Prediction of Future Change of Water Demand Following
Global Warming in the Cukurova Region, Turkey

Tomohisa YANO [1], Tomokazu HARAGUCHI[2], Masumi KORIYAMA[2] and Mehmet AYDIN[3]

[1] *Faculty of Engineering, Kyushu Kyouritsu University*
1-8 Jiyugaoka, Yahata-nishi-ku, Kitakyushu 807-8585, Japan
[2]*Faculty of Agriculture, Saga University*
1 Honjo-cho, Saga 840-0027
[3]*Faculty of Agriculture, Mustafa Kemal University*
31034 Antakya, Hatay, Turkey

1. Introduction

It has been reported that the globally averaged surface temperature is projected to increase by 1.4 to 5.8 ℃ over the period of 1990 to 2100 (IPCC 2001). It is not likely that precipitation will have increased in arid regions and the effects of future climate change on irrigation and water resources may become of major concern. Although the raised temperature increases evaporative demand of the atmosphere, actual crop water use is dependent on growth response to temperature rise. The purpose of the research is to predict future change of water demand in the Mediterranean climate regions of Turkey by using the predicted climate change data, considering the effect of elevated CO_2 concentration and rise in temperature on crop growth.

2. Materials and methods

The GCM-based climate change data are available with seven climate models at the IPCC web-site (http://ipcc-ddc.cru.uea.ac.uk/). Among seven models, the CGCM2 model of Canadian Center for Climate Modeling and Analysis (CCCma) was selected, because the climate data are daily while those of other models are monthly. The predicted climate change data for the CGCM2 model are available for 4608 locations of the world which correspond to a grid distance of 412 km on the equator. Two kinds of the projected climate data of the regional climate model (RCM) with the grid distance of 25 km which were supplied by the climate subgroup were also used. The RCM data are based on a newly suggested method which uses reanalysis data as a boundary forcing of the RCM while a specially created boundary condition, in which projected changes of meteorological variables in the GCMs (MRI and CCSR/NIES) simulation are added on reanalysis data,

is used for simulation (Sato *et al.*, in press).

Monthly water balance was first calculated for a double cropping pattern of wheat and second crop maize grown in Adana (37.00°N, 35.33°E) for a period of 10 years from 2070 to 2079 using the SWAP model developed in the Netherlands (van Dam *et al.*, 1997). The A2 scenario of the Special Report on Emission Scenarios (SRES) was used. This scenario depicts a very heterogeneous world. The underlying theme is that of strengthening regional cultural identities, with an emphasis on family values and local traditions, high population growth, and less concern for rapid economic development (IPCC, 2001).

3. Results and discussions

3.1. Projection of air temperature and precipitation

Variations of annual mean temperature and precipitation collected from four GCM-based models for 111 years from 1990 to 2100 in Adana are shown in **Fig. 1** as the difference from 1990 – 2004 mean. Four models are: CGCM2 model of Canadian Center for Climate Modeling and Analysis (CCCma), ECHAM4/OPYC3 model of Max Planck Institute für Meteorologie (MPIfM), CGCM2.2 model of Meteorological Research Institute (MRI) and AGCM + CCSR OGCM model of Center for Climate System Research and National Institute for Environmental Studies (CCSR/NIES). The MRI data are not available at the IPCC web-site. These data were computed for Adana using the projected values at the four nearest neighboring grid points using the inverse distance weighted method. Annual temperature increases gradually. According to the linear regression equation, averaged surface temperature is estimated to increase by 3.1-8.6 ℃ over the period of 1990 to 2100. Among the four models, the CCSR/NIES and MRI data denote the highest and lowest increase, respectively. Although annual precipitation denotes noticeable variations year
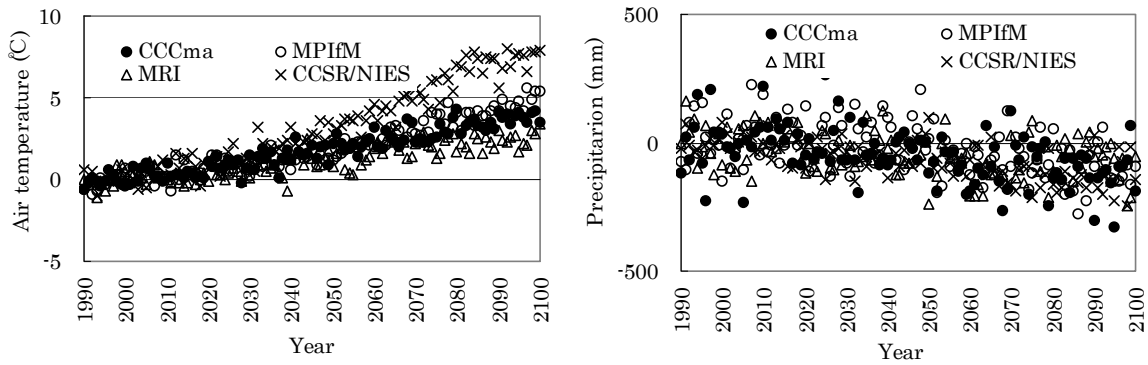
Fig. 1. Projections of air temperature and precipitation difference from 1990 – 2004 mean.

by year, it is not likely that it will have increased in the future.

A comparison of the predicted monthly temperature as well as precipitation with the CCCma GCM (hereafter referred as GCM) and MRI RCM (hereafter referred as MRI) models and observed ones for 10 years from 1994 in Adana is given in **Fig. 2**. Annual air temperature is 18.0, 18.2 and 19.2 ℃, respectively for the GCM, MRI and observed data. Although the GCM and MRI data show about same average values, annual pattern is different. Predicted air temperatures with the GCM data denote lower values than those with the observed one during spring and summer, while the MRI data show lower during summer and autumn. Also, the agreement between predicted and observed precipitation values is not reasonably well. Annual precipitation predicted with the models is 540, 526 and 662 mm, respectively for the GCM and MRI and observed data, and estimated values were underestimated when compared with observed one.

Monthly variations of potential evapo- transpiration from reference crop (ETref) to represent the evaporative demand of the atmosphere are shown in **Fig. 3**. ETref was calculated with the Penman-Monteith equation based on the GCM and RCM data and the observed data. Calculated potential ET from the different climate

data shows the similar monthly variations with the air temperature variations. Since potential ET is the fundamental parameter for water demand prediction, it is supposed that direct use of the original GCM and MRI data would result in the erroneous results.

For the GCM data with large grid distance, the climatic scenarios for the future are sometimes created by superimposing the observed values to the change between the present and the future estimated values (Tao et al., 2003). The same procedure was used to create the future climate data using the GCM data. For the RCM data, predicted values were decided to use by correcting with the observed data for the current and future climate conditions.

Monthly air temperature and precipitation created for Adana are depicted in **Fig. 4**. It can be seen that created air temperatures and precipitation were modified in accordance with the discrepancy between the predicted values and the observed values in Fig.2. Projections of temperature rise over a time periods of 2070-2079 compared with 1994-2003 are 2.8 ℃, 1.4 ℃, 2.3 ℃ for GCM, MRI and CCSR/NIES RCM (hereafter referred as CCSR/NIES). Lower increase for MRI than those for GCM and CCSR/NIES is due to the process of data correction based on observed data. Projected mean annual precipitation during 2070-2079 compared with
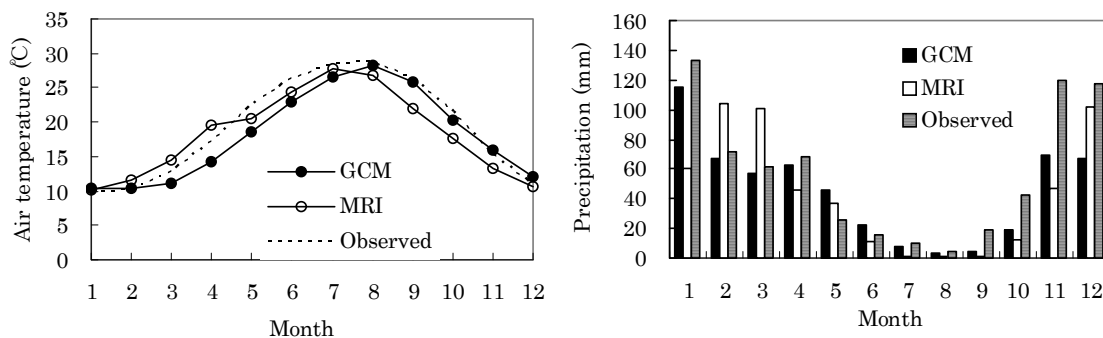

Fig. 2. Predicted air temperature and precipitation with the GCM, MRI and observed data.

1994-2003 would decrease by 56, 303, and 279 mm (equivalent to 11, 46 and 42% decrease) according to the GCM, MRI and CCSR/NIES models, respectively.

3.2. Water balance change due to global warming

The interactive effects of global warming and increasing CO_2 levels could especially impact agriculture, affecting water demand, growth and development of crops and ultimately impacting yield and food production.

Simulation models are a means to analyze the potential effects of climate change on crop growth, but testing model performance against measured data under such scenarios is essential for such an analysis to be meaningful. Before the water balance calculation for wheat and maize, crop growth was simulated using a detailed growth model of SWAP. It was parameterized with the crop growth measurement of two growing years for wheat and one growing year for maize. Detailed description about parameterization is given in the article "Simulation of crop productivity for evaluating climate change effects" by Yano *et al.* of this issue.

The average values and standard deviations of the water balance components for the periods of 10 years from 1994, and from 2070 together with biomass, grain yield and growing duration for wheat and second crop maize are given in **Table 1** and **Table 2**, respectively. Since CO_2 concentration in 2070s is estimated to increase up to doubling concentration under SRES A2 scenario, calculations were done for under doubling CO_2 concentration condition. In doing calculation, the percent change in acclimatized photosynthesis rate was assumed to be +27% and +4% for wheat and maize, respectively (Cure and Acock, 1986). It is well-known that actual ET decreases considerably due to stomata closure under elevated CO_2 concentration (e.g. Ainsworth and Long, 2005).

The percent change in transpiration decreases by 17% and 26%, respectively for wheat and maize was used for calculation for the period 2070-2079 (Cure and Acock, 1986).
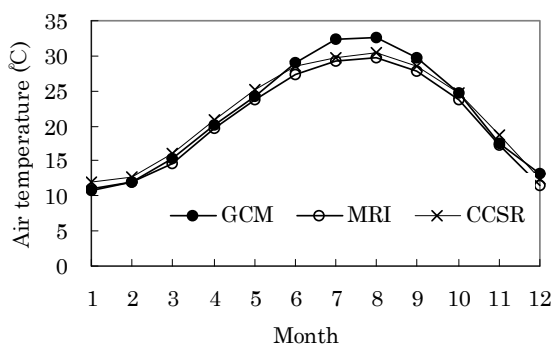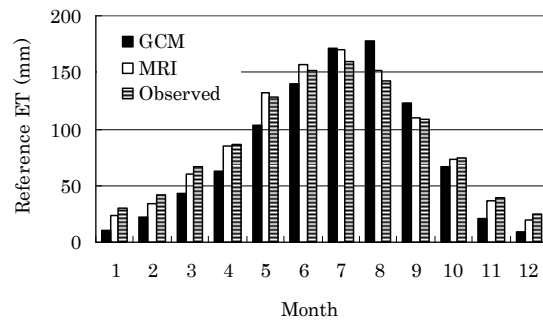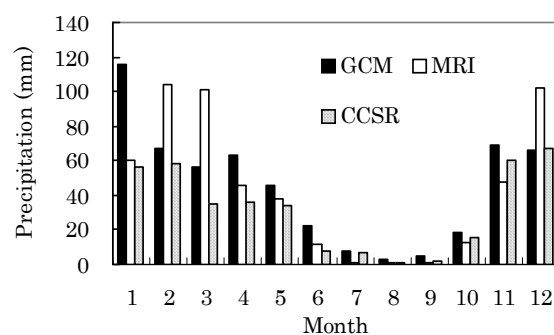

Fig. 3. Calculated reference ET from the GCM, MRI and observed data.

Comparison of calculated actual ET between the current climatic condition and the future for the GCM, MRI and CCSR/NIES data shows the decrease of 28%, 8% and 16%, respectively for wheat and 24%, 28% and 26%, respectively for maize, reflecting the different rises in air temperature in the future.

Future air temperature rise results in increase in evaporative demand of the atmosphere. However, decrease in actual ET for both wheat and maize shown in Tables 1 and 2 can be attributed to reduction of growing days and LAI due to temperature rise and transpiration reduction due to stomata closure regardless of increase in evaporative demand.

Irrigation water demand was estimated to increase in the future for wheat mainly due to decrease in precipitation. On the contrary, it was estimated to considerably decrease for maize, reflecting decrease of actual ET due to stomatal closure. The water balance components and crop growth under the assumption that there is no transpiration reduction even at elevated CO_2 concentration are shown in **Table 3** in which the GCM data was used for simulation. If there would be no reduction in transpiration at elevated CO_2 concentration, actual ET would increase by 32 and 79 mm for wheat and maize, respectively. As the result, irrigation for maize would increase by 73 mm (equivalent to 23% increase).

The duration of the regular crop-growing season for

Fig. 4. Comparison of projected air temperature and precipitation for 10 years from 2070.

wheat is 14, 7 and 11 days shorter in the future. This change is caused by the projected air temperature rise of 2.2, 1.6 and 2.4 ℃ for a growing period by the 2070s for GCM, MRI and CCSR/NIES. Duration of growth period for maize becomes shorter by 9 days for GCM and CCSR/NIES while only 3 days for MRI. Air temperature rise projected with the GCM, MRI and CCSR/NIES models was 3.5, 1.4 and 3.0 ℃ during growing period of maize, respectively. In other words, high temperatures accelerate the phenological development of plants, resulting in quicker maturation.

The predicted biomass and grain yield for wheat and maize in the 2070-2079 denote the complicated results to explain in accordance with the different photosynthesis rate and air temperature rise in the future. In case of wheat, biomass decreases for GCM, but increases for both of RCMs. Grain yield increases for all the models. Since rise in temperature for MRI is less than other two models, higher yields are expected to occur. However, biomass of more than 23 ton/ha may be too high. The reason why grain yield for all the models increase can not be explained well.

In case of maize, both biomass and grain yield decrease for GCM and CCSR/NIES, but increase for MRI because of less rise in temperature than those for GCM and CCSR/NIES.

As described earlier, original RCM data were corrected based on observed data. The difference between the current and future annual mean air temperature is 2.4 and 1.4 ℃ for the original and corrected MRI data and 3.6 and 2.3 ℃ for the CCSR/NIES data, respectively.
It seems

that simulated results using the corrected RCM data would not reflect correctly the effect of air temperature on crop growth and water balance components. Therefore, although it is generally difficult to downscale GCM data with large grid point distance accurately to the study area, the approach to use the GCM data in this study to predict the future change in water demand must be appropriate under the present situation with less reliable RCM data.

4. Conclusions

Four kinds of GCM data published by four research organizations of CCCma, MPIfM, CCSR/NIES and MRI were downscaled for the study area with the projected data at the four nearest neighboring grid points using the inverse distance weighted method. Averaged surface temperature is estimated to increase by 3.1-8.6 ℃ over the period of 1990 to 2100. Among the four models, the CCSR/NIES and MRI data denote the highest and lowest increase, respectively. Although annual precipitation denotes noticeable variations year by year, it is not likely that it will have increased in the future.

The future climate scenario for GCM by CCCma was created based on the observed values and the change of predicted values between present and future, assuming that only change between the present and the future is correct. Two kinds of original RCM data based on CCSR/NIE and MRI GCM were corrected using observed data to avoid bias. Projected climate change data in 2070s when CO_2 concentration is estimated to

Table 1 Predictions of the combined effects of projected climate change with elevated air temperature and doubling CO_2 concentration with transpiration reduction due to stomata closure for wheat

Model	Period	Precipitation (mm)	ET (mm)	Irrigation (mm)	Biomass (ton/ha)	Grain yield (ton/ha)	Growth days
GCM	1994 - 2003	535.0 ± 186.3	349.2 ± 35.2	0 ± 0	17.5 ± 1.8	5.0 ± 0.9	198.5 ± 7.8
	2070 - 2079	503.6 ± 211.8	250.9 ± 32.1	16.6 ± 36.9	16.8 ± 2.0	5.8 ± 0.8	174.1 ± 6.6
MRI	1994 - 2003	597.9 ± 190.1	301.8 ± 30.1	24.8 ± 45.3	16.9 ± 1.7	4.5 ± 0.9	188.1 ± 5.8
	2070 - 2079	313.9 ± 82.5	276.6 ± 20.9	68.9 ± 56.8	23.3 ± 0.9	6.1 ± 1.3	181.3 ± 4.1
CCSR	2070 - 2079	308.0 ± 88.1	252.5 ± 26.7	79.2 ± 88.1	19.0 ± 2.1	5.6 ± 0.9	167.6 ± 4.5

Table 2 Predictions of the combined effects of projected climate change with elevated air temperature and doubling CO_2 concentration with transpiration reduction due to stomata closure for maize

Model	Period	Precipitation (mm)	ET (mm)	Irrigation (mm)	Biomass (ton/ha)	Grain yield (ton/ha)	Growth days
GCM	1994 - 2003	47.5 ± 23.8	414.1 ± 26.1	375.5 ± 51.7	27.3 ± 1.5	15.1 ± 1.3	115.9 ± 3.8
	2070 - 2079	24.9 ± 18.0	314.0 ± 23.7	318.4 ± 27.6	22.6 ± 1.6	11.4 ± 1.2	106.7 ± 0.7
MRI	1994 - 2003	9.8 ± 6.0	439.8 ± 5.8	423.1 ± 7.8	30.1 ± 1.0	16.4 ± 0.9	118.8 ± 2.9
	2070 - 2079	8.5 ± 8.0	317.6 ± 5.9	331.4 ± 36.0	31.0 ± 1.0	16.9 ± 0.8	115.8 ± 2.4
CCSR	2070 - 2079	10.7 ± 17.1	326.6 ± 5.2	328.2 ± 24.8	29.2 ± 0.8	15.5 ± 0.7	109.8 ± 1.3

Table 3 Predictions of the combined effects of projected climate change with elevated air temperature and doubling CO_2 concentration without transpiration reduction for wheat and maize using GCM

Crop	Period	Precipitation (mm)	ET (mm)	Irrigation (mm)	Biomass (ton/ha)	Grain yield (ton/ha)	Growth days
Wheat	2070 - 2079	503.6 ± 211.8	282.6 ± 24.4	16.6 ± 36.9	16.9 ± 2.0	4.4 ± 0.6	164.4 ± 6.0
Maize	2070 - 2079	24.9 ± 18.0	393.1 ± 33.9	391.0 ± 37.7	20.4 ± 1.4	10.4 ± 1.1	106.7 ± 0.7

reach doubling concentration were used for comparison with the current climate (1994-2003). Water balance components and crop growth were estimated using the SWAP model in which parameterization of the growth model for wheat and maize was done based on observed data.

Projections of temperature rise over the time period of 2070-2079 compared with 1994-2003 are 2.8 ℃, 1.4 ℃, 2.3 ℃ for CCCma GCM, MRI and CCSR/NIES RCM, respectively. Lower increase for MRI than those for GCM and CCSR/NIES is due to the process of data correction based on observed data. Projected mean annual precipitation during 2070-2079 compared with 1994-2003 would decrease by 56, 303, and 279 mm (equivalent to 11, 46 and 42% decrease) according to the GCM, MRI and CCSR/NIES models, respectively.

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The duration of the regular crop-growing season for wheat is 14, 7 and 11 days shorter in the future. This change is caused by the projected air temperature rise of 2.2, 1.6 and 2.4 ℃ for a growing period by the 2070s for GCM, MRI and CCSR/NIES. Duration of growth period for maize becomes shorter by 9 days for GCM and CCSR/NIES while only 3 days for MRI. Air temperature rise projected with the GCM, MRI and CCSR/NIES models was 3.5, 1.4 and 3.0 ℃ during growing period of maize, respectively. In other words, high temperatures accelerate the phenological development of plants, resulting in quicker maturation.

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In this study, RCM data corrected based on observed values were used. The difference between the current and future annual mean air temperature is 2.4 and 1.4 ℃ for the original and corrected MRI data and 3.6 and 2.3 ℃ for the CCSR/NIES data, respectively. It seems that simulated results using the corrected RCM data would not reflect correctly the effect of air temperature on crop growth and water balance components.

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