Estimation of Crop Production by the Future Climate Changes in Surrounding Areas of the Seyhan River in Turkey

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1. Introduction

In Turkey wheat is the most dominant crop. Since five decades wheat production has increased from 7000 to 18000 kt and yield from 0.91 to 2.09 t ha^{-1} although cultivated area has a few increased (USDA, 2006). Second dominant crop is barley and its total production is less a half of the wheat total production and the production has increased during 50 years probably because of increased requirement of livestock fee for meet production (USDA, 2006). Most of these winter crops are grown in rain-fed area except of a few areas under irrigation system. The other important crop for livestock fee is maize and its total production is 18% of the wheat production now. Maize can be grown in irrigation areas because of growth terms in summer season when rainfall is very few.

We estimate the impact of climate change on crop production, particularly for wheat in winter crops and maize in summer crops, in the future for surrounding areas of the Seyhan River including rain fed areas of the upper Seyhan and irrigation areas of the lower Seyhan in Turkey.

2. The estimation Concept of Crop Production in the Future

The estimation of crop production in the future was from crop growth models of tow different concepts.

The first model employs a simplified process approach to simulate crop growth and development (Sinclair, 1994; Horie 1995). This model uses environmental variables of temperature, radiation and day length. Model parameters were decided for Turkish spring wheat by field experiments under irrigated conditions in Adana of Turkey and Ishikawa of Japan. Soil desiccation was incorporated by the model that suppression of transpiration rate coincides with that of biomass while soil desiccation rate was supplied from other environmental simulation models.

The second model is from the SWAP (Soil-Water-Atmosphere-Plant) model which was developed in the Netherlands. The parameters were decided based on the observed data.

The effect of temperature elevation would be immediately calculated by these models but the effect of CO_2 elevation was incorporated by changes of radiation use efficiency from other past experimental results. Estimated data in the future (MRI and CCSR) were input these model and results were output.

3. Predicting the Impact of Global Warming on Crop Production

(1) Estimation with the Simple Model

The impact of global warming on wheat production in Adana was predicted by using a wheat growth model, SimWinc, outputs of climate models for 9 years (MRI and CCSR) and soil water conditions simulated by SiBUC. SimWinc was parameterized with the growth data of wheat crops grown under nearly ideal conditions at Çukurova University in Adana. In the model, a change in CO_2 concentration from 370 ppm (the current level) to 690 ppm (an assumed level in 2070s) enhances biomass production by 23.6%. Simulated yields can be converted into actual farmers' yields, multiplied by 'technological coefficient (TC)', which is the ratio of actual farmers' yields to simulated yields.

The values of TC under the current climate conditions were relatively stable (51 to 65 %) in the districts of the plain area in Adana and ranged 28 to 57% in the mountainous area. We simulated wheat yields under the future climate conditions, assuming that the value of TC would be unchanged in each district.

Without the CO_2 effect, wheat yields were expected to be decreased by MRI and CCSR climates in the plain area mainly due to decreases in precipitation, and to be increased by both climates in the mountainous area due to increases in temperature. At the simulation runs with the CO_2

effect, wheat yields in every district were expected to be increased by global warming, excluding one district under the CCSR climate. The average predicted yield was 4.03 t ha^{-1} in Adana Prefecture under the current climate. Reductions of 8.1 and 9.5 % in average yield in Adana were predicted for MRI and CCSR climates without CO_2 effect, respectively. The predicted yield reduction of CCSR was larger than that of MRI, because precipitation in CCSR decreased from the current level more than that in MRI. When we included the CO_2 effect in simulation runs, average yields were predicted to increase by 13.5 and 11.9 % for the two pseudo-warming climates, respectively. The yield variability was predicted to increase in the plain area under the future climates, while to decrease in the mountainous area.

In conclusion, a decrease in precipitation by global warming would have a possibility to reduce and destabilize wheat yields in the plain area of Adana, although CO_2 fertilization effects will be able to partly compensate for the negative effect of global warming. In the mountainous area with severe winter, an increase in temperature would improve the wheat production under the future climates.

(2) Estimation with the SWAP Model

Four kinds of GCM data, 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) were downscaled for Adana as the study area using the projected values at the four nearest neighboring grid points using the inverse distance weighted method. Annual temperature increases gradually for 111 years from 1990 to 2100. 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 by year, it is not likely that it will have increased in the future.

A simulation study was carried out to predict future changes in climate, irrigation water demand and crop growth in a Mediterranean environment of Turkey. Climate changes were projected by using data of one GCM data: CGCM2 model of CCCma (hereafter referred as GCM) and two RCM data: CGCM2.2 model of MRI (hereafter referred as MRI) and AGCM + CCSR OGCM model of CCSR/NIES (hereafter referred as CCSR) for a time period of 2070-2079 when CO_2 concentration is supposed to increase up to doubling concentration under the A2 scenario of Special Report on Emissions Scenarios (SRES). The effects of projected climate change on water balance components and yields of spring wheat and second crop maize were predicted using the detailed crop growth subroutine of the SWAP (Soil-Water-Atmosphere-Plant) model which was developed in the Netherlands. Projected climate data and collected soil and crop management data for the study location were used to run the SWAP.

Three climate models projected air temperature rises by 2.8, 1.4 and 2.4 ℃ for a period of 2070-2079 relative to a period of 1994-2003 as the baseline for GCM, MRI, and CCSR/NIES, respectively. Precipitation is projected to decrease by about 56, 303 and 279 mm, respectively.

In order to evaluate the positive effect of elevated CO_2 concentration and the negative effect of risen air temperature on crop yields, simulation was done by doubling CO_2 concentration and by increasing maximum and minimum temperature by 1, 3, 5 ℃ relative to the current condition.

From results of calculated yields as well as evapotranspiration (ET) for wheat and maize, increase of biomass due to doubling CO_2 concentration is about 15% and 6% for wheat as a C3 crop and maize as a C4 crop, respectively. On the other hand, ET does not similarly increase and even decreases for maize, probably due to temporal water stress resulted from active crop growth. Decrease of biomass and ET following temperature rise is clearly shown in that temperature increase of 3 ℃ results in biomass decrease for 17% and 20%, respectively. ET decreases similarly as biomass does. Thus, increased yields by doubling CO_2 concentration are counteracted by temperature rise of 3 and 1 ℃, respectively for wheat and maize. More than 1 ℃ of temperature rise is estimated in 2070s when CO_2 concentration is supposed to increase up to doubling concentration, although much variations of temperature rise is recognized among models.

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 calculated. Although rise in temperature results in a higher evaporative demand of the atmosphere in the future, actual ET for a time period for 10 years from 2070 under a doubling CO_2 concentration shows the decrease of 28%, 8% and 16%, respectively for wheat and 24%, 28% and 26%, respectively for maize, for the GCM, MRI and CCSR/NIES data reflecting the different rise 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 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.

If there would be no transpiration reduction at elevated CO_2 concentration, actual ET would increase by 32 and 79 mm for wheat and maize. As the result, irrigation for maize would increase by 73 mm (equivalent to 23% increase).

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. Projected air temperature rise was 3.5, 1.4 and 3.0 ℃ during growing period of maize. In other words, high temperatures accelerate the phenological development of plants, resulting in quicker maturation.

In case of wheat, biomass decreases for GCM, but increases for both of RCMs. Grain yield increases for all the models. In case of maize, both biomass and grain yield decrease for GCM and CCSR/NIES, but increases for MRI because of less rise in temperature than those for GCM and CCSR/NIES.

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. 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.

4. Future Overview of Crop Production in Surrounding Areas of the Seynan River

From results with two simulation models wheat and maize yields in Adana areas increase at most by 15% of current yield in the future climate change conditions, although wheat yields in one model decrease by 10% if CO_2 concentration is not incorporated for the estimation. These results suggest that in the future grain production in dominant crops will be maintained in surrounding areas of the Seynan River. However, these results should not promise stable crop production in the future, because drought would be a key factor reducing the potential production and hence the estimation accuracy for precipitation and evaporative demand becomes critical for the yield more than temperature.

Furthermore, the model estimation includes some problems that should be improved for more accurate estimation of the yields. The effect of temperature and drought on harvest index (a ratio of grain yield to biomass) is not adequately incorporated in the models. For grain crops pollination and grain-filling are the most critical phases under high temperature or drought conditions (Levitt et al. 1980) and harvest index should be highly affected by stresses in the phases**.** Other factor affecting harvest index in winter wheat is a low temperature requirement during winter seasons for flower initiation. Particularly in mountain areas temperature elevation during winter season in the future would inhibit flower initiation to decrease harvest index to zero. This suggests that farmers in winter wheat cultivation areas will have to change wheat cultivar. If these factors are adequately introduced into the models the reliability of the estimation will be expected to increase more.

See the individual report for detail for each result.

5. References

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