Integrated Approach to Climate Change Impact Assessment on Agricultural Production System

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Abstract

The research project ICCAP (Impact of Climate Change on Agricultural Production System in Arid Areas) is a completed project of RIHN (Research Institute for Humanity and Nature) of Japan, to analyze the relationship between climate and agricultural system. It has been implemented since 2002 mainly in Turkey as an international joint project in cooperation with the Scientific and Technological Research Council of Turkey.

This project attempted to comprehend 'the agriculture as a system of relationship between human and nature', with a view to identifying current and future challenges, and effective countermeasures against possible climate changes. Based on a comprehensive assessment of the basic structure of agricultural production system with special reference to regional climate, land and water use, cropping pattern and irrigation system, the project attempted to predict and evaluate the impacts of future climate change and the regional adaptability. Finally, the correlations between changes in nature and human activities are to be examined in an integrated manner. In this process, regional climate change prediction with higher resolution is critical to precise impact assessment.

In this paper, the ICCAP is outlined focusing on its challenging aspect to develop the methodology with some primary outputs. In the ICCAP, methodology for quantitative analysis of climate change impacts was developed, which is applicable to other regions in the world. As the results, the directions and dimensions of the potential impacts of climate change on the agricultural production systems were identified in the Seyhan River Basin. The possible problems were assessed through projected impacts including temperature rise, precipitation decrease, sea level rise, and so on.

1. Introduction

The research project ICCAP - Impact of Climate Changes on Agricultural Production System in Arid Areas - is the project of RIHN (Research institute for Humanity and Nature) launched in 2002 as five year project, to analyze the relationship between climate and agricultural system. It has been being implemented as an international joint project in cooperation with TÜBİTAK (The Scientific and Technological Research Council of Turkey).

The ICCAP project assessed the impacts of global warming on regional climate changes and on regional hydrology and agriculture. The directions and dimensions of the potential impacts of climate change on agricultural production systems were identified in the Seyhan

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River Basin, located on the eastern coast of the Mediterranean Sea. Possible problems were assessed by projecting impacts such as rises in temperature, decreases in precipitation and sea level rise.

In this paper, the project framework is outlined and the outcomes are summarized, focusing on its challenging aspect on developing the methodology for integrated assessment, which is to be applicable to not only the case study area but also other agricultural regions in the world.

2. Objectives and Framework

2.1 Scope of the Research

Agricultural is basically a human activity. To cope with climate and other subsequent changes in natural conditions, humans have adapted to the new environment, or taken appropriate measures accordingly. Then now, is the conventional 'wisdom' of region or agriculture adequate enough to overcome the future global climate change?

The ICCAP attempts to comprehend 'the agriculture as a system of relationship between human and nature', with a view to identifying current and future challenges, and effective countermeasures against possible climate changes.

Agriculture is based on the interaction of human activities with the natural system including climate changes. This relationship is complex and causes various problems if they malfunction. This project aims at considering this interaction through the investigation of fundamental structure of land and water management as well as through the projections of abrupt climate changes and the assessment of their impacts.

2.2 Main Objectives

The original research objectives include the following four points:

(1) To examine and diagnose the structure of land and water management in agricultural production systems in arid areas, especially to evaluate quantitatively the relationship between cropping systems and hydrological cycle and water balance in farmland and its environs.
(2) To develop the methodology or model for integrated assessment on impacts of climate change and adaptations for it on agricultural production systems, mainly on the aspect of the land and water management.
(3) To assist the development and improvement of the Regional Climate Model (RCM) for more accurate prediction with higher resolution of future changes in regional climate.
(4) To assess the vulnerability of agricultural production systems from natural change and to suggest possible and effective measures for enhancing sustainability of agriculture, through integrated impact and adaptive assessment of climate changes.

3. Methodology and Case Study Area

3.1 Methodology

The research was implemented in the east coast of the Mediterranean Sea, mainly in the Seyhan River Basin of Turkey as a main case study area. Firstly, a comprehensive assessment of the basic structure of agricultural production system was carried out with special reference to regional climate, land and water use, cropping pattern and irrigation system. Then, it has been attempting to predict and evaluate the impacts of future climate change and the regional adaptability, and finally through these analyses, the correlations between changes in nature and human activities are to be examined in an integrated manner.

In this process, regional climate change projection with higher resolution is critical to precise impact assessment. Furthermore, impacts on the regional water resources, irrigation and drainage system, natural vegetation, crop production, farm management and cropping patterns as well as the effect on the food production and marketing are to be taken into account. The research aimed at providing suggestions for regional policies and monitoring systems for the further climate change impact assessment. The research procedures in the original research plan are shown in Figure 1.

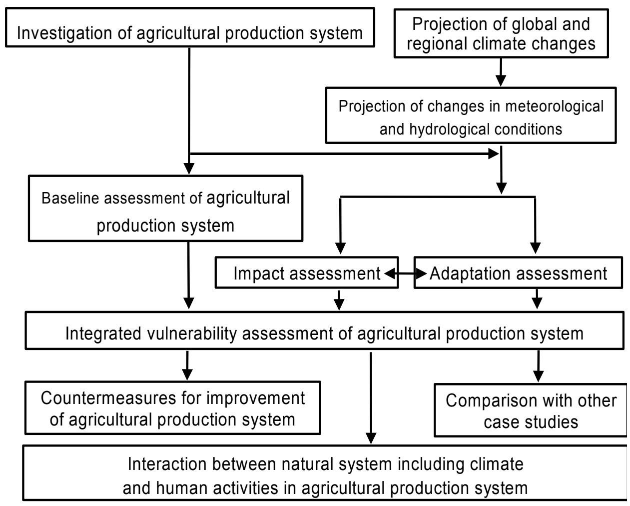

Figure 1: Research Flow Plan

3.2 Case Study Area

The Seyhan River Basin (Figure 2) is dominated by a Mediterranean climate, with most precipitation occurring in winter. Precipitation increases in accordance with elevation but is particularly low in the upper basin, which is dominated by a continental climate. Rain-fed wheat is widespread in the upper hilly areas of the basin. Large-scale irrigated agriculture extends throughout the lower delta, where maize, citrus, cotton, wheat, and vegetables are cultivated. These crops depend on water supplied by reservoirs that store the runoff of winter rain and snow in the upper mountainous areas.

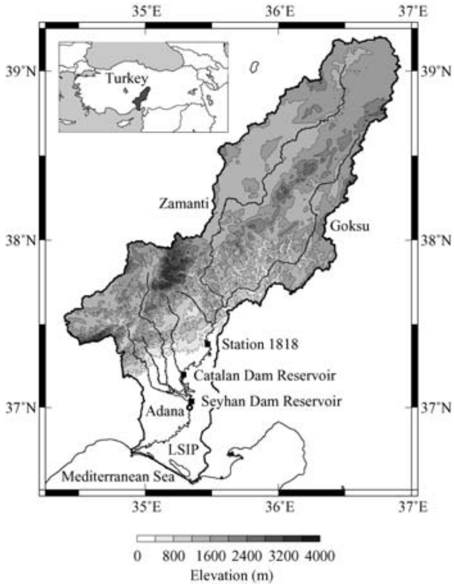

Figure 2: The Seyhan River Basin of Turkey

4. Approach in Integrated Assessment

Based on the preliminary diagnostic studies on the natural condition of the basin, present basic structure of the agricultural production system was analyzed. Simultaneously, the future climate change scenarios of the basin in the 2070s were generated by two most advanced GCMs and RCM with downscaling methods based on the SRES scenarios of A2. With generated climate scenarios, impacts of climate changes on regional hydrological regime, natural vegetation, crop productivity, irrigation management, cropping system and regional crop production were assessed by some particular models developed in this research.

These assessments proved the basic structure of the present agricultural system and the path of climate change impacts on the system, as summarized below:

a. The climate change scenarios for the 2070s of the basin were generated, with which impacts of climate changes on basin hydrology and agriculture were assessed and discussed. The projection of future climate by the climate model has still some uncertainty, while measures for model improvement were developed and applied during the model development stage.
b. The path of climate-change impacts on agricultural production in the Seyhan Basin was depicted as Figures 3 by a framework of associated components, critical factors, and relations. The reciprocal relationships between crops and livestock, pests and diseases, and ecosystem transitions were not direct objects of the assessment.

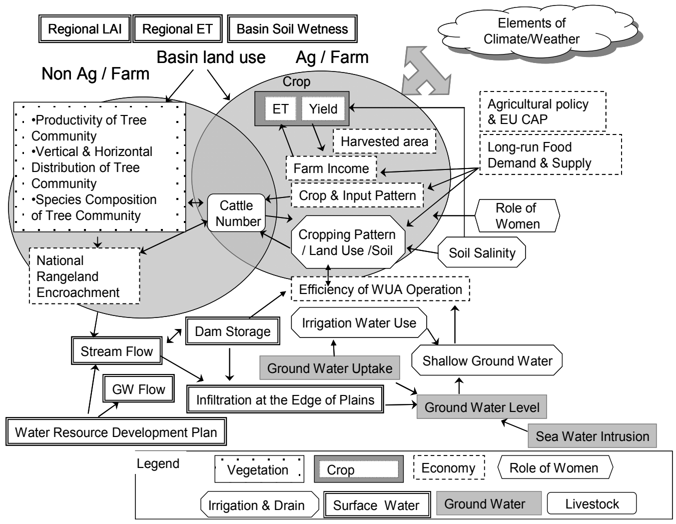

Figure 3: Major components and paths of climate change impacts on agricultural production system in the Seyhan River Basin

The combined agricultural production model consisting of some sub-models was not developed and applied, since in this moment, the basic policy, structure and elements, temporal and spatial resolution of parameters of the sub-models are quite different and difficult to be linked each other. The research project tried to connect the sub-models implicitly in repeated feedbacks, avoiding difficult and troublesome works for the explicit linkage of them. In the implicit combination, the models share the common input parameters and some model provide another with its outputs and another model received the outputs as its inputs.

In the research, the following processes were implemented for integrated assessment of the climate change impacts and for identifying the adaptation and mitigation measures (see Figure 4). At first, two GCMs for the future (2070s) were dynamically downscaled using a regional climate model with approximately 8.3-km spatial resolution. The future regional climate scenarios were generated with these downscaled data. Even with future climate prediction, it is very difficult to predict the exact features of future agricultural production in the basin such as land use, cropping patterns, and farm prices, since the future socio-economic conditions can not be predicted with a certain reliable accuracy.

After, basin hydrology models and agriculture production models were driven using present-day (1990s) climate data to simulate the current conditions.

Possible problems were estimated under the current basin conditions and future regional climate scenarios, in various aspects of agriculture and water use, including crop yield and production, natural vegetation, water resources, irrigation water supply, and others. And then, to bring future possible problem to light, we set up some future basin conditions assuming some human reactions to climate changes.

At last, three future basin conditions in land and water management were supposed. The possible future changes were projected in water resources availability, water supply security, cropping pattern and water balance by the basin-condition scenarios, and analyzed comparatively. The future basin scenarios cover the cropping patterns and the management of land and water uses.

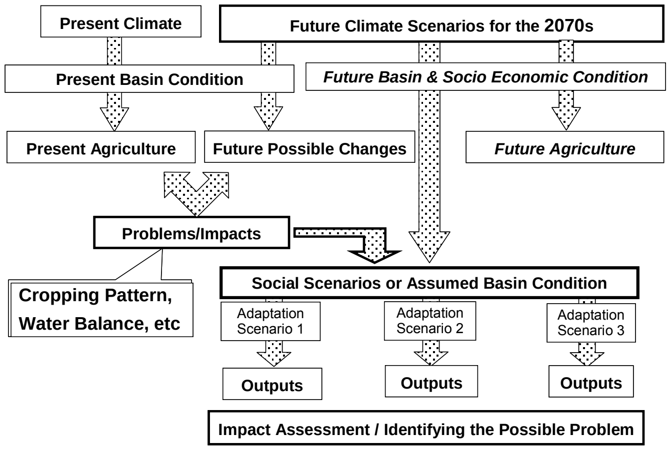

Figure 4: Approach in integrated impact assessment

5. Highlights of the Results

5.1 Future Regional Climate Changes

The future likely climate change scenarios of Turkey by increased greenhouse gases were generated are estimated for ten years in the 2070s. The outputs of GCMs were downscaled for ten years climate during the 2070s in whole Turkey with 25 km and that in Seyhan with 8.3 km grid interval. The provided climate dataset contains interpolated precipitation, temperature, moisture and insolation at every observation stations in Turkey.

Two independent GCM projections were downscaled by only one RCM. Another GCM with a very high horizontal resolution is used as a reference in order to assess the reliability of the downscale done in this research.

Figure 5 indicate the downscaling of the model output with an example of the change in winter precipitation of January in the 2070s. The example predicts the possibility of the decreased precipitation in winter time.

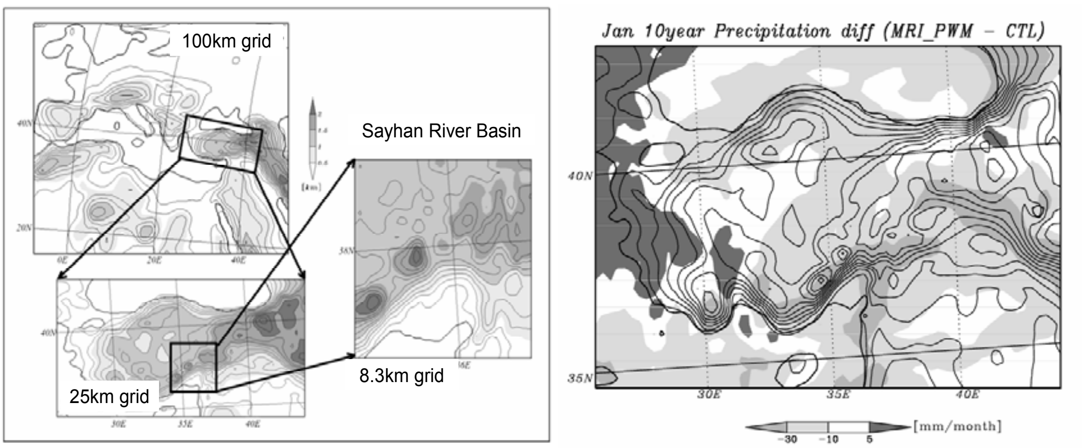

Figure 5: Projected changes in precipitation of January in the 2070s of Turkey

According to the generated scenarios, surface temperature in Turkey may increase by 2.0 degree Centigrade (MRI-GCM) and 3.5 degree Centigrade (CCSR/NIES-GCM). Total precipitation in Turkey may decrease about 20 % except summer and deference with GCMS is relatively small. The projected trend of changes in temperature and precipitation in the Seyhan River Basin is almost similar to the changes in the whole Turkey, while there precipitation my decrease about 25% (Figure 6.).

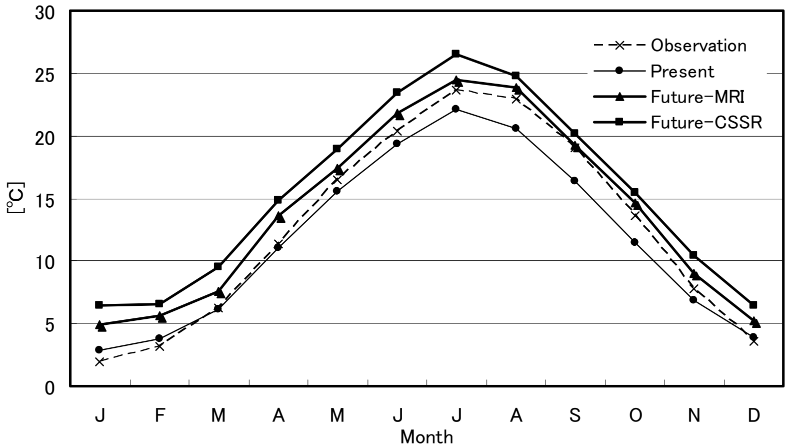

Figure 6: Changes in monthly average temperature in the Seyhan River Basin

5.2 Hydrology and Water Resources

The direct impacts of future sea-level rise on groundwater salinity will not be serious, while increased evaporation and decreased precipitation with sea-level rise could cause significant increase in salinity of the lagoon. Therefore, further groundwater withdraw may result in salt water intrusion. Buildup of a higher saline zone in the aquifer beneath the lagoon could cause water-logging on the land surface. Water logging and increased salinity in shallow groundwater may cause salt accumulation on land surface. To minimize the damage with salt accumulation on the land surface, improvement of local drainage system is strongly recommended in the future.

Precipitation in the basin is projected to decrease by about 170 mm, while evapotranspiration and runoff will decrease by about 40 mm and 110 mm, respectively. Because of snow fall decrease and temperature rise, snow amount will considerably decrease (Figure 7).

Compared with the present condition, decreased precipitation may result in considerably decrease of the inflow to the Çatalan and Seyhan Reservoirs, in which the peak of monthly inflow might occur earlier than in the present. Less flood events will occur with under the warmed condition. The expansion of irrigated land in the middle basin with increased water demand and decreased river flow may lead to the water scarcity for the lower plain of the basin as shown in Figure 8. Here, the “Reliability” is defined as “Water Supply/Water Demand”, that is an indicator to show how much the demand is satisfied by supply from the reservoirs. The figure shows that irrigation in the delta region might face to water shortage when water use in the upstream increases in the case of Social Scenario No. 2, or Adaptation Scenario No. 2.

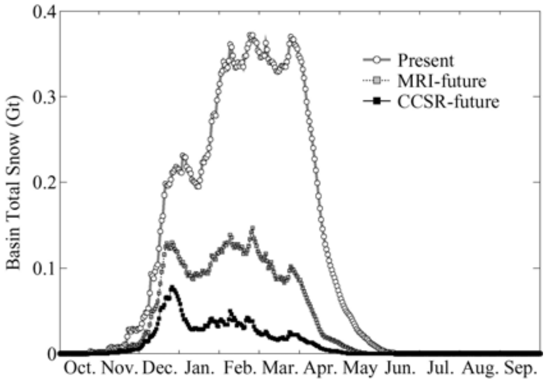

Figure 7: Changes in total snow fall in volume equivalent to water (unit: 109 m3)

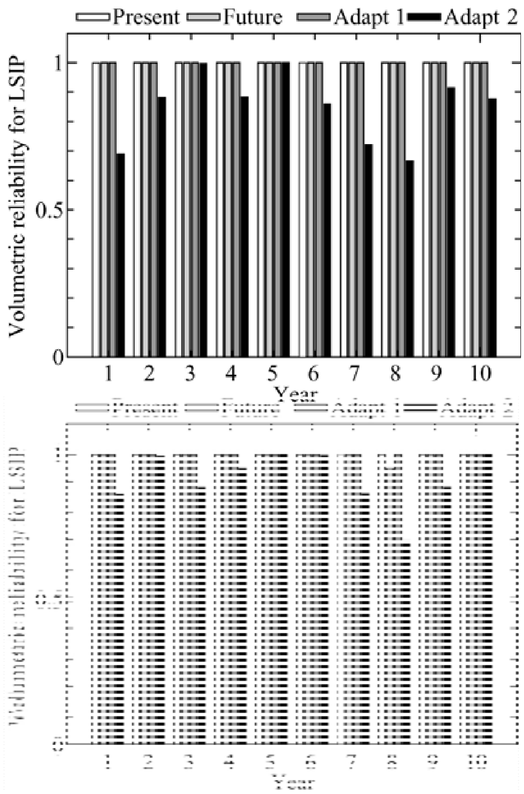

Figure 8: Changes in water resources reliability
(Top: by MRI, Bottom: by CCSR/NIES)

5.3 Natural Vegetation

The actual and potential present vegetations were estimated using satellite images and field data. Areas of Maquis and woodland with broadleaved evergreen trees in potential present vegetation were practically occupied by crop field and P.bruitai as secondary forest, respectively. Areas of steppe and Maquis will be increased in the 2070s while those of coniferous evergreen forest will be decreased. Biomass of Maquis and deciduous broadleaved woodland in future were increased and coniferous evergreen forest will be markedly decreased, and total biomass in the area will be only 45% of the present one.

In the research, difference of area occupied by each vegetation type was made clear, and its difference in biomass between the practical and potential present was clarified. The future changes in these items are predicted. These outcomes suggest the method to assess the climate change impacts on vegetation.

5.4 Crop Production

In the research, two crop growth simulation models were developed. The models project that wheat and maize yields in Adana areas may increase at most by 15% of the current yield in the 2070s with the changed climate in the generated scenarios, although wheat yields in one model decrease by 10% if CO_2 concentration is not incorporated for the estimation (Figures 9 and 10).

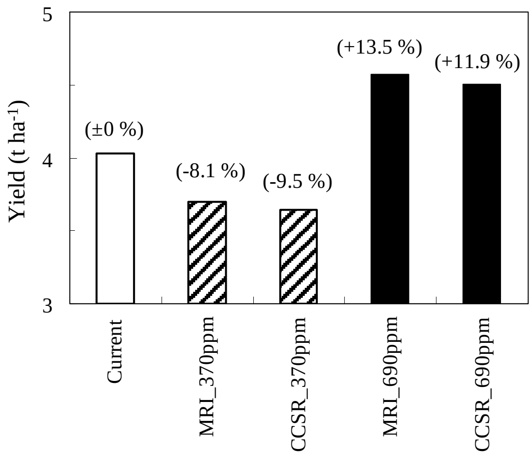

Figure 9: Estimated grain yield in wheat and maize in the 2070's.
(Left is from the simplified process model (SimWinc) and the right is from SWAP model.)

The yield estimated by two models suggests that the effect of elevated CO_2 almost offsets the impact of elevated temperature and reduced rainfall on wheat and maize grain yield.

In the future, the models should include accurate estimation for the effects of elevated temperature and water deficit on harvest index (yield / biomass yield). Furthermore, the sub-model evaluating the effects also should be developed.

The wheat growth and yield is one of the main interests that attract the public attention in the context of climate change impacts on agriculture in Turkey. The findings on this issue are summarized below.

a. The projected decrease in precipitation will give negative effects on wheat yield, especially in the plain area of Adana, where total precipitation during the growth period of wheat will decrease to below 500 mm. The amount and intensity of rain at the beginning of rainy season also may affect the wheat production through their effects on the establishment of seedlings.
b. Negative effects of elevated temperature would be expected on wheat yield due to the shortening of the growth duration and some adverse effects on reproductive growth in the plain area. On the other hand, increase of temperature will enhance canopy development, resulting in the better yield in the mountainous regions with sever winter.
c. Those negative effects of climate changes will be at least partly compensated by increased CO_2 in the 2070s.
d. The global warming effects on wheat yield in Adana projected both by the wheat growth model and the economic model, which will be explained in the following

section, are around +13%, and another wheat growth model projects them to range between + 25% and +37%.

e. Wide spatial variability will be expected in the climate change impacts on wheat yield within the Adana Province. Climate changes will increase and stabilize the wheat yield in the mountainous area, while it will destabilize the yield in the plain.

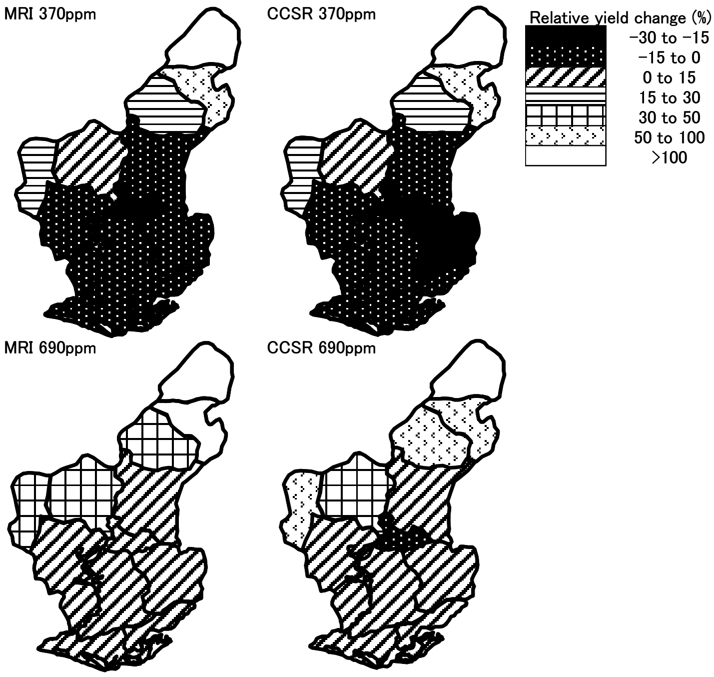

Figure 10: Differences in changes of wheat grain yield in the 2070s among the counties in the Adana Province

5.5 Irrigation and Drainage

In the topics of the irrigation and drainage, as the results of the research, typical problems of the present system were identified by visiting and questioning all water users associations (WUAs) in the area of the Lowe Syhan Irrigation Project(LSIP). Farmers and WUAs had more concern on recent conflicts over allocation of water at the peak irrigation season. Through remote sensing, spatial distribution of the land use in present and in the past were detected and the wheat cultivated area was identified. With field observations, reference water budget was obtained and the characteristics of the actual irrigation method are examined.

In this research, Irrigation Management Performance Assessment Model (IMPAM) was developed. It was validated being applied the small monitored area in the LSIP. Field monitoring of salinity of soil and shallow water table in the coastal area proves that EC of shallow water table in the irrigated area has continuously decreased over the past twenty years, yet in the coastal area, soil salinity still reflects distribution of shallow water table back in 1977, suggesting poor drainage.

With simulation of land-use changes in the 2070s using pseudo-warming outputs and expected value-variance (E-V) model, it is projected that in the 2070s, land use would shift to more cash generating crops than present, even under decreased water resources availability (Table 1). Using the IMPAM, crop growth and water budget of the whole delta was simulated, and as the results it is revealed that irrigation demand for the future increases due to extended irrigation period. However, the change seems to be within the range of its adaptive capacity.

Table 1: Simulated cropping pattern with climate and social scenarios T (ypes de moisson simulés avec les scénarios climatique et social)

Scenario	Base case	MRI-S1	MRI-S2	MRI-S3	CCSR-S1	CCSR-S2	CCSR-S3
Available water (mm)	585	469	429	579	398	330	480
Citrus	22.0	22.1	22.1	21.9	21.9	18.3	21.8
Cotton	59.3	24.0	15.1	48.3	4.3		26.0
Vegetables	7.0	4.4	3.6	6.4	3.0	3.2	4.7
Watermelon & Maize		41.3	51.7	12.9	64.0	78.5	38.8
Fruit	11.6	8.3	7.5	10.4	6.8		8.6
Gross revenue (YTL/da)	717.9	706.9	702.6	715.6	696.4	670.0	707.9
Shadow price of water		0.1	0.1	0.1	0.2	0.1	0.1
Idle water (mm)	23.5						

*The case of risk aversion parameter set as 0.01

Water table was more sensitive to the degree of management than to climate change. In general, the risk of higher water table seems less possible due to projected decrease in precipitation and due to decrease in water supply. Water logging only partially occurred in along the coast (Figure 11).

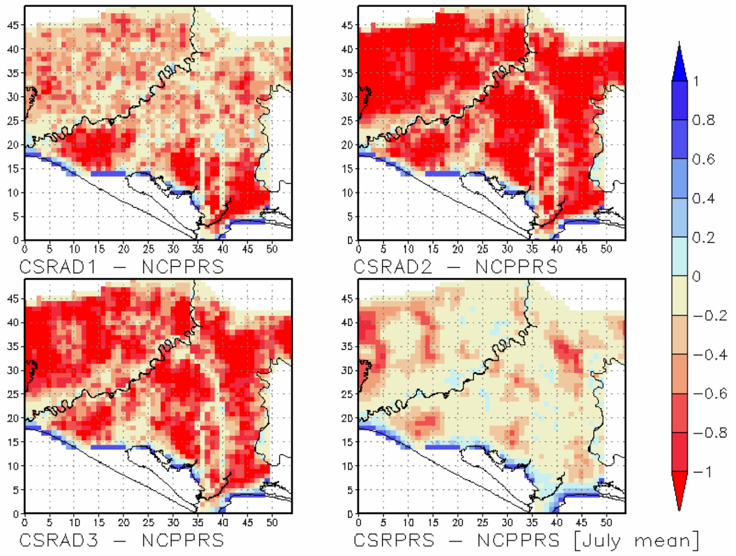

Figure 11: Comparison of water table level between present and different adaptation scenarios (The case of CCSR runs for July average, Scenario 1: Top left, Scenario 2: Top right, Scenario 3: Bottom left, Present landuse: Bottom right)

In the 2070s citrus would remain constant around 20% and in the case of scarce water supply, water melon would emerge. Watermelon is usually cultivated only once in five years to avoid replant failure. In order to take the crop rotation of watermelon into account, weighted average of watermelon (one year) and maize (four years) was used for simulation.

5.6 Socio-economics

The econometric analysis estimated the climate change impacts on the production of wheat and barley and the farmers' economy and behavior in the Adana and Konya region.

Changes in crop yield were predicted with price effect, drought effect, high temperature effect, and CO_2 concentration effect. Changes of the area sown were predicted with price effect and soil moisture effect. According to the predictions, with climate change the wheat and barley yield in Adana will decrease by 18% and 24% respectively in the 2070s, while in Konya they will decrease by 48% and 47% respectively. The larger temperature increase in Konya than Adana may cause this difference. The area sown for wheat and barley in Adana and Konya will decrease slightly. The higher CO_2 will increase the yields of wheat and barley by 18.45 %, which was assumed by available references and suggestion of the crop scientist in the research. This assumed value is considerably high for future changes compared with the predicted extent of changes caused by higher temperature and decreased rainfall, while this assumption is to be modified with further research and information.

Consequently, the total production of wheat in Adana will decrease by 3% and the production of barley decrease by 13%. On the other hand, in Konya, the production of both wheat and barley will decrease by 31% and 29%, respectively in the 2070s. The results imply that in Turkey they may face to possible food security problem or food shortage with global warming, since Konya is a representative wheat producing area in Turkey. Estimation in the case that Turkey will gain the membership of EU shows that the yield decrease of both of wheat and barely will be smaller than the decrease in the case that Turkey will not be admitted to EU.

In the farm surveys, farm economy situation, rural credit market, rural land tenure problems and their relation with cropping patterns, livestock economy, and other farmers' behavior were studied. The results were used to understand the actual farm situation.

6. Conclusions and Further Necessary Works

Although this research of the ICCAP has made the above preliminary conclusions, predicting the future changes caused by global warming is still a difficult undertaking, and in some quarters, prediction of future agricultural production in a specific place and year, like in one river basin in the 2070s, is considered "impossible". At the moment, future climate change projection is still uncertain and a challenging topic, and the response of crops to climate change is also still in the basic study stages, even for a major staple crop like wheat.

If the phenomena or factors associated with climate change and its attendant impacts are difficult to appraise, how can the humans respond or react? There are problems of natural events that are difficult to be simulated or examined quantitatively in the laboratory or computer. Likewise, the impacts of human activity in a natural system, such as land reclamation or irrigation development, also can not be evaluated precisely in advance even though a substantial knowledge base is available.

One of more effective and feasible measures for such a dilemma are to take actions incrementally , as in trial-and-error manner, utilizing the best available current knowledge and past experiences, and collecting additional information as needed. In pursuing such an adaptive approach, stakeholders should participate in the decisions and actions taken incrementally. For adaptation and mitigation in agriculture against global warming, farmers and their associations or cooperatives, and other organizations interested in climate, water resources, and agriculture need to be involved jointly.

Acknowledgments

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References

The Research Project ICCAP(Impact of Climate Change on Agricultural Production System in Arid Areas. 2007. Final Report, RIHN (Research Institute for Humanity and Nature), Japan, http://www.chikyu.ac.jp/iccap/