Predicting the Impact of Global Warming on Wheat Production in Adana

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1. Introduction

Adana Prefecture (Adana) is faced to the Mediterranean Sea and the coastal area belongs to Mediterranean climate with mild winter, although the other end extends deeply into the inland mountainous area, which experiences severe winter, along the Seyhan River. The average of total precipitation during the growth period of wheat is about 650 mm on average for 16 locations spread over Adana, which is sufficient for wheat cultivation for normal years, although wheat crops sometimes suffer drought stress in dry years.

Climate models, MRI-GCM (MRI) (Yoshikane et al., 2001) and CCSR/NIES-GCM (CCSR) (Yukimoto et al., 2001), projected increases in temperature and decreases in precipitation under an elevated atmospheric CO_2 concentration (690ppm) in 2070's in Adana. Those climate changes should give impacts on the production of wheat, which is the most important crop in Adana.

In this report, the impact of global warming on wheat production in Adana was predicted by using a wheat growth model, SimWinc (Nakagawa and Kobata, 2005), outputs of climate models, MRI and CCSR for 9 years and soil water conditions simulated by SiBUC (Tanaka and Ikebuchi, 1994). We first conducted district-based analyses, followed by the integration into the prefecture level, for Adana includes regions with diverse climates.

2. Current Wheat Production in Adana

Total wheat production in Adana is about 1.3 million tons on average for recent seven years, produced from the cultivated area of 0.31 million ha with the average yield of 4.0 t ha^{-1} (Table 1). 95 % of wheat production is concentrated in districts in the pain

Table 1. Wheat cultivation area, average yield and production in each district in Adana Prefecture (calculated from Agricultural Statistics in Adana during 1999-2005). The number of each district corresponds to that in the map of Fig. 1.

No.	District	area (x10^3 ha)	yield (t ha^{-1})	production (x10^3 t)
1	Tufanbeyli	15.4	2.06	31.7
2	Saimbeyli	2.5	1.50	3.7
3	Feke	3.8	1.61	6.1
4	Pozantı	1.9	2.14	4.2
5	Aladağ	5.4	3.01	16.4
6	Kozan	41.0	3.79	155.2
7	İmamoğlu	30.6	3.79	115.9
8	Karaisalı	19.1	3.42	64.9
9	Seyhan	9.0	4.92	44.2
10	Yüreğir	64.4	4.63	298.1
11	Ceyhan	83.4	4.26	352.5
12	Karataş	16.2	4.79	77.2
13	Yumurtalık	20.7	4.32	87.9
total/mean		313.3	4.01	1258.0

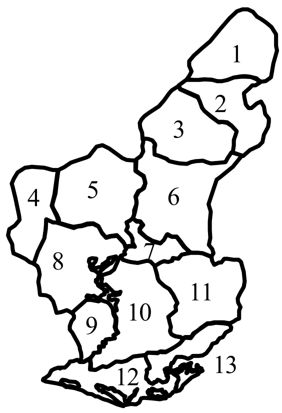

Fig. 1. Districts in Adana with the reference numbers of Table 1.

area (district number 6 - 13 in Table 1). Average wheat yield is 4.2 t ha^{-1} in the plain area, while 2.1 t ha^{-1} in the mountainous area. However, wheat production in mountainous districts (district number 1-5) is still important, because their farming is rather for their subsistence and more directly linked to their lives.

For example, a mixed cropping system with common and durum wheat, barley and rye was found in a mountainous area between Feke and Saimbeyli in our field survey for cropping system. We heard farmers there sowed and harvested mixed-species all at once, and made bread from the mixed flour. That production system, possibly with long history, seemed to be mainly for their own consumption.

Wheat crops are cultivated mostly under rainfed conditions, excluding additional irrigation in some dry years in irrigation areas. The irrigated wheat area is restricted to only a few percentage. Spring and winter wheat cultivars are sown in autumn in the plain and mountainous areas, respectively.

3. The Wheat Model SimWinc and its testing

SimWinc is a simplified process model for simulating the growth of winter cereals, such as wheat, under drought-prone environments. The model consists of four sub-models related to phenology, LAI growth, biomass production and yield formation process.

Biomass production is simply expressed by the product of intercepted solar radiation and radiation use efficiency (*RUE*) as a function of atmospheric CO_2 concentration ($[CO_2]$) and fraction of transpirable soil water content (*FTSW*):

$$RUE = RUE_{370} \cdot \{1+0.3784 \cdot \ln([CO_2]/370)\} \times f\,(FTSW) \quad (1)$$

The effect of CO_2 on biomass production was parameterized after the results of FACE experiments for wheat (Kimball et al., 1995). *f (FTSW)* was determined by a pot experiment for wheat (Kobata et al., unpublished). Other parameters in SimWinc were determined with the results of field experiments at Çukurova University in Adana and at Ishikawa Prefectural University in Japan.

Attainable yields under rainfed conditions were simulated by SimWinc for each district in Adana between 1994 and 2002. The average attainable yields for 9 years were compared with actual farmers' yields in statistics averaged over 7 years from 1999 to 2005 (Fig. 2). Simulated attainable yield was tuned to a yield level observed under

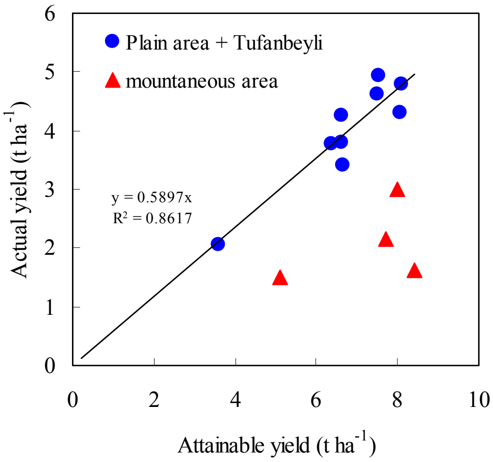

Fig. 2. Comparison between reported wheat yields (the average during 1999-2005) and attainable yields simulated by SimWinc (the average during 1994-2002) for every districts in Adana. A line that coincided with the origin was fitted to the data from districts in plain area and Tufanbeyli.

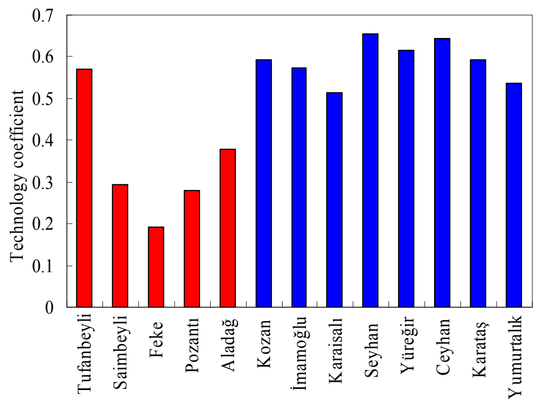

Fig. 3. Technology coefficients, which are used to convert attainable yields to farmers' yield levels. Red and blue bars denote districts in the mountainous and plain areas in Adana, respectively.

nearly ideal conditions at the experimental field of Çukurova University, and was always larger than farmers' average yield. There was a close relationship between actual and attainable yields excluding several districts in the mountainous area, indicating that SimWinc could partly explain the location-to-location yield variation in Adana. Farmers' yields were 59% of attainable yields on average for the districts in the plain area. Simulated yields (Y_p) can be converted into actual farmers' yields (Y_a), multiplied by 'technological coefficient (TC)', which is the ratio of actual farmers' yields to simulated yields and regarded as a kind of integrated index for agricultural technology:

$$Y_p = TC \times Y_a \quad (2)$$

The values of TC under the current climate conditions were relatively stable in the plain area and ranged 28 to 57% in the mountainous area (Fig. 3). We simulated wheat yields under the future climate conditions, assuming that the value of TC would be unchanged in each district.

4. Effect of Climate Change on Wheat Production in Adana

4.1 Input data

For predicting the effects of elevated CO_2 and the resulting climate on wheat production in Adana, one or two representative points were selected in each district of Adana (16 points in total). We used daily weather data for nine years from 1994 to 2003 at the representative points, which were the outputs of MRI model, for a base line analysis. Similarly we used outputs of MRI and CCSR models for 9 years in 2070's as pseudo warming climates with the atmospheric CO_2 concentration of 690 ppm.

The soil water content of root zone was estimated by SiBUC under the respective climates. The estimated soil water content *(W)* was converted into *FTSW* by the use of field capacity (W_{fc}) and permanent wilting point (W_{pw}):

$$FTSW=(W - W_{pw})/(W_{fc} - W_{pw}) \quad (3)$$

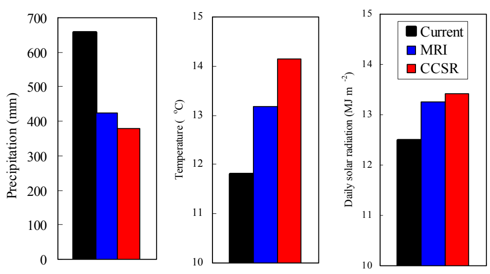

Fig. 4. Total precipitation, mean temperature and mean daily solar radiation during the growth period of wheat crops under the current, MRI and CCSR climates.

Precipitation was predicted to decrease by 234 and 278 mm on average over the 16 representative points for 9 years under MRI and CCSR climates, respectively, from the current level of 657 mm (Fig. 4). Similarly, average growth temperature would increase 1.4 and 2.3 ºC and average daily solar radiation would increase by 6.3 and 7.7%.

CO_2 concentration was set at the current (370 ppm) or a future level (690ppm) for simulating wheat yields under the future climates.

4.2 Effect of pseudo warming on attainable yields

Fig. 5 shows the effects simulated by SimWinc under the MRI and CCSR climates with or without an increase in CO_2 concentration on the relative change in wheat yield from the current. 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 districts 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.

4.3 Probability analysis on effects of pseudo warming on wheat yields

Probability analyses were made on effects of pseudo warming and nearly doubling CO_2 on wheat yield for representative locations, by using simulation results for 9 years under the current and pseudo warming climates described previously. Fig. 6 gives the probability analysis by SimWinc at four representative locations.

At Adana city, the average predicted yield under the current climate was 4.99 t ha^{-1} with a coefficient of variation (CV%) of 7.0%. Decreases of 10.8 and 13.0% in yield were predicted for MRI and CCSR

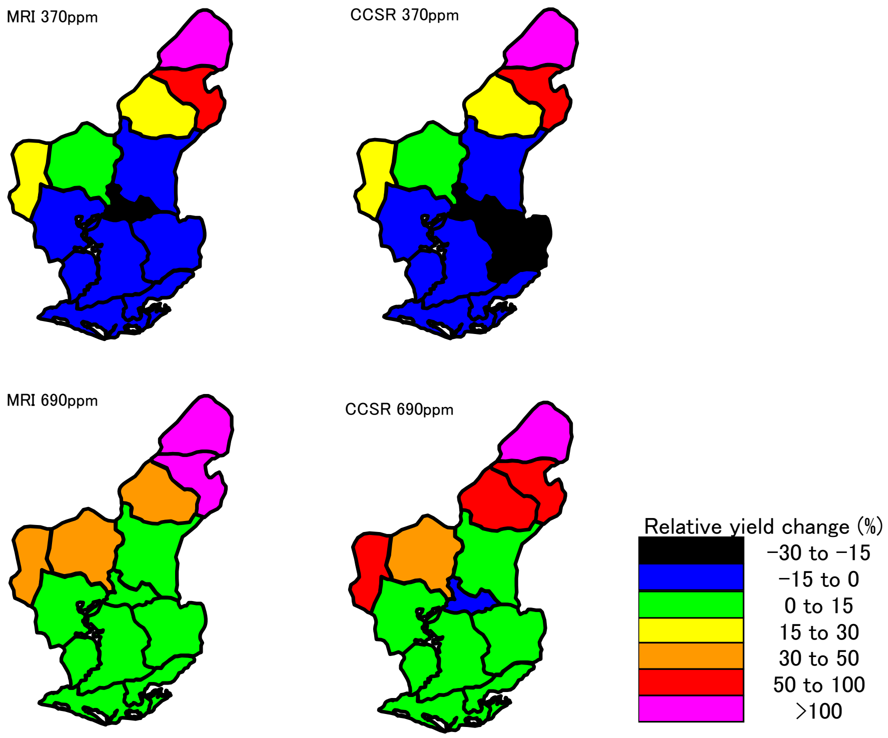

Fig. 5. Effects of climate change predicted by two GCMs with and without CO_2 fertilization effects on wheat yield in Adana (predicted by SimWinc).

climates, respectively, when we did not include the CO_2 effects. With CO_2 effects, increases of 10.2 and 7.5% were predicted. Predicted CV%'s were 10.9 and 12.5% under MRI and CCSR climates, respectively, irrespective of CO_2 concentration. Under the both pseudo warming climates, decreases in rainfall were predicted to cause yield reduction and to increase the variability of wheat yield. While the negative effects of global warming on average yield was expected to be compensated for by an increase in CO_2 concentration, yield variability would not be improved by that.

Similar results were obtained at other locations in the plain area, Yemişli and Sevinçli, although reduction in average yield was predicted in Sevinçli under CCSR climate even with CO_2 effects.

On the other hand, large improvement in average yield by pseudo warming was predicted at Kayarcık in the mountainous area due to increases in temperature. Also yield variability would decrease under the future climates. In the current study, a phenological parameter for a spring cultivar Adana99 was tuned to well explain the current phenology in each district, based on our field survey. Although farmers use winter cultivars in some districts in the mountainous area, such as Tufanbeyli, our simulation results may be reasonable even in those districts on the assumption that farmers would readily change their cultivars into spring types under the global warming climates.

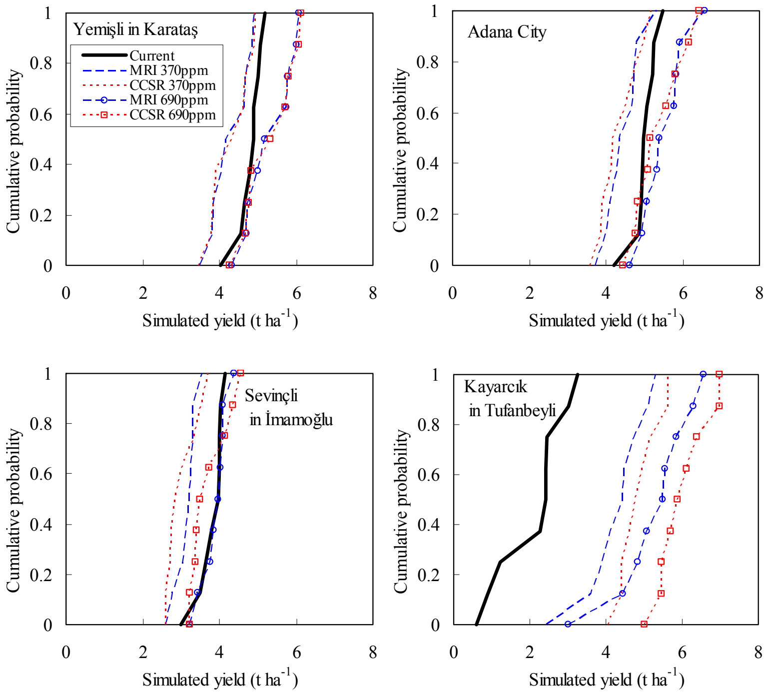

Fig. 6. Cumulative probability distributions for wheat yield at four locations in Adana under MRI and CCSR climates with and without CO_2 fertilization effects (predicted by SimWinc).

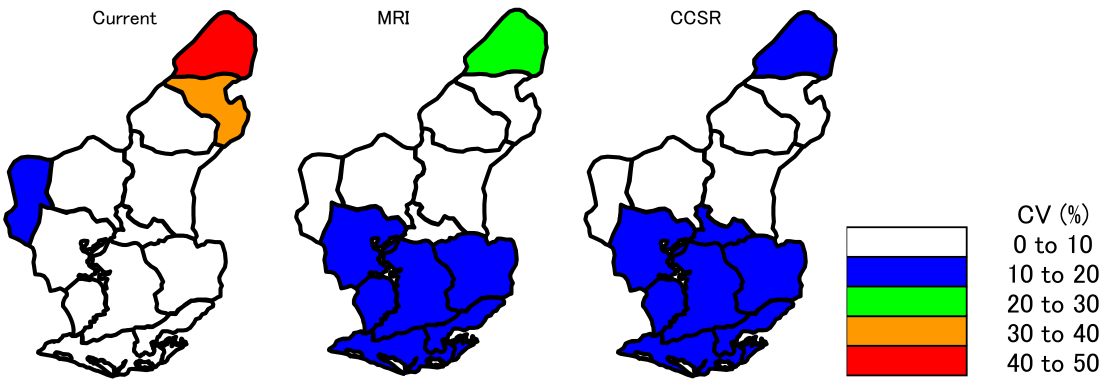

Fig. 7. Coefficients of variation in year-to-year change of wheat yield in Adana (predicted by SimWinc).

The same analysis was made for each district in Adana (Fig. 7). Similarly, the yield variability was predicted to increase in the plain area under the future climates, while to decrease in the mountainous area.

4.3 Rainfall and attainable yields

Simulated attainable yields under the current, MRI and CCSR climates without CO_2 effects were plotted against total precipitation during the growth period of wheat in Fig. 8. Although data were scattered in the figure, the maximum yield level attainable at an amount of total precipitation (a broken curve) seemed to be related with total precipitation. The maximum yield level was not related with precipitation above 500 mm, while it decreased with a decrease in precipitation below the value. Any yield data below the broken curve may be reduced by other factors, such as temperature and solar radiation.

A similar figure was made for Sağkaya in Ceylan, where precipitation was more important yield determinant (Fig. 9). Attainable yield was more clearly related with total precipitation during the growth period. This relationship shows that decreases in precipitation by global warming would reduce wheat yield in some drought-prone areas in Adana.

5. Conclusions

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.

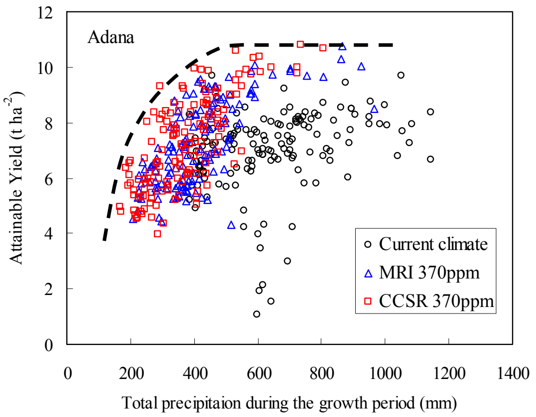

Fig. 8. Simulated attainable yield as a function of total precipitation during the growth period of wheat at 16 representative locations in Adana.

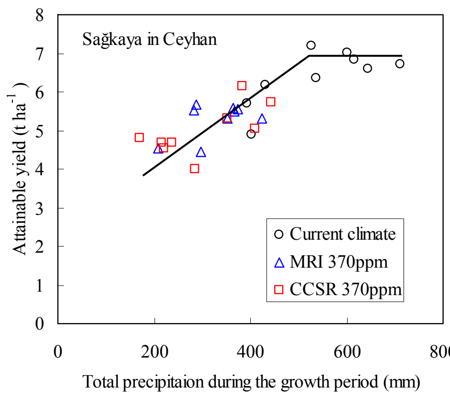

Fig. 9. Simulated attainable yield as a function of total precipitation during the growth period of wheat at Sağkaya in Ceyhan District.

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