK, Australia and China and their countermeasures against climate change. Chapter seven suggested the basic direction for formulating the counterstrategies for the agricultural sector against climate change, determining the priorities of adaptation strategies, and the implementation strategies for adaptation to climate change. Lastly, Chapter eight presented the summary and conclusion.

The main results of this study can be summarized as follows:

First, according to National Institute of Meteorological Research, the average temperature is expected to rise by 1.5℃ by 2010, 3.0℃ by

2050, and 5.0℃ by 2080, precipitation will rise by five percent by 2020, seven percent by 2050, and fifteen percent by 2080, in comparison to the average values over the past 30 years (1971~2000).

Second, the temperature rise due to global warming has caused the shift in suitable regions for cultivation and the appearance of new blights and pests, resulting in crop switchover and the spread of crop damage. Most especially, it appears that damage to apples, peaches, grapes, and beans by *Paratlanticus ussuriensis* have increased and the areas damaged by rice stripe virus has expanded and shifted north.

Third, the analysis of climatic variables that affect the crop disasters shows that the rise in average annual temperature has increased the frequency and severity of typhoons, gusts of wind, snow and increases in extreme temperature differences. This has led to an increase in damage caused by tidal waves, gusts of wind, windstorms, and snow. Also, increases in precipitation have led to increasing damage by torrential rain but a decrease in damage by hail, lightening, and gust of wind. It is analyzed that the increase in the precipitation intensity also results in the increase in damages by torrential rain and typhoon.

Fourth, the result of analyzing the contributing factors to rice yield stagnation in 2002~03 and 2006~07 to identify the impact of meteorological factors shows that technology accounted for 23.6%, while the meteorological factor accounted for 76.4% of the change. According to the trends of factors that affect the rice yield, the impact of technology dissemination has continuously decreased, that of cultivation has remained the same, but that of meteorological factors has increased.

Fifth, the result of crop simulation analysis to identify the impact of climate change adaptation measures shows that, if the cultivation period is fixed regardless of rice variety, amount of nitrogenous fertilizer, and irrigation condition, that rice yields are reduced as global warming proceeds. On the other hand, if the cultivation period is adjusted, the rice yield appears to increase. This implies that it is possible for the agricultural sector to minimize the risk of climate change by developing proper technologies for adaptation to the climate change.

Sixth, the shift in main production regions of perennial crops such as apples, peaches, grapes and Halla oranges due to climate change shows that most of suitable regions for cultivation have shifted north and the cultivation regions for peaches and grape have spread all over the country. Tropical crops are currently cultivated in Jeju mostly at the adaptation testing stage. However, it is analyzed that in a few years a considerable number of tropical fruit varieties can be cultivated in Jeju.

Seventh, the result of analyzing the agricultural productivity of rice, Korean cabbage, radish and apples using a Kernel regression approach shows that the temperature rise of 1℃ will increase the rice yield by 24.4kg per 10are (10a) when the average temperature during the cultivation period is 19℃ or lower but reduce it by 6.2kg per 10a when the average temperature during the cultivation period is higher than 20℃. For Korean cabbage, radish, and apple, the impact of temperature and precipitation appears to vary with every variety and region.

Eighth, the result of analyzing the impact of climate change on the farm household’s property by using Ricardian Model shows that when the average annual temperature (12.4℃) rises by 1℃, the farmland price per ha drops by 14,550~19,240 thousand won. The same approach to analysis of the impact of climate change on the agricultural gross income reveals that the temperature rise of 1℃ will result in the decrease in farmland price by 2,600~4,000 thousand won per ha.

Ninth, the level of farmers’ awareness of climate change appears to be high. They have generally experienced unusual changes in weather and the increase in blights and pests. Though they are interested in the countermeasures against climate change and very willing to implement the adaptation measures for individual farm households, there are some difficulties for them such as lack of proper technologies, knowledge, and information, and a shortage of manpower.

Tenth, the result of estimating of the difference in expected profits between when the adaptation measures are applied and when they are not, using the expected utility model, shows that the difference would be 790 thousand won in Gwangju, 1,200 thousand won in Milyang, and 1,400 thousand won in Jeonju based on the climate change scenario for 2011~2040. The probability of the farmer to apply the adaptation measures is estimated to be around 65% when calculated based on the result of the expected utility analysis, which implies that the farmer are very much interested in adaptation to climate change and willing to accommodate proper technologies for adaptation

Lastly, the result of determining the priorities of adaptation measures for the agricultural sector shows that breeding has the highest priority, agricultural water management the second highest and the production technology development the third highest, both from the short-term and the mid/long-term points of view, implying that R&D and infrastructure management are the most important adaptation measures.

So far, the countermeasures for the agricultural sector against climate change have mostly focused on greenhouse gas mitigation. However, more interest and policy support should be directed to adaptation measures in consideration of the inevitability of global warming and the characteristics of climate-dependent agriculture. In particular, it is necessary to understand that the countermeasures for the agricultural sector against climate change are to minimize the risk of climate change and utilize it as an opportunity. For this, proper education and training programs for the farmer, public officials and the personnel from the related agencies should be developed and put into practice so that they can properly cope with climate change. It is also urgent to expand the adaptation measures for the agricultural sector (that have thus far been limited to research and development) towards more active policy programs including popularization the technology and the adaptation manual among to the farmer and instituting proper incentive programs. As shown by the results of questionnaire research for the farmer, they are highly interested in adaptation to climate change and very willing to participate in carbon reduction programs, so it is necessary to develop technologies and customized programs that they can apply in the field.

The improvement of agricultural production infrastructure has focused on the farmlands for rice farming so as to become self-sufficient in food production. Improvements have included securing water resources in preparation against drought, preventing floods, and arranging for mechanized farming. Now, more scientific measures in the agricultural water and facility management should be formulated and implemented in preparation against unusual weather, including localized torrential rain and typhoons.

In ensuring effective implementation of the agricultural sector's adaptation strategies, it is necessary to divide roles properly between the bodies concerned such as the government, farmers, researchers, and other related institutions and to build up the integrated management system for comprehensive planning and implementation of those adaptation strategies.

The government declared "low-carbon green-growth" as a key strategy for future national development. Since then, the related ministries have formulated policy programs and put them into practice. For the agricultural sector to have the capacity for green growth, comprehensive adaptation measures against climate change should take precedence over climate change mitigation measures. The result of this study can be utilized as basic data for formulating the master plan for the agricultural sector's adaptation to climate change. Most especially, the prospect of shifts in main production regions and the result of analyzing the farmers' responses to adaptation measures are expected to be used as reference data for formulating the mid/long-term agricultural development plan and farming plan for each region.

Systematic research into the impact of climate change on the agricultural sector and the formation of counterstrategies against climate change have to be undertaken as interdisciplinary research among agricultural science, ecology, agricultural engineering, hydrology, meteorology, and agricultural economics. For a more reliable analysis of the climate change impact, efforts need to be made to develop the integrated models, consolidating the estimates produced by climate change scenario, the simulation analysis based on the agricultural characteristics, and the economic analysis reflecting the socioeconomic factors of agriculture. Furthermore, future studies should carry out more detailed analysis for the economic and policy effects of each adaptation measures for the agricultural sector.

APPENDIX

Table A1. Rice cultivation area and yield data of the variety (1996~2008)

	Yield (kg/10a)	1996	1997	1998	1999 (ha)	2000	2001	2002
Odae	481	50,600	44,617	44,327	39,196	31,323	27,455	41,603
Bongkwang	447	16,100	10,846	10,146	6,260	3,321	-	142
Shinsunchal	485	12,500	11,000	9,573	8,220	6,199	6,010	4,708
Choojung	453	126,500	90,587	80,263	59,561	35,174	48,940	106,482
Dongjin	479	238,900	185,264	136,826	71,456	38,155	18,243	17,501
Hwasung	493	70,300	86,559	85,704	58,689	48,597	38,672	29,452
Ilpum	534	101,400	84,378	72,022	72,463	83,577	88,202	98,233
Seoan	505	14,300	18,790	21,551	21,502	15,104	12,215	5,787
Gaehwa	478	52,800	30,083	19,726	12,221	3,361	708	1,093
Hwanam	509	31,300	59,083	33,673	18,170	10,616	3,272	1,349
Youngnam	479	41,300	23,649	22,040	15,718	7,185	3,411	1,242
Mankeum	478	43,400	19,173	12,197	5,627	1,826	1,175	2,577
Sangju	531	19,400	20,024	14,263	12,328	11,028	9,003	3,376
Anjung	519	14,700	16,038	10,015	5,827	4,800	3,475	469
Daesan	531	-	52	11,641	106,822	146,675	65,818	12,194
Ilmi	522	80	18,029	95,830	131,987	122,966	104,459	99,926
Hwayoung	505	67,900	80,828	85,420	60,553	58,284	53,548	41,658
Daean	511	2,100	16,886	24,700	58,506	55,794	56,259	28,339
Keumnam	521	14,000	62,168	70,726	53,664	34,737	17,906	6,447
Daejin	504	-	31	7,998	18,981	28,993	23,242	4,310
Hwasam	534	-	944	10,784	15,426	25,347	15,929	2,589
Dongjin 1	567	-	-	-	-	-	-	6,824
Nampyoung	547	-	-	31	7,339	55,738	115,033	175,978
Joonam	576	-	-	-	-	-	7,012	72,281
Woonkwang	586	-	-	-	-	-	-	-
Shindongjin	596	-	-	-	-	512	11,386	29,080
Samkwang	569	-	-	-	-	-	-	-
Saechoojung	558	-	-	-	-	-	318	20,691
Dongan	527	-	40	9,586	81,577	91,145	91,351	64,529
Onnuri	594	-	-	-	-	-	-	-
Dongjinchal	549	-	-	-	-	709	3,591	9,474
Sub total		917,580	879,069	889,042	942,093	921,166	826,633	888,334
(ratio)		(87.8)	(83.8)	(84.1)	(89.7)	(86.8)	(79.3)	(86.5)
Others		126,980	169,535	168,661	107,608	140,419	216,141	139,216
Total Area (ha)		1,044,560	1,048,604	1,057,702	1,049,701	1,061,585	1,042,774	1,027,550
Dissemination yield (kg/10a)		489.3	497.5	501.1	509.2	516.8	521.7	524.4

Table A1. (Continued).

	Yield (kg/10a)	2003	2004	2005 (ha)	2006	2007	2008
Odae	481	46,566	46,557.4	56,075.6	47,197.6	38,585.8	32,604.4
Bongkwang	447	229	37.7	6.0	7.6	8.0	4.0
Shinsunchal	485	2,033	2,282.7	2,102.8	2,146.3	1,860.5	1,584.8
Choojung	453	113,169	119,000.1	121,997.4	125,817.7	126,628.5	126,281.7
Dongjin	479	7,943	1,478.4	964.1	299.8	263.8	151.4
Hwasung	493	22,195	13,455.7	8,356.2	5,880.6	3,088.0	2,065.0
Ilpum	534	81,696	57,888.0	51,466.9	52,287.6	45,162.5	41,075.8
Seoan	505	1,736	535.0	230.5	55.5	20.4	56.0
Gaehwa	478	360	80.4	123.5	76.0	117.4	14.0
Hwanam	509	125	20.7	9.8	5.0	8.0	
Youngnam	479	672	60.3	55.1	2.0		
Mankeum	478	942	125.8	105.2	9.3		
Sangju	531	1,675	812.9	847.6	552.7	338.0	148.2
Anjung	519	16	18.8		1.0		
Daesan	531	1,166	252.7	140.9	20.0	17.9	13.9
Ilmi	522	111,126	83,045.0	69,664.2	72,533.9	71,575.5	67,494.6
Hwayoung	505	32,511	28,239.4	27,863.3	25,255.8	22,818.5	18,308.4
Daean	511	20,739	23,258.2	19,388.8	21,764.6	22,171.7	19,113.5
Keumnam	521	892	158.8	28.8	7.0	10.0	6.0
Daejin	504	1,291	328.1	122.7	73.3	30.5	10.3
Hwasam	534	344	63.3	3.1	7.5		
Dongjin 1	567	75,494	143,892.3	198,444.9	205,119.5	190,147.2	167,350.2
Nampyoung	547	170,263	160,151.4	144,853.3	125,105.8	116,017.7	112,489.5
Joonam	576	89,642	112,266.4	91,636.9	78,296.3	91,163.3	101,633.3
Woonkwang	586			69.8	6,569.6	30,658.7	46,170.0
Shindongjin	596	15,791	9,668.1	17,372.9	22,633.7	31,987.3	35,556.8
Samkwang	569		4.9	382.5	4,822.0	14,465.4	24,085.1
Saechoojung	558	40,953	41,436.6	41,482.7	36,020.3	25,067.7	16,256.9
Dongan	527	49,522	25,927.5	15,363.9	17,348.6	16,063.2	12,712.4
Onnuri	594				305.9	6,238.5	11,135.2
Dongjinchal	549	5,377	6,862.5	7,296.3	9,687.7	10,279.4	10,573.2
Sub total		894,468	877,909	876,456	859,910	864,793	846,895
(ratio)		(89.7)	(90.5)	(92.1)	(93.0)	(93.9)	(93.4)
Others		102,496	92,530	75,118	64,460	56,377	59,495
Total Area (ha)		996,964	970,439	951,574	924,370	921,170	906,390
Dissemination yield (kg/10a)		528.6	532.7	533.8	533.6	536.6	539.4

Table A2. Trend of changes in quantitative capacity yield/dissemination yield/average annual yield/farm household yield of rice

Unit: kg/10a

Year	Quantitative Capacity Yield (A)	Dissemination Yield(B)	Average annual yield(C)	Farm household yield(D)
1982	488.2	454.5	428.5	413
1983	490.5	457.3	431.4	420
1984	492.9	460.2	434.4	446
1985	495.2	463.0	437.4	437
1986	497.5	465.8	440.3	449
1987	499.8	468.6	443.3	431
1988	502.1	471.4	446.2	469
1989	504.4	474.2	449.1	463
1990	506.7	477.0	452.0	442
1991	508.9	479.8	455.0	444
1992	511.2	482.6	457.9	461
1993	513.4	485.3	460.7	418
1994	515.7	488.1	463.6	459
1995	517.9	490.8	466.5	445
1996	520.1	493.5	469.3	507
1997	522.4	496.2	472.2	518
1998	524.6	498.9	475.0	482
1999	526.8	501.6	477.9	495
2000	529.0	504.3	480.7	497
2001	531.2	506.9	483.5	516
2002	533.3	509.6	486.2	471
2003	535.5	512.2	489.0	441
2004	537.6	514.8	491.8	504
2005	539.8	517.4	494.5	490
2006	541.9	520.0	497.2	493
2007	544.0	522.6	500.0	466
2008	546.1	525.2	502.7	520

Table A3. Contribution by each factor to the rice yield.

Year	Factor (kg)				Contribution ratio (%)				
	Dissemination A-B	Cultivation B-C	Meteorological |C-D|	Total	Dissemination	Technological	Meteorological	Total	10 year
1982	33.7	26.0	15.5	75.2	44.8	34.6	20.6	100.0	
1983	33.2	25.9	11.4	70.5	47.1	36.7	16.2	100.0	
1984	32.7	25.8	11.6	70.0	46.7	36.8	16.6	100.0	
1985	32.2	25.6	0.4	58.2	55.3	44.1	0.6	100.0	
1986	31.7	25.5	8.7	65.8	48.1	38.7	13.2	100.0	
1987	31.2	25.4	12.3	68.8	45.3	36.9	17.8	100.0	
1988	30.6	25.2	22.8	78.7	38.9	32.1	29.0	100.0	
1989	30.1	25.1	13.9	69.1	43.6	36.3	20.1	100.0	16.8
1990	29.6	25.0	10.0	64.7	45.8	38.6	15.5	100.0	
1991	29.1	24.8	11.0	64.9	44.9	38.3	16.9	100.0	
1992	28.6	24.7	3.1	56.5	50.7	43.7	5.6	100.0	
1993	28.1	24.6	42.7	95.4	29.5	25.7	44.8	100.0	
1994	27.6	24.4	4.6	56.7	48.7	43.1	8.2	100.0	
1995	27.1	24.3	21.5	72.9	37.2	33.3	29.5	100.0	
1996	26.6	24.2	37.7	88.5	30.1	27.3	42.6	100.0	
1997	26.2	24.0	45.8	96.0	27.3	25.0	47.7	100.0	
1998	25.7	23.9	7.0	56.5	45.4	42.2	12.3	100.0	
1999	25.2	23.7	17.1	66.1	38.1	35.9	26.0	100.0	24.9
2000	24.7	23.6	16.3	64.6	38.2	36.5	25.3	100.0	
2001	24.2	23.5	32.5	80.2	30.2	29.2	40.6	100.0	
2002	23.8	23.3	15.2	62.3	38.1	37.4	24.5	100.0	
2003	23.3	23.2	48.0	94.5	24.6	24.5	50.8	100.0	
2004	22.8	23.0	12.2	58.1	39.3	39.7	21.0	100.0	
2005	22.4	22.9	4.5	49.8	44.9	46.0	9.1	100.0	
2006	21.9	22.8	4.2	48.9	44.8	46.6	8.7	100.0	
2007	21.4	22.6	34.0	78.0	27.5	29.0	43.5	100.0	
2008	21.0	22.5	17.3	60.8	34.5	37.0	28.5	100.0	28.0

Table A4. Rice yield and biological conditions by seed rasing year in ORYZA2000

Biological Characteristic	Cultivation time	Seed Raising (Year)	Rice Yield (kg/ha)	Growth Temperature (℃)	Temperture before Heading (℃)	Temperature for the whole time (℃)	Uptake of Nitrogen (kg/ha)	Rainfall[1] (mm)	Irrigaion Level* (mm)	growing period (day)
Early-ripening	Fixed	1971-2000	4,821	22.2	25.3	24.2	110.6	752.3	179.0	128
		2011-2040	4,697	24.2	26.3	25.6	106.7	627.9	192.3	120
		2041-2070	4,733	26.4	27.6	27.1	104.2	763.8	128.8	115
		2071-2100	4,416	28.1	28.9	28.6	102.4	798.4	130.7	114
		Average	4,667	25.2	27.0	26.4	105.9	735.6	157.7	119
	Unfixed	1971-2000	4,821	22.2	25.3	24.2	110.6	752.3	179.0	128
		2011-2040	4,928	22.3	27.1	25.4	108.9	594.6	206.3	123
		2041-2070	5,393	22.2	29.0	26.5	107.9	701.0	163.4	121
		2071-2100	5,582	22.1	30.5	27.4	107.1	697.8	160.9	122
		Average	5,181	22.2	28.0	25.9	108.6	686.4	177.4	124
Middle-ripening	Fixed	1971-2000	4,906	22.3	24.1	23.5	105.3	846.6	210.7	141
		2011-2040	4,602	24.5	25.2	24.9	101.3	718.4	215.9	133
		2041-2070	4,447	26.7	26.3	26.4	98.7	808.9	167.3	127
		2071-2100	3,864	28.4	27.6	27.7	96.9	866.2	161.9	125
		Average	4,454	25.5	25.8	25.6	100.6	810.0	188.9	131
	Unfixed	1971-2000	4,906	22.3	24.1	23.5	105.1	846.6	212.9	141
		2011-2040	4,971	22.2	26.4	25.0	103.4	672.3	230.0	133
		2041-2070	5,392	22.2	28.5	26.3	102.0	794.1	158.3	128
		2071-2100	5,527	22.2	30.2	27.4	101.0	742.6	170.6	128
		Average	5,199	22.2	27.3	25.5	102.9	763.9	192.9	133
Middle-ripening	Fixed	1971-2000	5,166	21.7	22.6	22.3	113.9	920.8	296.8	165
		2011-2040	4,831	24.3	23.6	23.7	109.2	788.5	300.8	154
		2041-2070	4,432	26.7	24.7	25.1	106.1	922.1	228.9	147
		2071-2100	3,471	28.7	25.8	26.4	104.1	940.4	228.4	143
		Average	4,475	25.4	24.2	24.4	108.3	892.9	263.7	152
	Unfixed	1971-2000	5,166	21.7	22.6	22.3	113.9	920.8	296.8	165
		2011-2040	5,083	22.3	25.2	24.3	109.5	764.1	273.7	148
		2041-2070	5,371	22.2	27.8	26.0	106.0	887.9	183.0	140
		2071-2100	5,454	22.2	29.6	27.2	104.7	844.4	182.7	138
		Average	5,269	22.1	26.3	24.9	108.6	854.3	234.0	148

Note: 1) The amount of rainfall and irrigation during growing period in this study rice field.

Table A5. Rice yield by the amount of nitrogen and condition of irrigation in ORYZA2000

	Cultivation time	Amount of Nitrogen (kg/ha)	Uptake of Nitrogen (kg/ha)	Rice Yield (kg/ha)	Irrigation Duration[1)] (day)	Irrigaion Level (mm)	Rice Yield (kg/ha)
Early-ripening	Fixed	0	38.6	2,690	0	343.8	5,020
		30	57.8	3,525	3	246.5	4,947
		60	76.8	4,178	6	191.6	4,830
		90	96.1	4,753	9	159.4	4,702
		120	115.6	5,318	12	138.7	4,602
		150	135.0	5,763	15	112.9	4,610
		180	154.3	5,689	30	68.7	4,484
		210	173.3	5,418	200	0.0	4,141
		Average	105.9	4,667	Average	157.7	4,667
	Unfixed	0	40.8	3,059	0	385.8	5,546
		30	60.1	3,968	3	280.1	5,470
		60	79.1	4,690	6	215.2	5,343
		90	98.7	5,357	9	182.4	5,243
		120	118.3	5,975	12	154.7	5,156
		150	137.9	6,392	15	128.2	5,112
		180	157.4	6,157	30	72.9	4,921
		210	176.7	5,851	200	0.0	4,658
		Average	108.6	5,181	Average	177.4	5,181
Middle-Ripening	Fixed	0	43.2	2,995	0	406.8	4,957
		30	59.9	3,684	3	297.5	4,836
		60	76.0	4,082	6	232.4	4,636
		90	92.2	4,375	9	188.2	4,507
		120	108.7	4,754	12	163.2	4,358
		150	125.2	5,140	15	143.7	4,320
		180	141.6	5,361	30	79.7	4,195
		210	157.9	5,243	200	0.0	3,825
		Average	100.6	4,454	Average	188.9	4,454
	Unfixed	0	44.3	3,362	0	415.1	5,570
		30	61.1	4,274	3	301.5	5,490
		60	77.4	4,691	6	236.0	5,375
		90	94.1	5,185	9	192.2	5,270
		120	111.1	5,684	12	167.1	5,178
		150	128.0	6,149	15	144.1	5,134
		180	145.0	6,256	30	87.5	4,929
		210	161.9	5,990	200	0.0	4,644
		Average	102.9	5,199	Average	192.9	5,199

Note: 1) Irrigation duration means the number of days in which irrigation would be need after leakage or vaporation (transpiration) from a rice field.

Table A5 (Continued).

	Cultivation time	Amount of Nitrogen (kg/ha)	Uptake of Nitrogen (kg/ha)	Rice Yield (kg/ha)	Irrigation Duration[1] (day)	Irrigaion Level (mm)	Rice Yield (kg/ha)
iddle lately-ripening	Fixed	0	62.9	3,396	0	570.1	5,141
		30	74.3	3,587	3	416.5	4,993
		60	87.4	4,011	6	322.7	4,678
		90	101.1	4,484	9	259.2	4,490
		120	114.7	4,828	12	228.3	4,391
		150	128.3	5,087	15	193.8	4,257
		180	141.9	5,251	30	119.0	4,086
		210	155.7	5,157	200	0.0	3,763
		Average	108.3	4,475	Average	263.7	4,475
	Unfixed	0	61.0	3,550	0	499.1	5,570
		30	72.6	3,891	3	365.9	5,542
		60	86.5	4,538	6	289.7	5,454
		90	100.8	5,247	9	237.0	5,363
		120	115.3	5,871	12	196.0	5,286
		150	129.7	6,338	15	175.0	5,213
		180	144.0	6,519	30	109.6	5,036
		210	158.5	6,196	200	0.0	4,687
		Average	108.6	5,269	Average	234.0	5,269

Note: 1) Irrigation duration means the number of days in which irrigation would be need after leakage or evaporation from a rice field.

Table A6. Regional estimation of rice yield considering temperature and CO_2 (Early- ripening)

Unit: kg/ha

Region			Temperature(unfixed), CO_2 (fixed)			Temperature(fixed), CO_2 (unfixed)			Temperature, CO_2 (unfixed)		
		1971-2000	2011-2040	2041-2070	2071-2100	2011-2040	2041-2070	2071-2100	2011-2040	2041-2070	2071-2100
Gyeonggi Region	Seoul	4,412	4,167	3,990	3,917	4,709	4,883	4,992	4,469	4,504	4,626
	Suwon	4,623	4,390	4,123	3,987	4,888	5,012	5,092	4,678	4,611	4,680
	Yangpyeong	4,778	4,522	4,267	4,135	4,970	5,089	5,295	4,759	4,696	4,732
	Icheon	4,802	4,506	4,367	4,190	4,945	5,131	5,407	4,688	4,764	4,841
	Incheon	4,772	4,464	4,222	4,115	4,971	5,093	5,291	4,712	4,652	4,822
Gyeongsang Region	Geoje	4,700	4,432	4,255	4,212	4,853	5,021	5,268	4,631	4,722	4,966
	Geochang	4,917	4,700	4,373	4,235	5,074	5,308	5,607	4,923	4,742	4,814
	Gum	4,754	4,511	4,317	4,176	4,988	5,056	5,236	4,789	4,843	4,920
	Namhae	4,644	4,444	4,280	4,209	4,835	4,906	5,107	4,735	4,817	4,989
	Daegu	4,469	4,330	4,166	4,035	4,775	4,929	4,984	4,660	4,766	4,831
	Masan	4,370	4,200	3,979	3,978	4,690	4,870	4,950	4,530	4,535	4,681
	Mungyeong	4,787	4,571	4,448	4,267	4,932	5,111	5,377	4,754	4,880	4,979
	Miryang	4,643	4,474	4,278	4,112	4,910	4,975	5,091	4,775	4,835	4,872
	Busan	4,661	4,470	4,305	4,185	4,856	4,904	5,097	4,758	4,855	4,996
	Sancheong	4,667	4,483	4,261	4,169	4,871	4,937	5,118	4,749	4,760	4,906
	Andong	4,642	4,429	4,285	4,104	4,875	4,978	5,097	4,722	4,800	4,835
	Yeongdeok	4,923	4,683	4,397	4,302	5,076	5,482	5,858	4,846	4,717	4,861
	Yeongju	4,951	4,711	4,438	4,270	5,113	5,400	5,740	4,910	4,778	4,824
	Yeongcheon	4,739	4,559	4,329	4,164	4,942	5,037	5,209	4,835	4,836	4,858
	Ulsan	4,580	4,390	4,213	4,104	4,843	4,930	5,018	4,691	4,760	4,886
	Uljin	5,170	4,845	4,400	4,225	5,419	5,943	6,362	4,959	4,723	4,710
	Uiseong	4,745	4,503	4,331	4,186	4,900	5,041	5,254	4,741	4,750	4,810
	Jinju	4,619	4,402	4,182	4,073	4,938	5,035	5,047	4,738	4,774	4,866
	Pohang	4,571	4,440	4,229	4,121	4,838	4,927	5,024	4,753	4,788	4,917
	Hapcheon	4,736	4,546	4,311	4,127	4,964	5,012	5,198	4,839	4,847	4,861
Jeolla Region	Goheung	4,679	4,498	4,370	4,214	4,811	4,969	5,213	4,749	4,857	4,943
	Gwangju	4,526	4,371	4,158	4,103	4,821	4,956	5,019	4,711	4,738	4,910
	Gunsan	4,582	4,434	4,177	4,090	4,859	4,967	5,053	4,740	4,747	4,854
	Namwon	4,676	4,451	4,294	4,181	4,920	4,944	5,104	4,764	4,834	4,910
	Mokpo	4,561	4,390	4,232	4,142	4,814	4,883	4,968	4,725	4,813	4,962
	Buan	4,713	4,578	4,372	4,240	4,844	5,036	5,319	4,795	4,801	4,914
	Suncheon	4,613	4,406	4,202	4,093	4,886	4,949	5,022	4,724	4,773	4,832
	Yeosu	4,693	4,500	4,331	4,205	4,876	4,936	5,133	4,789	4,900	5,049
	Imsil	4,974	4,701	4,445	4,350	5,096	5,414	5,774	4,904	4,813	4,939
	Jangsu	5,338	4,897	4,443	4,272	5,474	5,846	6,213	5,147	4,833	4,871
	Jangheung	4,645	4,394	4,215	4,088	4,949	5,056	5,095	4,730	4,788	4,839
	Jeonju	4,442	4,222	4,121	3,991	4,775	4,975	5,044	4,555	4,690	4,727
	Jeongeup	4,721	4,525	4,312	4,189	4,939	4,993	5,190	4,803	4,812	4,902
	Haenam	4,716	4,488	4,347	4,238	4,881	4,984	5,195	4,787	4,847	5,009

Table A6 (Continued).

Unit: kg/ha

Region			Temperature(unfixed), CO_2 (fixed)			Temperature(fixed), CO_2 (unfixed)			Temperature, CO_2 (unfixed)		
		1971 -2000	2011 -2040	2041 -2070	2071 -2100	2011 -2040	2041 -2070	2071 -2100	2011 -2040	2041 -2070	2071 -2100
Chungcheong Region	Geumsan	4,835	4,579	4,350	4,230	4,998	5,150	5,386	4,820	4,820	4,875
	Daejeon	4,619	4,381	4,175	4,083	4,908	5,018	5,095	4,684	4,728	4,841
	Boryeong	4,781	4,649	4,356	4,223	4,956	5,165	5,488	4,835	4,743	4,846
	Boeun	5,008	4,741	4,481	4,322	5,138	5,467	5,827	4,926	4,845	4,885
	Seosan	4,724	4,475	4,267	4,079	4,971	5,082	5,200	4,781	4,760	4,821
	Jecheon	5,023	4,689	4,412	4,219	5,189	5,416	5,712	4,896	4,812	4,843
	Cheonan	4,813	4,539	4,385	4,218	4,952	5,142	5,404	4,730	4,798	4,847
	Cheongju	4,587	4,474	4,207	4,077	4,867	4,944	5,014	4,794	4,732	4,824
	Chungju	4,782	4,559	4,341	4,210	4,947	5,098	5,328	4,781	4,802	4,876
Gangwon Region	Gangneung	4,796	4,538	4,185	4,058	5,042	5,170	5,267	4,824	4,659	4,759
	Sokcho	5,236	4,813	4,334	3,986	5,492	5,703	6,064	5,058	4,749	4,513
	Wonju	4,777	4,594	4,335	4,177	4,952	5,088	5,321	4,820	4,724	4,799
	Inje	5,222	4,833	4,378	4,223	5,399	5,755	6,158	5,029	4,715	4,658
	Cheorwon	5,045	4,641	4,269	4,012	5,329	5,443	5,611	4,931	4,793	4,674
	Chuncheon	4,748	4,500	4,223	4,035	5,007	5,120	5,227	4,796	4,716	4,693
	Hongcheon	4,808	4,563	4,313	4,142	5,010	5,136	5,353	4,763	4,690	4,707
Average		4,752	4,520	4,287	4,151	4,969	5,124	5,318	4,783	4,765	4,840

Table A7. Regional estimation of rice yield considering temperature and CO_2 (Middle-ripening)

Unit: kg/ha

Region			Temperature(unfixed), CO_2 (fixed)			Temperature(fixed), CO_2 (unfixed)			Temperature, CO_2 (unfixed)		
		1971-2000	2011-2040	2041-2070	2071-2100	2011-2040	2041-2070	2071-2100	2011-2040	2041-2070	2071-2100
Gyeonggi Region	Seoul	4,316	3,986	3,653	3,476	4,719	5,048	5,260	4,350	4,277	4,235
	Suwon	4,574	4,217	3,789	3,660	4,982	5,278	5,390	4,596	4,429	4,480
	Yangpyeong	4,951	4,428	4,035	3,864	5,352	5,421	5,425	4,809	4,683	4,702
	Icheon	4,891	4,420	4,056	3,870	5,261	5,453	5,445	4,775	4,712	4,706
	Incheon	4,789	4,271	3,854	3,684	5,159	5,407	5,403	4,631	4,494	4,543
Gyeongsang Region	Geoje	4,610	4,183	3,910	3,825	4,961	5,182	5,442	4,539	4,549	4,715
	Geochang	5,174	4,549	4,120	3,847	5,543	5,545	5,518	4,917	4,768	4,670
	Gum	4,666	4,294	3,999	3,835	5,037	5,233	5,451	4,673	4,663	4,701
	Namhae	4,482	4,125	3,967	3,827	4,838	5,058	5,235	4,483	4,627	4,722
	Daegu	4,193	4,013	3,812	3,688	4,574	4,886	5,081	4,376	4,455	4,496
	Masan	4,002	3,785	3,591	3,630	4,370	4,668	4,868	4,137	4,184	4,360
	Mungyeong	4,925	4,471	4,133	3,959	5,289	5,489	5,461	4,841	4,806	4,829
	Miryang	4,445	4,219	3,946	3,754	4,814	5,053	5,166	4,599	4,601	4,593
	Busan	4,405	4,174	3,888	3,775	4,744	4,948	5,108	4,530	4,522	4,646
	Sancheong	4,577	4,146	3,988	3,789	4,950	5,171	5,349	4,512	4,641	4,632
	Andong	4,602	4,254	3,892	3,753	4,991	5,258	5,404	4,617	4,545	4,574
	Yeongdeok	5,351	4,730	4,250	3,907	5,468	5,442	5,432	5,070	4,877	4,741
	Yeongju	5,333	4,674	4,205	3,999	5,485	5,465	5,427	5,033	4,878	4,812
	Yeongcheon	4,752	4,298	4,003	3,849	5,142	5,348	5,506	4,667	4,652	4,683
	Ulsan	4,357	4,078	3,827	3,689	4,735	5,012	5,148	4,432	4,461	4,525
	Uljin	5,589	4,935	4,235	3,951	5,524	5,457	5,498	5,266	4,865	4,788
	Uiseong	4,819	4,350	4,080	3,874	5,205	5,425	5,459	4,713	4,735	4,305
	Jinju	4,370	4,064	3,824	3,758	4,741	5,034	5,157	4,438	4,463	4,590
	Pohang	4,366	4,100	3,858	3,738	4,746	5,038	5,188	4,472	4,510	4,588
	Hapcheon	4,522	4,200	3,997	3,804	4,902	5,131	5,273	4,573	4,664	4,657
Jeolla Area	Goheung	4,593	4,270	4,016	3,887	4,950	5,140	5,393	4,640	4,653	4,747
	Gwangju	4,294	4,058	3,826	3,751	4,669	4,982	5,161	4,427	4,466	4,608
	Gunsan	4,500	4,164	3,849	3,729	4,898	5,185	5,321	4,534	4,490	4,579
	Namwon	4,560	4,274	4,010	3,813	4,945	5,194	5,321	4,653	4,676	4,496
	Mokpo	4,394	4,149	3,959	3,799	4,753	5,016	5,123	4,521	4,631	4,691
	Buan	4,828	4,379	4,087	3,929	5,173	5,432	5,517	4,752	4,744	4,798
	Suncheon	4,375	4,040	3,892	3,706	4,758	5,042	5,155	4,406	4,531	4,513
	Yeosu	4,494	4,188	3,968	3,797	4,850	5,054	5,225	4,548	4,639	4,695
	Imsil	5,388	4,670	4,209	3,955	5,578	5,543	5,514	5,044	4,848	4,796
	Jangsu	5,731	4,972	4,252	3,939	5,619	5,581	5,545	5,374	4,907	4,785
	Jangheung	4,476	4,181	3,884	3,745	4,868	5,142	5,244	4,562	4,525	4,572
	Jeonju	4,258	4,021	3,802	3,733	4,651	4,976	5,177	4,396	4,452	4,541
	Jeongeup	4,554	4,208	4,001	3,871	4,922	5,140	5,315	4,576	4,656	4,462
	Haenam	4,607	4,262	4,029	3,920	4,986	5,187	5,388	4,636	4,686	4,816

Table A7 (Continued).

Unit: kg/ha

Region		1971-2000	Temperature(unfixed), CO_2 (fixed) 2011-2040	2041-2070	2071-2100	Temperature(fixed), CO_2 (unfixed) 2011-2040	2041-2070	2071-2100	Temperature, CO_2 (unfixed) 2011-2040	2041-2070	2071-2100
Chungcheong Region	Geumsan	4,954	4,438	4,054	3,897	5,333	5,506	5,482	4,813	4,710	4,743
	Daejeon	4,471	4,161	3,922	3,745	4,866	5,162	5,317	4,534	4,586	4,592
	Boryeong	4,844	4,497	4,046	3,892	5,194	5,408	5,388	4,862	4,690	4,770
	Boeun	5,385	4,741	4,192	3,934	5,464	5,433	5,412	5,110	4,833	4,760
	Seosan	4,757	4,298	3,953	3,726	5,178	5,451	5,478	4,678	4,618	4,593
	Jecheon	5,566	4,802	4,214	3,878	5,478	5,453	5,430	5,206	4,880	4,720
	Cheonan	4,819	4,397	4,085	3,925	5,180	5,417	5,409	4,752	4,737	4,772
	Cheongju	4,462	4,207	3,977	3,766	4,853	5,156	5,293	4,577	4,644	4,602
	Chungju	4,784	4,420	4,036	3,828	5,178	5,412	5,457	4,797	4,693	4,669
Gangwon Region	Gangneung	4,924	4,399	3,897	3,659	5,357	5,437	5,449	4,800	4,559	4,476
	Sokcho	5,485	4,989	4,163	3,635	5,438	5,410	5,346	5,405	4,866	4,442
	Wonju	4,992	4,478	4,061	3,836	5,373	5,448	5,427	4,845	4,720	4,675
	Inje	5,481	5,182	4,363	3,872	5,430	5,363	5,370	5,354	5,049	4,684
	Cheorwon	5,540	4,661	4,127	3,757	5,452	5,425	5,430	5,089	4,805	4,580
	Chuncheon	4,976	4,446	3,999	3,727	5,417	5,417	5,414	4,829	4,676	4,550
	Hongcheon	5,075	4,570	4,124	3,853	5,423	5,397	5,385	4,948	4,779	4,668
Average		4,775	4,354	3,998	3,806	5,087	5,261	5,345	4,722	4,651	4,631

Table A8. Regional estimation of rice yield considering temperature and CO_2 (Middle lately-ripening)

Unit: kg/ha

Region			Temperature(unfixed), CO_2 (fixed)			Temperature(fixed), CO_2 (unfixed)			Temperature, CO_2 (unfixed)		
		1971-2000	2011-2040	2041-2070	2071-2100	2011-2040	2041-2070	2071-2100	2011-2040	2041-2070	2071-2100
Gyeonggi Region	Seoul	4,882	4,319	3,959	3,827	5,278	5,579	5,674	4,640	4,406	4,256
	Suwon	5,207	4,465	4,045	3,825	5,623	5,842	5,893	4,809	4,534	4,299
	Yangpyeong	5,552	4,865	4,286	4,018	5,934	5,835	5,748	5,216	4,787	4,536
	Icheon	5,510	4,746	4,271	4,004	5,847	5,817	5,732	5,049	4,743	4,502
	Incheon	5,253	4,576	4,094	3,778	5,614	5,782	5,802	4,934	4,594	4,260
Gyeongsang Region	Geoje	4,801	4,289	4,013	3,848	5,142	5,285	5,467	4,617	4,522	4,363
	Geochang	5,754	4,889	4,343	3,959	5,994	5,866	5,784	5,270	4,877	4,505
	Gum	5,163	4,531	4,090	3,930	5,571	5,757	5,862	4,883	4,564	4,419
	Namhae	4,562	4,187	3,975	3,859	4,908	5,098	5,154	4,496	4,444	4,344
	Daegu	4,490	4,142	3,929	3,888	4,838	5,101	5,200	4,430	4,337	4,112
	Masan	4,179	3,984	3,902	3,859	4,478	4,741	4,906	4,202	4,184	4,152
	Mungyeong	5,519	4,817	4,292	4,063	5,880	5,905	5,819	5,152	4,798	4,579
	Miryang	4,732	4,312	4,059	3,930	5,114	5,372	5,416	4,643	4,542	4,380
	Busan	4,560	4,166	3,882	3,852	4,915	5,154	5,190	4,479	4,361	4,322
	Sancheong	4,898	4,376	4,058	3,892	5,281	5,483	5,587	4,701	4,531	4,351
	Andong	5,200	4,585	4,080	3,956	5,613	5,834	5,901	4,940	4,574	4,475
	Yeongdeok	5,692	5,041	4,325	4,074	5,943	5,845	5,766	5,362	4,823	4,586
	Yeongju	5,962	5,098	4,467	4,160	5,946	5,819	5,755	5,439	4,989	4,679
	Yeongcheon	5,242	4,598	4,210	3,966	5,658	5,856	5,882	4,952	4,740	4,511
	Ulsan	4,663	4,193	3,959	3,832	5,042	5,311	5,408	4,502	4,413	4,236
	Uljin	5,982	5,330	4,550	4,069	6,061	5,957	5,881	5,637	5,036	4,558
	Uiseong	5,475	4,826	4,303	4,007	5,884	5,951	5,868	5,193	4,834	4,533
	Jinju	4,669	4,209	3,949	3,937	5,060	5,343	5,452	4,525	4,414	4,369
	Pohang	4,730	4,289	3,982	3,871	5,110	5,374	5,443	4,604	4,446	4,328
	Hapcheon	4,865	4,428	4,096	3,912	5,247	5,464	5,539	4,771	4,596	4,410
Jeolla Region	Goheung	4,837	4,300	4,047	3,932	5,175	5,314	5,518	4,626	4,541	4,454
	Gwangju	4,529	4,126	3,957	3,918	4,902	5,174	5,312	4,416	4,407	4,315
	Gunsan	4,801	4,271	3,982	3,867	5,204	5,466	5,542	4,598	4,489	4,377
	Namwon	4,935	4,308	4,095	3,974	5,340	5,566	5,638	4,633	4,593	4,457
	Mokpo	4,438	4,147	3,971	3,929	4,794	5,042	5,111	4,467	4,474	4,426
	Buan	5,112	4,557	4,183	3,982	5,445	5,629	5,746	4,903	4,684	4,503
	Suncheon	4,756	4,249	4,036	3,979	5,155	5,404	5,507	4,558	4,492	4,416
	Yeosu	4,566	4,184	3,936	3,827	4,919	5,120	5,155	4,509	4,452	4,363
	Imsil	5,917	5,039	4,404	4,063	5,987	5,873	5,797	5,415	4,947	4,627
	Jangsu	5,830	5,521	4,583	4,083	6,119	6,003	5,941	5,975	5,220	4,745
	Jangheung	4,697	4,263	4,032	3,961	5,102	5,378	5,488	4,599	4,523	4,435
	Jeonju	4,488	4,166	3,955	3,943	4,859	5,160	5,324	4,472	4,390	4,352
	Jeongeup	4,838	4,420	4,056	3,992	5,202	5,354	5,491	4,752	4,544	4,309
	Haenam	4,856	4,332	4,028	3,956	5,220	5,380	5,533	4,681	4,535	4,514

Table A8 (Continued).

Unit: kg/ha

Region		1971-2000	Temperature(unfixed), CO_2 (fixed) 2011-2040	2041-2070	2071-2100	Temperature(fixed), CO_2 (unfixed) 2011-2040	2041-2070	2071-2100	Temperature, CO_2 (unfixed) 2011-2040	2041-2070	2071-2100
Chungcheong Region	Geumsan	5,475	4,760	4,185	3,967	5,882	5,956	5,866	5,127	4,705	4,495
	Daejeon	4,818	4,398	4,020	3,922	5,214	5,495	5,555	4,731	4,500	4,401
	Boryeong	5,347	4,668	4,153	3,909	5,665	5,851	5,777	5,001	4,667	4,369
	Boeun	6,094	5,221	4,459	4,024	5,967	5,845	5,779	5,598	5,002	4,569
	Seosan	5,199	4,563	4,082	3,903	5,616	5,849	5,852	4,932	4,586	4,442
	Jecheon	5,990	5,346	4,558	4,143	5,992	5,857	5,796	5,745	5,137	4,760
	Cheonan	5,371	4,757	4,203	3,975	5,722	5,851	5,769	5,078	4,658	4,440
	Cheongju	4,958	4,404	4,036	3,933	5,370	5,624	5,698	4,746	4,527	4,436
	Chungju	5,390	4,762	4,254	3,973	5,765	5,903	5,818	5,101	4,765	4,490
Gangwon Region	Gangneung	5,361	4,756	4,178	3,885	5,765	5,943	5,900	5,120	4,718	4,430
	Sokcho	5,964	5,427	4,558	4,014	6,138	6,013	5,931	5,787	5,141	4,601
	Wonju	5,698	4,947	4,316	4,060	5,992	5,861	5,798	5,312	4,817	4,586
	Inje	5,805	5,731	4,739	4,198	5,989	5,864	5,802	5,898	5,240	4,713
	Cheorwon	5,915	5,398	4,456	4,024	6,116	5,982	5,900	5,845	5,066	4,635
	Chuncheon	5,599	4,904	4,283	3,949	6,026	5,909	5,821	5,300	4,840	4,497
	Hongcheon	5,764	5,105	4,389	4,073	5,928	5,799	5,714	5,466	4,907	4,597
Average		5,180	4,623	4,168	3,958	5,501	5,615	5,637	4,961	4,666	4,451

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