STUDIES ON AGRICULTURE ADAPTATION TO CLIMATE CHANGE

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Abstract

Though the positive effects of adaptation strategies of agriculture to climate change have been confirmed in many studies, the nature and adaptation processes to climate are still poorly understood and rarely investigated directly. Most often, responses are simply assumed in impact research. It has been argued that adaptation to climate change is more likely in areas where are currently less climatically stressed, and the best way to adapt to some uncertain future climate is to improve adaptation to present day climate variability and reduce vulnerability to extreme events. Measures have been identified for agricultural adaptation to climate impact, but few of them have been actually evaluated and combined into strategies to meet given goals and objectives. Neither the costs nor the benefits of adaptation to climate change have been systematically studied so far.

Key Words: agricultural adaptation, climate change, impacts assessment

Running Head: Review of Agricultural Adaptation to Climate Change

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1 Introduction

Although forecasts of regional global warming are still far from precise, the warming expected by 2050, without any deliberate mitigation, is estimated by IPPC[1)] to be 1.4°C above the 1961-1990 average. About 0.25°C of this has already occurred by the 1990s. Observations in Europe have revealed that the average annual growing season (changes in phenology) of plant/crop has lengthened by 10.8 days since the 1960s, these shift can be attributed to changes in air temperature[2)]. Impacts are inevitable. Adaptation is necessary for society. However, it has received very little attention compared with mitigation, this may be partly because adaptation seems more complicated than mitigation, emission sources are relatively few, but the array of adaptation is vast, yet to ignore adaptation is both unrealistic and perilous[3)].

Adaptation refers to efforts to reduce system's vulnerabilities to climate. According to IPCC[4),] adaptation is concerned with responses to both the negative and positive effects of climate change. It refers to any adjustments – whether passive, reactive, or anticipatory – that can respond to anticipated or actual consequences associated with climate change. Thus it implicitly recognizes that future climate change will occur and must be accommodated in policy. Adaptation can be spontaneous or planned, and can be carried out in response to or in anticipation of changes in conditions. IPCC technical guidelines distinguish difference between autonomous adjustments and adaptation strategies. Autonomous adjustments are natural or spontaneous adjustments that will probably occur in response to climate change. In addition to autonomous adjustments, a wide range of responses can be implemented exogenously by management or policy decisions at the regional or national level. These adjustments are adaptation strategies[5)].

Many scientists and policy makers see adaptation as a powerful option by which to reduce the negative impacts of climate change or take advantage of the positive effects. As Burton[6)] pointed out, there are six reasons to adapt to climate change now.

1) Climate change cannot be totally avoided.
2) Anticipatory and precautionary adaptation is more effective and less costly than forced, last-minute, emergency adaptation or retrofitting.
3) Climate change may be more rapid and more pronounced than current estimates suggest. Unexpected events are possible.
4) Immediate benefits can be gained from better adaptation to climate variability and extreme atmospheric events.
5) Immediate benefits can also be gained by removing maladaptive policies and practices.
6) Climate change brings opportunities as well as threats. Future benefits can result from climate change.

Adapting to climatic variability will have a substantially greater effect in reducing impact than will mitigation. For example, reducing water demand shown in Table 1 as being reduced in each country by 5 and 10 per cent below current projections for 2050, reducing water demand by just 5% has four times as great an effect as reducing emissions by 30 per cent[3)].

Agriculture is the world's food and fiber-producing industry. It includes both traditional farming and intensive livestock and crop production. Agriculture also covers enterprises concerned with the development, manufacture and distribution of commodities such as animal feeds, crop seeds, fertilizers, agricultural chemicals, veterinary products and machinery. Among the most frequently cited human systems likely to be affected by climatic change are agriculture. It is especially sensitive to the consequences of global warming as it relies heavily on the weather and climate. Climate change presents a challenge for research the impact on agriculture, due to the global scale of likely impacts, the diversity of agricultural systems, and the decades-long time scale.

2 Proceedings on Agricultural Adaptation

More or less, at any time, adaptation to climate is always the topic of agriculture. For instance, agronomists are trying to develop crop/vegetation which can resist stress climate condition, and appropriate way to manage resources, *etc*. However, these generally treat climate as though it were constant over decades[6]. Climate change on average will go on slowly, but this by far means that climate change impacts will behave in a proper, linear manner. It is the changes in the statistics of extreme events, rather than in the mean temperature, that will probably have the strongest impact on human living conditions.

Earlier work of estimate of the impacts of climate change tested sensitivities and relied on disparate estimates of the impact on crop yields with very limited information for many areas of the world. The study relies on detailed crop growth models for specific geographical points, the results from these few points form the basis for extrapolating to states or provinces, nations and regions[7]. For example, Lin *et al*.[8] adopted ORYZA1, CERES-Wheat and CERES-Maize model to study the climate change impact on rice, wheat and maize at different geographical testing points in China. The impacts of climate change on crop yields are significant (Table 2). In general, yield of rice and maize are estimated to decrease, while wheat yield changes from -10~50% in three GCM scenarios due to different wheat species (winter wheat and spring wheat). Another approach is to use databases of global geographical information, such as global climate and soils, to estimate crop potential on the basis of the specific climate in each grid and estimates of how that climate will change[7]. For instance, Takahashi *et al*.[9] developed a GIS-based FAO's AEZ method and estimated the global staple crops yield between 1990 and 2100 by using global soil information and climate scenarios from seven GCM models (CCC, GISS, GFDL, GFDL R30, GFDL Q-flux, OSU, Ukmet) (Table 3). Soil phase, soil texture and land slope were considered in soil constraints in this study.

Rapid change of climate may seriously inhibit the ability of some crops to survive or to achieve desired yields in their current region without intervention. Therefore, a wide range of measures that would affect agricultural production systems should be implemented exogenously. Tremendous agricultural adaptation measures have been stated in previous studies and report[4,10-14]. Adaptation strategies for agricultural sector summarized by Carter[5] are as the followings.

1) Change topography of land
2) Use artificial systems to improve water use/availability and protect against soil erosion
3) Change farming practices
4) Change timing of farm operation
5) Use different crop varieties
6) Governmental and institutional policies and program
7) Research into new technologies

Findings from studies on agricultural adaptation to climate change impacts can be summarized in following catalogues.

2.1 Study on Crops Response

Studies on the impact of climate change on agriculture have been carried out in different country for various crops, such as maize, rice, wheat, cotton, groundnut and soybean[15-25]. The adaptation effects are found to be significant. For example, Seino[24, 25] found that maize yield and wheat yield significantly increased in Obihiro and Kitami, respectively, when adaptation measure of changing the planting date combined with irrigation was applied (Table 4). Similar result has also been found in Zimbabwe[21] by changing the planting date. These findings of the direct effect of physical change in climate on crop yield is an important step in understanding the impact of climate change on agriculture.

However this information as a whole, is not complete. Impacts on individual crops do not necessarily equal to impacts on agriculture due to complicated cropping system. Especially, most of the existing analyses examine the changes in crop yield in specific sites that are generated by changes in the physical climate. Studies of climate change impact by considering the mixture of different crops in different regions would provide more information for formulating agricultural adaptation policy.

2.2 Study on Policies

People have always adapted to climate, and many policies and practices are already in place. These policies generally treat climate as though it were constant over decades. Some existing agricultural and resource policies are likely to discourage effective adaptation, and are a source of current land degradation and resource misuse[26,27]. For example, study[26] in USA shows the agricultural sector could largely offset any negative impacts of climate change by altering production practices, assuming that the government will not create disincentives for farmers to adapt, however, adaptations measures such as rotating crops, investing in water conserving technologies, are often discouraged. Easterling[28] also hold these arguments.

Investment in research to develop new cultivars, cultural practices, and machinery, all specifically adapted to changing climate conditions, is a promising policy option. Investments to expand the range of farm management practices appropriate for changing climatic conditions also would be promising policy option. Policies that aim to increase resilience to short-term climatic variability (for example, drought, flooding, cold spells, and the like) incidentally will often improve resilience to possible changes of climate over the longer time[28]. Table 5 shows results of a 1992 survey of more than 2000 agronomists and plant breeders in China[29]. The researchers were asked which constraints contributed to the gap between actual yields and the highest experimental yields for the three major grain crops. Differences in crop characteristics, such as plant architecture, photosynthetic efficiency, time to maturity, and so on, had the largest impact, accounting for about half of the yield differences due to genetic constraints (different species of same crop) for all three crops. Differences in environmental conditions had the second most important impact on yield between experimental fields and average farmers' fields; factors included selection of planting date, soil moisture management, *etc*. Soil conditions, pests, diseases, and weeds accounted for the rest of the yield differences.

Drought is perhaps the most important abiotic stress limiting crop productivity around the world. One of the most effective ways to alleviate problems of crop production associated with drought is the development of crops that withstand moisture stress. However, as Gebisa *et al*.[30] pointed out, Identification and testing of drought resistant germplasm in a plant breeding program is an arduous and slow process. Drought tolerance is a complex trait; the genetic and physiological mechanisms that condition its expression are poorly understood. Controlled by many genes and dependent on the timing and severity of moisture stress, it is one of the most difficult and seemingly intractable agronomic traits to characterize and study. Efforts have been made to individual genetic factors and their functions in determining complex [30-34]. However, the results are still not optimistic. Many biotic and abiotic factors are even frequently misinterpreted as expressions of drought tolerance[35]. Under the expected changing climate, the stress of climate may be more severe, at least, increasing temperature would worsen the drought severity. Efforts to breed stress resistance cultivars must be consider the expected changing climate. The other problem associated with the creation of new varieties that are better adapted to the future climatic conditions is that the seed companies are underlain current economic strains that may act preventive in that respect.

2.3 Study on Land-Use Change

Agricultural production as a process varies spatially and temporally. By altering temperature and precipitation patterns, climate change will shift the production possibilities associated with land and water resources in most areas. Shifts in the distribution of agricultural land use may be more complex than simply moving a particular mixture of land use to another location. These shifts, combined with changing economic conditions, will alter the nature of competition for land and water resources, and resulting land-use changes are likely to alter patterns of agricultural production. Questions may arise as to what represents an optimal mixture of land use in a region after climate change. Simply simulation of crop yield change does provides some information for country's policy to climate change, but detailed information such as, where, when, and how climate change imposes negative impact on country's agricultural production must be provided. Wu[36] made an attempt to simulate the climate change impact on China's cropping system, the conclusion is the cropping systems in China almost no changes, although cropping season becomes earlier and harvesting season becomes later in the region to the north of Yangtze River in China. The limitation of this analysis lies in that only accumulated active temperature was considered as the index for simulation, the critical factor of water was excluded.

2.4 Study on Seawater Invasion

Agricultural production relies on land. The rising of the sea level due to temperature increase will inundate some land in coastal areas, and the invasion of seawater will decrease the land quality for crop production. Current studies[37-41] on sea level rise emphasize on non-agricultural impacts, such as on population and urban construction. Much cultivated land is distributed along the coastal areas, and for many countries, the coastal region is a major crop-growing area. Attention must be paid to an inundation of seawater threatening land resources, which are the basis of agricultural production.

2.5 Study on Consumer and Producer Behavior

Changing agricultural production patterns require changing consumption patterns. Tastes, habits, prices and incomes are four important factors affecting the behavior of both consumers and producers. Producers are most affected by their past investment decisions. On all but the production side of agriculture, consumers have a strong influence on agricultural adaptation to climate impact. Politicians aren't the only people whom researchers must win over in making a case for what life may be like in a warming world[42].

Rosenzweig *et al*.[43] pointed out that agriculture's response to climate change will depend not only on the new climate conditions facing farmers and agriculture's interactions with domestic sectors, but also on the responses of producers and consumers around the world, as signaled through prices determined in global markets. Brown[42] holds the same opinion that the effects of climate look totally different when people's behaviors are considered. Study in Sweden[44] that present patterns of consumption and production for fresh vegetable are unlikely to be sustainable; the consumption of one kg of tomatoes affects climate change approximately 10 times more than the consumption of the same quantity of carrots.

2.6 Study on Global Trade

By altering temperature and precipitation conditions on a global scale, climate change threatens to shift national and world patterns of comparative advantage in the production of many crop and livestock products. The response of a country's agriculture to climate change, then, will depend not only on how domestic farmers adapt to new environmental conditions, but also on a host of other factors that affect national and international commodity markets, for farms are linked with consumers, locally and around the world. Studies[45-48] based on developed regions situations show that interregional adjustments in production and consumption will serve to buffer the severity of climate change impacts on world agriculture and result in relatively small impacts on domestic economy from doubled CO2 Climate.

Rosenzweig and Parry[43] used a world food trade model to simulate the economic consequences of these potential changes in crop yields, and estimated changes in world food prices and in the number of people at risk of hunger in developing countries. Their major finding was that there appears to be a large disparity in agricultural vulnerability to climate change between developed and developing countries. This occurs even though the declines of simulated global agricultural production of major grain crops are only small to moderate under the climate change conditions. Their work was the first extensive effort to produce a consistent estimate of the impacts of climate change worldwide from specific GCM scenarios[7]. Fischer *et al*.[49] obtained similar results in their study, finding that the loss of production in developing countries, together with rising agricultural prices, is likely to increase the number of people at risk of hunger, on the order of 5-50% depending on GCM scenario.

There are competing and widely divergent views on the extent to which adaptation can succeed in preventing potentially adverse effects on the global balance between food supply and demand, which determines food prices – a key indicator of overall agricultural vulnerability. Trade is a mutual behavior, the ability of developing nations to pay world prices is questionable; therefore, global trade as an adaptation strategy remains questionable. The ability to estimate climate change impacts on world food supply, demand and trade is surrounded by large uncertainties with regard to such important aspects as the magnitude and spatial characteristics of climate change, the magnitude of benefits from atmospheric CO_2 enrichment, the potential for pest damage to crops, imprecise understanding of the regional effects of climate change on crops and the unexplored but probably large effects of change in climate variability and extreme events on crops, the range and efficiency of adaptation possibilities, the long-term aspects of technological change and agricultural productivity, and even future demographic trends. So, what is needed are more accurate predictions in future climate, individual crop yield, and technological prediction.

3 Proceedings on Adaptation Strategies Evaluation

IPCC technical guidelines[4)] distinguish between autonomous adjustments and adaptation strategies. Autonomous adjustments are natural or spontaneous adjustments that will probably occur in response to climate change. In addition to autonomous adjustments, a wide range of responses can be implemented exogenously by management or policy decisions at the regional or national level. These adjustments are adaptation strategies. Tol *et al*.[50)] grouped adaptation further into four categories: no adaptation, arbitrary adaptation, observed adaptation (analogues) and modeled adaptation (optimization). Schimmelpfennig *et al*.[51)] distinguished agricultural adaptation to climate change at three levels: (1) farm-level adjustments to climate change; (2) national adjustments to climate change; and (3) global adjustments to climate change. Fischer *et al*.[49)] group the adaptation measures at the farm level further into two levels. Level 1 implies little change to existing agricultural systems, reflecting relatively easy and low-cost farmer response to a changing climate. Level 2 implies more substantial changes to agricultural systems, possibly requiring resources beyond the farmer's means.

Agricultural adaptation to climate change at the farm level depends on the technological potential (different varieties of crops, irrigation technologies); basic soil, water, and biological response; and the capability of farmers to detect climate change and undertake any necessary actions. Climatic variability is a feature of current climate in most geographic areas. This variability may make it difficult for farmers to readily detect climate change and respond appropriately.

At the national level, government policies and programs, ranging from crop insurance and disaster assistance to acreage reduction programs, tariffs and quotas, and the level of agricultural research, will affect the farm sector's response to climate change by affecting the economic incentives for farmers (and others) to adapt and the technological options with which they can adapt.

3.1 Methods for Assessing Climate Impact on Crops

Climate change presents a challenge for research due to the global scale of likely impacts, the diversity of agricultural systems, and the decades-long time scale. Current climatic, soil, and socioeconomic conditions vary widely across countries and the world. Each crop and crop variety has specific climatic tolerances and optima. It is not possible to model world agriculture in a way that captures the details of plant responses in every location. Two basic methods have been used to estimate the effect of climate on crop production[51)]: (1) structural modeling of crop and farmer responses, combining the agronomic response of plants with the economic/management decisions of farmers; and (2) spatial analogue models that exploit observed differences in agricultural production and climate among regions.

The first approach is called crop response model. Sufficient structural detail is needed to represent specific crops and crop varieties, whose responses to different conditions are known through detailed experiments. Similar detail on farm management allows direct modeling of the timing of field operations, crop choices, and how these decisions affect costs and revenues. The advantage of this approach is that it provides a detailed understanding of the physical, biological, and economic responses and adjustments. A major disadvantage is that for aggregate studies, heroic inferences must be made from a relatively few sites and crops to large areas and diverse production systems.

The spatial analogue approach may involve statistical estimation using cross-section data, and is basically an elaboration of the case study approach. Statistical analysis of data across geographic areas allows researchers to separate out factors that explain production differences across regions. The statistical approach provides direct evidence on how commercial farmers have responded to different climatic conditions. Statistical estimation allows for factors that crop response models do not routinely consider, such as land quality, but relies on data being representative and on the ability of statistical analysis to isolate confounding effects. A potential serious limitation of this approach is that large and widespread climate change could cause crop prices to change for prolonged periods all around the world. In this case, the impact of climate change on land values would be estimated incorrectly because it is based on information for incremental change. The degree and direction of error would depend on how prices changed.

Mendelsohn *et al*.[52] described the Ricardian method, which compares actual farmer behavior across different climates, and explore a new application of the Ricardian method capturing how climate affects both per acre value of farms and how much land is farmed. These empirical relationships are used to predict the agricultural impacts of simple climate warming scenarios. The approach adopted by Antle[53] in his study on methodological issues in the assessing the potential impacts of climate change on agriculture is based on a model of function of spatial heterogeneity of the physical environment, technology, prices of inputs and outputs, and policy variables. Using this model, it is possible to discuss a number of key issues that arise in modeling the impacts of and adaptation to climate change.

3.2 Proceedings on Adaptation Strategies Evaluation

A single accepted set of procedures has not been established for formulating regional or national polices for adapting to climate change. This situation is probably due in part to the large difference in priorities between different regions; furthermore, assessing adaptation options involves value adjustments, which are subjective and can be controversial. Parry *et al*. [54] provide a guideline for assessing climate change adaptations (Figure 1).

All methodologies address the need to measure the effectiveness of the adaptation and to incorporate the information into a concise form usable by decision-makers. Approaches that can be used to help assess the effectiveness of adaptation strategies are cost-benefit analyses, cost-effectiveness analysis and multicriteria assessment[55,56], The complexity of dealing with conflicting objectives and multiple criteria is recognized as one of the most difficult issues in conducting adaptation analyses. Analytic techniques are used to assess the benefits and costs of each measure and evaluate barriers to implementation.

3.2.1 Costs and Benefits

Neither the costs nor the benefits of adaptation to climate change have been systematically studied so far. Very limited cases of cost-benefit analysis are based on assumption that there are no changes of social-economic circumstance except for the climate. This is not the true case. For instance, studies on the impact of global change on agriculture in China[16,17] simply estimated the extra investment based on the current investment level on agricultural production under current climate conditions, and found that with rises in temperature and changes in precipitation (mostly decreases, but some increases), the maximum production would probably drop by at most 10%. To meet the demand from an increasing population, the additional investment for dealing with climate variation would be 4%, 9% and 17% over the investment in agriculture in 1990 for the years 2000, 2020 and 2050, respectively.

Assessments of climate change costs usually ignore the costs of transition and concentrate on the equilibrium impact of climate change. This ignores the fact that doubled CO2 may not be the equilibrium at which the atmospheric greenhouse gas concentration is eventually stabilized, and that, in all likelihood, concentration levels and climate will continue to change in the foreseeable future. The classification of climate change costs by Tol *et al*.[50] gave a nice example (Table 6).

3.2.2 Cost-effectiveness analysis

The cost-benefit analysis is the best to study the effectiveness of adaptation options, however, in most cases, it is very difficult to calculate the benefit from adaptation measures for agriculture, for most of the adaptation measures has benefits not only on agriculture. For example, long distance transfer of water have not only positive effects on agriculture, but also on industry, urban residual, environment, *etc*. Therefore, for identifying the effectiveness of adaptation measures, cost-effectiveness method was adopted.

3.2.3 Implementation of Adaptation Strategies

The implementation of appropriate adaptation strategies is the desired outcome of adaptation assessments. It is also the activity that involves the most risk, both financially and politically. Proper communication of adaptation assessment results to decision-makers and the public is crucial in moving to successful implementation. The most acceptable adaptation strategies are likely to be those that have other economic benefits beyond what is to be gained by forestalling damage from climate change or have minimal costs.

The most effective strategies are likely to be to reduce present vulnerability and to enhance a broad spectrum of capacity in responding to environmental, resource and economic perturbations[57)]. There are many kinds of 'win-win' solutions that serve both our present and future needs, such as increasing irrigation efficiency, breeding more drought-resistant crops and developing buffer stocks of food. For example, increasing irrigation efficiency, breeding more drought-resistant crops and developing buffer stocks of food, for example, study[58)] in Loess Plateau, China, shows that water use efficiency increased from 7.8~8.4 kg per mm water to 11.0~13.1 kg/per mm water when soil organic content is increased from 0.76% to 1.2%. Horie[59)] found that rice yield increase by 23-26% in Sapporo, Japan, by increasing new cultivar and advanced planting date.

Can agriculture adapt to relatively rapid future changes in climate? The answer from Easterling[60)] in his review of North American agriculture is that it depends on a number of factors. The capacity of different regions to adapt to climate variability differs greatly. In general, developed regions are better equipped to resist climate variations than developing regions[61)]. In developing countries, overall social, environmental and economic vulnerability enhances the effects of droughts and other climatic events. Overpopulation, poverty, and land degradation translate into a poor capacity to face any kind of crisis. As a result, these regions have difficulty in facing climatic crises, although such crises are recurrent. Any extreme climatic event can become a social catastrophe when combined with the social-political characteristics of a region. Financing could become an issue if protection expenditures grew too large[62)]. Evaluation and selection of suitable adaptation strategies for developing countries must consider the local situation. The best way to adapt to an uncertain future climate is to improve adaptation to present day climate variability and reduce vulnerability to extreme events[3,50,57,63)]. However, this is not always being accepted in many developing regions. People there conduct their economic activities considering the short-term economic benefits more, for extreme events do not happen every year.

4 Conclusions

The effects of adaptation strategies have been estimated based on assumptions or calculated based on field experiment in many studies. In most cases, the adaptation strategies can offset the negative effects of climate change. Many studies agree that adaptation to climate change is more likely in areas where are currently less climatically stressed. The best way to adapt to some uncertain future climate is to improve adaptation to present day climate variability and reduce vulnerability to extreme events. The extent of their adaptation depends on the affordability of adaptive measures, accessing to technology, and biophysical constraints such as land and water resource availability, soil characteristics and genetic diversity for crop breeding (e.g. crucial development of a heat-resistance rice cultivar), and topography. Therefore, study on agricultural adaptation to climatic change must be based on the country level rather than the global or regional level, in which the negative effects in some countries may be overlooked.

Notwithstanding this growing recognition of the role of human agency, relatively few impact studies have considered the actual processes of adaptation to climate in detail. Most often, it is simply assumed that systems will either adjust or not adjust to the scenarios specified, although some empirical studies have focused more directly on adaptation of how, when, why, and under what conditions adaptation actually occurs in economic and social systems[64)]. Analyses that do address adaptation use a variety of interpretations and perspectives resulting in an incomplete, and at times inconsistent, understanding of human adaptation to environmental variations[50,64,65)].

The uncertainty is poorly represented in existing studies of climate change impacts, including (1) uncertainty in agricultural/economic climate change models, and (2) behavioral responses and adaptation to uncertainty in the agricultural impact of climate change[66)]. As Reily[67)] pointed out, one of existing issues in climate change study is the timing of expected climate changes. Rosenzweig and Parry[43)] assume that 4.0 ℃ to 5.2 ℃ scenario will occur in 2060, but most recent IPCC work suggests the mean estimate for 2060 closer to 1.5 ℃.

Some measures have been identified for agricultural adaptation to climate impact, but few of them have been actually evaluated and combined into strategies to meet given goals and objectives. Some major categories of adaptation, such as insurance, disaster assistance, and changes in land use and location, receive little or no attention in the adaptation options described in IPCC reports[6)]. Competition for resources from other sectors and other resources changes are not well considered in adaptation study.

5 Discussion

There are tremendous agriculture adaptation measures, each of them may suitable for different regions according to different social economic conditions. The parameterization of agriculture adaptation measures is another important study sector for climate impact on agriculture by considering the adaptation measures. Collection and extrapolation of information from certain specific sites are third research sectors. These includes behavioral change of both producers and consumers. Very few studies have evaluated the economic or social effects of changes in crop production[68)]. On comments to Rosenzweig and Parry's work, Reily[7)] pointed out that the focus on crops that are staples of temperature agriculture may have led to an overestimate of the negative impacts in tropical regions.

The results of a large number of experiments have confirmed a beneficial effect of elevated CO_2 on crops[69)]. CO_2 fertilization effects have been considered in some studies[43,46,70)] and shown that the effects of potential CO_2 fertilization are dramatic. However, scientific controversy remains concerning this effect. Scientists studying the physiological effects of CO_2 have raised a number of questions. Such as field responses may different from the experimental response. The assessment of the relative contributions of the direct effects of CO_2 (parameter value changes in some models) remains a crucial research question.

The model predictions of future greenhouse warming are still uncertain to within around 50 per cent. The bottleneck in the development of an effective climate policy is not so much the uncertainty of climate predictions as out lack of understanding of the interactions of climate change, the environment and the global socioeconomic systems. To analyse the problem of transferring climate research into climate policy, we need to develop models of the interactions between the climate, social and economic subsystems of the complete coupled system[71)]. To avoid the misleading assessments of - and inappropriate adaptation strategies to - climate change impact, future studies should consider the impacts of natural multi-decadal climate variability alongside those of human-induced climate change, as study[72)] of river runoff and agricultural potential in Europe shows that, in some regions, the impacts of human-induced climate change by 2050 will be undetectable relative to those due to natural multi-decadal climate variability, but this by far means that all other impacts will behave in a proper, linear manner, it is the changes in the statistics of extreme events, rather than in the mean temperature, that will probably have the strongest impact on human living conditions[73)].

Reference

1) IPCC (1996). *Climate Change 1995: The Science of Climate Change*. Cambridge University Press, Cambridge.

2) Menzel, A. and P. Fabian (1999). Growing season extended in Europe. *Nature*, 397: 659.

3) Parry, M., N. Arnell, M. Hulme, R. Ncholls and M. Livermore (1998). Adapting to the inevitable. *Nature*, 395, 741

4) IPCC (1996). *Climate Change 1995: Impacts*, *Adaptation and Mitigation of Climate Change: Scientific-Technical Analyses*, 831. Cambridge University Press, Cambridge, UK.

5) Carter, T. R. (1996). Assessing climate change adaptations: the IPCC Guidelines. In: J.B. Smith *et al*. (ed.). *Adapting to Climate Change: An International Perspective*, 27-43.

6) Burton, I. (1996). The growth of adaptation capacity: Practice and policy. In: J.B. Smith *et al*. (ed.). *Adapting to Climate Change: An International Perspective*, 55-67.

7) Reily, J. (1994). Crops and climate change. *Nature*, 367:118-119.

8) Lin, E. D., H. X. Zhang and J. H. Wang (1997). *Simulation of global climate change impact on China's agriculture*. 54-87. China Agricultural Press, Beijing.

9) Takahashi, K., H. Harasawa and Y. Matsuoka (1997). Climate change impact on global crop production. *Journal of Global Environment Engineering*, 3: 145-167.

10) IPCC (1998). *The Regional Impacts of Climate Change: An Assessment of Vulnerability*, Cambridge University Press.

11) Smit, B., D. McNabb and J. Smithers (1996). Agricultural Adaptation to Climatic Variation. *Climatic Change*, 33:7-29.

12) Jodha, N. S. (1989). Potential strategies for adapting to greenhouse warming: Perspectives from the developing world. In: N. J. Rosenberg *et al*. (ed.). *Greenhouse Warming: Abatement and Adaptation*, *Resources for the Future*. Washington, DC, 147-158

13) Rosenberg, N. J. (1992). Adaptation of agriculture to climate change. *Climatic Change*, 21:385-405.

14) Toman, M. and R. Bierbaum (1996). An overview of adaptation to climate change. In: J. B. Smith *et al*. (ed.). *Adapting to Climate Change: An International Perspective*, 5-15.

15) Easterling, III, W. E., P. R. Crosson, N. J. Rosenberg, M. S. Mckenney, L. A. Katz and K. M. Lemon (1993). Agricultural impacts of and responses to climate change in the Missouri-Iowa-Nebraska-Kansas (MINK) Region. *Climatic Change* 24:23-61.

16) Tao, Z. (1993). Influences of global change on agriculture of China. In: *Climate Biosphere Interactions*, John Wiley & Sons, Inc., New York.

17) Lin, E. D. (1996). Agricultural vulnerability and adaptation to global warming in China. *Water*, *Air*, *& Soil Pollution*, Kluwer Academic Publishers.

18) Wang, J. H. and E. D. Lin (1996). The impact of potential climate change and climate variability on simulated maize production in China. *Water*, *Air*, *and Soil Pollution*, 92:75-85.

19) Bayasgalan, Sh., B. Bolortsetseg, D. Dagvadorj and L. Natsadorj (1996). The impact of climate change on spring wheat yield in Mongolia and its adaptability. In: J.B. Smith *et al*. (ed.). *Adapting to Climate Change: An International Perspective*, 164-173.

20) El-Shaer, M. H., H. M. Eid, C. Rosenzweig, A. Iglesias and D. Hillel (1996). Agricultural Adaptation to Climate Change in Egypt. In: J.B. Smith *et al*. (eds.), *Adapting to Climate Change: An International Perspective*, 109-127.

21) Matarira, C. H., F. C. Mwamuka and J. M. Makadho (1996). Adaptive measures for Zimbabwe's agricultural sector. In: J.B. Smith *et al*. (ed.). *Adapting to Climate Change: An International Perspective*, 129-147.

22) Mizina, S. V., I. B. Eserkepova, O. V. Pilifosova, S. A. Dolgih and E. F. Gossen (1996). Model-based climate change vulnerability and adaptation assessment for wheat yields in Kazakhstan. In: J.B. Smith *et al*. (eds.), *Adapting to Climate Change: An International Perspective*, 149-163.

23) Zhang, Y., L. H. Wu, X. L. Wang, Z. Q. Jin and Q. G. Wu (1997). Climatic change impact on yield of main crops in China. In: E. D. Lin *et al*. (ed.). *Simulation of global climatic change impact on China agriculture*, China agricultural Science and Technology Press (in Chinese).

24) Seino, H. (1999). The impacts of climatic warming on cereal crop production in Japan. *J. Agric. Meteorol*., 51: 131-138 (in Japanese with English summary)

25) Seino, H., M. Amano, and K. Sasaki (1998). Impacts on Agriculture, Forestry and Fishery. In: Nishioka *et al*. (ed.), *Global Warming: The Potential Impact on Japan*. 101-129.

26) Lewandrowski, J. K. and R. J. Brazee (1993). Farm programs and climate change. *Climatic Change*, 23:1-20.

27) Amadore, L., W. C. Bolhofer, R. V. Cruz, R. B. Feir C. A. Freysinger, S. Guill, K. F. Jalal, A. Iglesias, A. Jose, S. Leatherman, S. Lenhart, S. Mukherjee, J. B. Smith and J. Wisniewski (1996). Climatic change, vulnerability and adaptation in Asia and the Pacific: Workshop summary. *Water*, *Air*, *and Soil Pollution*, 92:1-12.

28) Easterling, III, W. E., M. L. Parry and P. R. Crosson (1988). Adapting future agriculture to changes in climate. In: N. J. Rosenzweig *et al*. (ed.). *Greenhouse Warming: Abatement and Adaptation*, RFF, Proceedings of a workshop held in Washington, D.C., June 14-15. 91-104.

29) Lin, J. Y. (1998). *How did china feed itself in the past? How will china feed itself in the future?* Second distinguished economist lecture. Mexico, D. F.: CIMMYT.

30) Gebisa, Ejeta, Mitchell R. Tuinstra, Edwin M. Grote, and Peter B. Goldsbrough (1999). Genetic Analysis of Pre-Flowering and Post-Flowering Drought Tolerance in Sorghum. *Workshop on Molecular Approaches for the Genetic Improvement of Cereals for Stable Production in Water-Limited Environments*. CIMMYT headquarters, Mexico, Mexico, June 21-25, 1999 Preliminary papers.

31) Andrew K. Borrell, Yuezhi Tao and C. Lynne McIntyre (1999). Physiological basis, QTL and MAS of the stay-green drought resistance trait in grain sorghum. *Workshop on Molecular Approaches for the Genetic Improvement of Cereals for Stable Production in Water-Limited Environments*. CIMMYT headquarters, Mexico, Mexico, June 21-25, 1999 Preliminary papers.

32) Bidinger, F. R., S. Chandra, and V. Mahalakshmi (1999). Genetic Improvement of Tolerance to Terminal Drought Stress in Pearl Millet (*Pennisetum glaucum* (L.) R. Br.). *Workshop on Molecular Approaches for the Genetic Improvement of Cereals for Stable Production in Water-Limited Environments*. CIMMYT headquarters, Mexico, Mexico, June 21-25, 1999 Preliminary papers.

33) Li Zhikang, L. S. Shen, B. Courtois, R. Lafitte (1999). Development of near isogenic introgression line (NIIL) sets for QTLs associated with drought tolerance in rice . *Workshop on Molecular Approaches for the Genetic Improvement of Cereals for Stable Production in Water-Limited Environments*. CIMMYT headquarters, Mexico, Mexico, June 21-25, 1999 Preliminary papers.

34) Yadav, R. S., C. T. Hash, F. R. Bidinger, and C. J. Howarth (1999). Identification and utilization of quantitative trait loci to improve terminal drought tolerance in pearl millet (*Pennisetum glaucum* (L.) R. Br.). Workshop on Molecular Approaches for the Genetic Improvement of Cereals for

Stable Production in Water-Limited Environments. CIMMYT headquarters, Mexico, Mexico, June 21-25, 1999 Preliminary papers.

35) Richard, T and W. H. Pfeiffer (1999). Challenges and Future Strategies in Breeding Wheat for Adaptation to Drought Stressed Environments: A CIMMYT Wheat Program Perspective. Workshop on Molecular Approaches for the Genetic Improvement of Cereals for Stable Production in Water-Limited Environments. CIMMYT headquarters, Mexico, Mexico, June 21-25, 1999 Preliminary papers.

36) Wu, L. H. (1997). Simulation of climate change impact on China's cropping system. In: Lin *et al*. (ed.), *Simulation of global climate change impacts on China's agriculture*. China agricultural press, Beijing. (in Chinese)

37) Teves, N., G. Laos, S. Carrasco, C. San Roman, L. Pizarro, G. Cardenas and A. Romero (1996). Sea-level rise along the Lima coastal zone, Peru, as a result of global warming: environmental impacts and mitigation measures. In: J. B. Smith *et al*. (ed.). *Adapting to Climate Change: An International Perspective*, 283-298.

38) Jallow, B. P. (1996). Response strategies and adaptive measures to potential sea-level rise in the Gambia. In: J. B. Smith *et al*. (ed.). *Adapting to Climate Change: An International Perspective*, 299-310.

39) Huang, J. C. K. (1996). Climate change adaptation strategies: A challenge for small island nations. In: J. B. Smith *et al*. (ed.). *Adapting to Climate Change: An International Perspective*, 311-321.

40) Rijsberman, F. R. and A. van Velzen (1996). Vulnerability and adaptation assessment of climate change and sea-level rise in the coastal zone: A perspective from the Netherlands and Bangladesh. In: J. B. Smith *et al*. (ed.). *Adapting to Climate Change: An International Perspective*, 322-334.

41) Al-Farouq A. and S. Huq (1996). Adaptation climate change in the coastal resources sector of Bangladesh: Some issues and problems. In: J. B. Smith *et al*. (ed.). *Adapting to Climate Change: An International Perspective*, 335-344.

42) Brown, K. S. (1999). Taking global warming to the people, *Science*, 283,1440-1441.

43) Rosenzweig, C. and M. L. Parry (1994). Potential Impact of Climate Change on World Food Supply. *Nature*, 367, 133-138.

44) Annika, Carlsson-Kanyama (1998). Food consumption patterns and their influence on climate change. *Ambio*, 27(7):528-534.

45) Reily, J. and N. Hohmann (1993). Climate change and agriculture: the role of international trade. *Economic Modeling of Greenhouse Warming*, 83(2): 306-312.

46) Reily, J. N. Hohmann and S. Kane (1994). Climate Change and Agricultural trade: who benefits, who loses? *Global Environmental Change*, 4(1) 24-36.

47) Goklany, I. M. (1995). Strategies to enhance adaptability: technological change, sustainable growth and free trade. *Climatic Change*, 30:427-449.

48) Adams, R. M., R. A. Fleming, C. C. Chang, B. A. McCarl and C. Rosenzweig (1995). A reassessment of the economic effects of global climate change on U.S. agriculture. *Climatic Change*, 30:147-167.

49) Fischer, G., K. Frohberg, M. L. Parry and C. Rosenzweig (1994). Climate change and world food supply, demand and trade: who benefits, who loses? *Global Environmental Change*, 4(1) 7-23

50) Tol, R. S. J., S. Fankhauser and J. B. Smith (1998). The scope for adaptation to climate Change: what can we learn from the impact literature? *Global Environmental Change*, 82(2): 109-123.

51) Schimmelpfennig, D., J. Lewandrowski, J. Reilly, M. Tsigas and I. Parry (1996). *Agricultural adaptation to climate change: Issues of longrun suitability*, Washington, DC, AER-740.

52) Mendelsohn, R., W. Nordhaus and D. Shaw (1996). Climate impacts on aggregate farm value: accounting for adaptation. *Agricultural and Forest Meteorology*, 80: 55-66.

53) Antle, J. M. (1996). Meteorological issues in assessing potential impacts of climate change on agriculture, *Agricultural and Forest Meteorology*, 80:67-85.

54) Parry, M. and T. Carter (1998). *Climate Impact and Adaptation Assessment*. Earthscan Publication Ltd., London.

55) Smith, J. B., S. E. Ragland and G. J. Pitts (1996). A process for evaluating anticipatory adaptation measures for climate change. *Water*, *Air*, *and Soil Pollution*, 92:229-238.

56) Smith, J. B. and N. Bhatti (1996). Rapporteur's Statement. In: J. B. Smith *et al*. (ed.). *Adapting to Climate Change: An International Perspective*, 3-4.

57) Downing, T. E., L. Ringlus, M. Hulme and D. Waughray (1997). Adapting to climate change in Africa. *Mitigation and Adaptation Strategies for Global Change*, 2:19-44.

58) You, M, and H. Wang (1996). Assessment on soil water resources, Meteorological Publication House, Beijing, China, pp. 119 -138.

59) Horie, T. (1988). The effect of climatic variations on rice yield in Hokkaido, In: M. L. parry *et al*. (eds.), The Impact of Climatic Variation on Agriculture, 1. Assessment in Cool Temperate and Cold Regions, Kluwer Academic Publishers, Dordrecht, 809-825.

60) Easterling, W. E. (1996). Adapting North American agriculture to climate change in review. *Agricultural and Forest Meteorology*, 80:1-53.

61) Magalhaes, A. R. (1996). Adapting to climate variations in developing regions: a planing framework. In: J. B. Smith *et al*. (ed.). *Adapting to Climate Change: An International Perspective*, 44-54.

62) Yohe, G. (1997). Planning for sea level rise and shore protection under climate uncertainty. *Climatic Change*, 37:243-270.

63) Burton, I. (1997). Vulnerability and adaptive response in the context of climate and climatic change. *Climatic Change*, 36:185-196.

64) Smithers, J. and B. Smit (1997). Human adaptation to climate variability and change. *Global Environmental Change*, 7(2): 129-146.

65) Carter, T. R., M. L. Parry, H. Harasawa and S. Nishioka (1994). *IPCC Technical Guidelines for Assessing Climate Change Impacts and Adaptations*, WMO/UNEP, Geneva.

66) Schimmelpfennig, D. (1996). Uncertainty in economic models of climate change impacts. *Climatic Change*, 33:235-274.

67) Reily, J. (1995). Climate change and global agriculture: recent findings and issues. *American Journal of Agricultural Economics*, 77:727-733.

68) Eglesias, A., E. D. Lin and C. Rosenzweig (1996). Climatic change in Asia: A review of the vulnerability and adaptation of crop production, *Water*, *Air*, *and Soil Pollution*, 92:13-27.

69) IPCC (1996). *Climate change 1995*, *the IPCC second Assessment Report*, *Volume 2: Scientific-Technical Analyses of Impacts*, *Adaptations*, *and Mitigation of Climatic Change*. Cambridge University Press.

70) Mendelsohn, R., W. D. Nordhaus and D. Shaw (1994). The impact of Global warming on agriculture: A Ricardian Analysis. *The American Economic Review*, 84(4): 753-771.

71) Hasselmann, K. (1997). Climate Change research after Kyoto. *Nature*, 390, 225-226.

72) Hulme, M., E. M. Barrow, N. W. Arnell, P. A. Harrison, T. C. Johns and T. E. Downing (1999). Relative impacts of human induced climate change and natural climate variability. *Nature*, 397, 688-691.

73) Hasselmann, K. (1999). Linear and nonlinear signatures. *Nature*, 398, 755-756.

和文表題

レビュー：気候変動による農業影響に対する適応

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摘要

気候変動により引き起こされる影響を軽減するために適応策が有効であることはこれまでにも度々言われてきたが、その性質や具体的なプロセスに関する理解はいまだ乏しく、農業影響の評価に際して適応の効果はかなり簡略化された形で取り扱われるのみである。不確実性の高い将来の気候変動に対する最適な適応策の決定は困難であるが、次善の方法として、現状気候下での気候の変動性に対する適応能力を高め、突発的な異常気象に対する脆弱性を減少させることができる適応策をまず選択することが考えられる。

農業影響への適応策の選択肢は挙げられてきているが、それらの適応手段のうちどれがいつとられていくべきかという評価は多くは行なわれていない。そのような評価には、適応手段の費用便益分析が重要であるが、システマティックに行なわれた例はいまだない。

キーワード： 農業適応、気候変動、影響評価