Climate Change and Alternative Cropping Patterns in Lower Seyhan Irrigation Project: A Regional Simulation Analysis with MRI-GCM and CSSR-GCM

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1. Introduction

Water scarcity is a major concern for agricultural production in arid areas where the amount of rainfall is limited. According to the IPCC climate change scenario, it is often indicated that the summer temperature increases and winter rainfall decreases in the Mediterranean region (IPCC, 2001). How agricultural sector, or farmers will adapt the changes in future water scarcity in face of global warming? One way is to change cropping patterns and make adjustment for available water resources. Another way might be to change farming practices by adjusting cultivation period, applying appropriate crop rotations and/or developing and adopting new varieties that are resilient to future climate variability. The recent development in climate change forecast using global circulation models and regional climate models (GCM and RCM) made it possible to provide more detailed information on future changes in regional precipitation, temperature and other climatic variables in face of global warming. The Lower Seyhan Irrigation Project in Adana was initiated by the Turkish government as one of the most important irrigation projects located in southern Turkey. There is a strong concern over the impacts of future climate changes on the agricultural production systems. Thus it is of great importance to provide farmers and government authorities with the information on future regional changes in climate and possible scenarios and policy implications for the future.

The purpose of this paper is to assess the regional impacts of climate change on agricultural production systems in Seyhan river basin in Turkey. We estimate the water availability in the 2070s using the regional precipitation data from pseudo warming experiment and assess the possible cropping pattern and the farmer welfare in Lower Seyhan Irrigation Project (LSIP). We use expected value-variance (E-V) model that is used to analyze risk. The model maximizes basinwide total gross revenue of agricultural production according to the risk aversion coefficient. Higher values of risk aversion coefficient indicate more risk aversion. The solution of the model will give proportion of cropping area in LSIP to be allocated to different crops to maximize gross revenue per unit area under different risk aversion levels. By estimating future water availability in the LSIP during the 2070s, the simulation was run with i) base case under current water use level, ii) low water development scenario, and iii) high water development scenario, and iii) high water development scenario with the possibility of groundwater use.

Organization of the paper is as follows. The first section reviews current water use and cropping patterns in Lower Seyhan Irrigation Project. The second section explains the method of analysis, scenarios and data set used in the simulation analysis. The third section presents the results of simulation analysis and the last section concludes the paper with some policy implications for the future climate changes in the region.

2. Water Use and Cropping Pattern in Lower Seyhan Irrigation Project

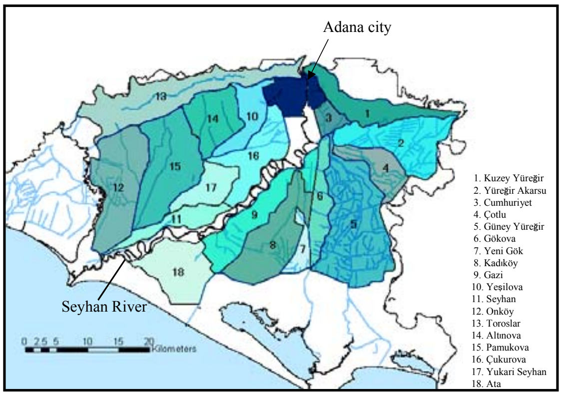

Figure 1. Lower Seyhan Irrigation Project and Water Users Associations

Lower Seyhan Irrigation Project (hereafter LSIP) is located in the south of Adana city stretching to the Mediterranean coast (Figure 1). Mediterranean climate prevails in the region with hot and dry summers and mild and rainy winters. The average annual rainfall is approximately 650mm and most precipitation occurs during the winter from November to March (Donma, 2004). The average temperature is 18 °C with max 45.6 °C and min –8.1 °C. The dominant irrigation technology is gravity irrigation.

For agricultural development in Turkey, three types of government intervention played an important role. Those are an access to credit facilities, price support policies, and the provision of irrigation infrastructure (Hale, 1981). The Lower Seyhan Irrigation Project in Adana was initiated by the Turkish government as one of the most important irrigation projects located in southern Turkey (Figure 1). The Government constructed The Seyhan Dam in 1956 for the purposes of irrigation, power generation and flood protection. The reservoir can store 1.2 billion cubic meters that supply irrigation water to LSIP. Construction of irrigation and drainage networks of Seyhan Plain has four stages. So far, area only up to stages I through III have completed and the area for stage IV at the down stream have left without concrete canal infrastructure. The completion of the stage IV is facing a problem of high water table, salinity and insufficient drainage. Until 1993 small-scale irrigation systems were transferred to water users at a pace of about 2,000 hectares per year. DSI (General Directorate of State Hydraulic Works) encouraged farmers to organize Irrigation Groups (IGs) or Water User Groups (WUGs) with limited responsibility for operation and maintenance. After 1994, large-scale irrigation systems including Lower Seyhan Irrigation Project (LSIP) started to be transferred to water users associations (Tekinel, 2001; Donma, 2004; Umetsu et al. 2005). Since then, water users associations have been playing an important role for water allocation at the secondary and tertiary canals and at the end-use in addition to DSI.

Figure 2 shows the area planted for eight major irrigated crops in LSIP during the period between 1964 and 2004. During the 1960s, after the construction of the Seyhan Dam in 1956, cotton production expanded very rapidly. However, since the early 1980s, other crops such as maize, soybean, melon (mostly watermelon) and citrus increased gradually. And during the early 1990s, the area planted by maize surpassed that of cotton. The completion of Ataturk Dam in the Southeastern Anatolia project in 1990 shifted the center of cotton production to the Harran plain. Since the early 2000s, the share of land allocated to high value crops such as citrus and vegetable production has been gradually increasing.

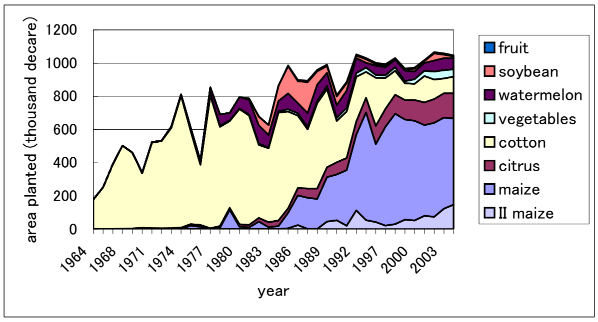

Figure 2. Area planted for 8 major irrigated crops in Lower Seyhan Irrigation Project (1964–2004); Source: DSI. Year 2002 Yield Census Results for Areas Constructed, Operated and Reclaimed by DSI. Verious years.

Table 1 shows the major agricultural crops in LSIP in 2002 cropping season. Irrigation season in Adana usually starts in April and ends in October or early November. When winter rainfall is not sufficient, spring wheat (November to May) is irrigated partially. The largest area was planted by maize (56.57%), followed by citrus (13.51%), cotton (7.36%), vegetables (6.30%), watermelon

Table 1. Major irrigated agricultural crops in LSIP in 2002

rank	area of production	%	production value	%	gross revenue	YTL/da
1	maize	56.57	citrus	38.90	strawberry	2,417
2	citrus	13.51	maize	33.43	citrus	1,180
3	cotton	7.36	watermelon	9.86	fruit tree	1,086
4	vegetables	6.30	vegetables	6.24	vineyard	875
5	watermelon	5.63	cotton	4.98	watermelon	718
6	soybean	4.38	soybean	1.40	greenhouse and II crop vegetable	640
	total	93.75	total	94.81	average	426
					average (2005 price)	707

Source: DSI (2003b) Transferred Irrigation Association Year 2002 Observation and Evaluation Report, DSI Region VI, Lower Seyhan Irrigation Project, Operation and Maintenance Department. II vegetables=second crop vegetabels.

(5.63%) and soybean (4.38%). In terms of production value, the highest value comes from citrus (38.90%), maize (33.43%), watermelon (9.86%), vegetables (6.24%), cotton (4.98%) and soybean (1.40%). Thus these major six crops covered 93.75% of total irrigated area and yielded 94.81% of total gross revenue of LSIP in 2002. Crops that yielded the highest gross revenue per decare[1] in 2002 are strawberry (2,417 YTL[2] / da) and citrus (1,180 YTL / da) followed by fruit tree (1,086 YTL / da) and vineyard (875 YTL / da).

Table 2 summarizes the result of Delphi forecast given by the staff members of 18 water users associations in LSIP in 2005. This method is typically used by the engineering sector to predict when the particular technology would be available in the future. Here Delphi forecast was used to obtain WUA staff members' view on the future cropping patterns in the year 2033. The column (a) shows the actual cropping pattern in LSIP reported in 2003. Maize acreage is 54.3% followed by citrus, cotton, watermelon and vegetables. The column (b) indicates the forecast of the cropping pattern of entire LSIP (Seyhan) in the year 2033. In

Table 2. Delphi forecast of cropping pattern in LSIP by WUA

	(a) Seyhan 2003 (observed)	(b) Seyhan 2033	(c) Seyhan by each WUA 2033	(d) Seyhan by WUA control	(e) Seyhan by WUA 10% water reduction	(f) Seyhan by WUA 20% water reduction
maize	53.3	40.6	42.6	31.9	26.3	21.3
citrus	14.2	21.3	23.9	26.4	25.9	27.2
cotton	8.7	10.9	9.0	9.0	12.9	14.4
watermelon	7.0	8.2	6.5	4.8	4.5	4.9
vegetables	4.8	6.2	7.8	8.8	8.0	5.3
onion	1.4	2.0	1.4	1.3	1.4	1.5
soybean	2.0	4.9	4.2	7.4	8.6	9.2
fruit	0.7	1.7	2.0	4.6	4.7	5.1
others	7.7	4.1	2.7	5.8	7.7	9.0
100%						
II maize	12.0	13.9	11.8	10.0	6.6	5.2
II vegetables	2.3	4.2	2.0	3.7	3.1	2.8

Source: Data in 2003 are from DSI (2004) Year 2003 Yield Census Results for Areas Constructed, Operated and Reclaimed by DSI. DSI Operation & Maintenance Department, Ankara.
Other information are from authors' interview survey (2005).
II maize = second crop maize; II vegetabels = second crop vegetables

1 decare (da) = 0.1 hectare
2 New Turkish Lira

this case, maize cultivation is reduced to 40.6% and citrus, cotton and watermelon increased. The column (c) shows the forecasts by WUA staff members for their WUA's own command area and then aggregated using land share parameters. Again maize area reduced and citrus area increased. Usually the decision of the cropping pattern is made by the individual farmers and then they are aggregated and reported to DSI by water users associations for planning water allocation for the next irrigation season. The column (d) shows the cropping pattern by assuming WUA has a full control of their command area. In this case, maize and watermelon decreased and citrus, vegetables and soybean expanded compared to 2003 cropping pattern. Additional questions were made in case of 10% and 20% irrigation water reduction case in column (e) and (f) respectively. In this case, maize cultivation is reduced to less than a half and citrus, cotton, soybean and fruit expanded. By the reduction of the water resources, farmers are more likely to choose high value crops such as citrus, vegetables and fruit.

3. Method and Data

3.1 *Method*

In order to estimate the optimal land resource allocated to various crops under different risky alternatives and constraint of water resources, expected value-variance (E-V) model was used. This model is used to analyze decision making in risky situations and it maximizes expected total return (or gross revenue) under different levels of variance of total return. In this model, expected return can be increased only at the expense of a larger variance of return. The optimal decision comes from the preferences on tradeoffs between expected return and variance of return. In other words, a risk-averse farmer will chose high expected return while choosing the low variance of return (Harwood et al., 1999). Using this E-V model, it is possible to analyze optimal decision making under risky situations. The specification of expected value-variance (E-V) model is as follows:

$$\text{Max } Z = \sum_j \bar{c}_j X_j - \Phi \sum_j \sum_k s_{jk} X_j X_k$$

$$\text{s.t} \quad \sum_j p_j X_j \le b \qquad (2)$$

$$\sum_j X_j = 1 \qquad (3)$$

$$\text{and} \quad X_j \;>= 0 \quad \text{for all } j,$$

where X_j is the proportion of land allotted to j^{th} crop, $\bar{c}_j$ is the mean gross revenue per decare for crop j, s_{jk} is the covariance of gross revenue between crop j and crop k, p_j is the water requirement per decare of j^{th} crop, and b is the maximum amount of water available per decare for irrigation and Φ is the risk aversion coefficient. Higher values of risk aversion coefficient indicate more risk aversion by decision makers. When Φ is equal to 0, the decision maker is risk neutral. The solution of the model will give proportion of the area to be allocated to different crops to maximize gross revenue per decare under different risk aversion levels. The equation (2) indicates that the amount of water used in the farm per decare is equal to or less than the total available water per decare for the entire LSIP.

3.2 *Scenarios*

For assessing the regional impacts of climate change on agricultural production systems in the 2070s, we used seven cases for simulation as shown in Table 3. Those include a base case, scenario 1, scenario 2 and scenario 3 using two types of climate change information given by MRI-GCM and CCSR-GCM, which we will describe later.

Table 3. Water availability in LSIP under the climate change and water development scenario

		Base	MRI-GCM			CCSR-GCM			
		Base	**Scenario 1** climate change with low water development	**Scenario 2** climate change with high water development	**Scenario 3** climate change with high water development with 150mm GW	**Scenario 1** climate change with low water development	**Scenario 2** climate change with high water development	**Scenario 3** climate change with high water development with 150mm GW	
		2002	2070s	2070s	2070s	2070s	2070s	2070s	
(a)	conveyance efficiency	0.8	0.6	0.8	0.8	0.6	0.8	0.8	
(b)	application efficiency	0.6	0.6	0.7	0.7	0.6	0.7	0.7	
(c)=(a)x(b)	total efficiency	0.48	0.36	0.56	0.56	0.36	0.56	0.56	
(d)	actural water released for LSIP	1424	1523	1112	1112	1294	854	854	million m3
(e)=(d)x(c)	actural water available for LSIP	683.5	548.1	622.7	622.7	465.8	478.5	478.5	million m3
(f)	total service area of LSIP	1,168,830.0	1,168,830	1,168,830	1,168,830	1,168,830	1,168,830	1,168,830	decare (da)
(g)=(e)/(f)	water availability per decare	585	469	533	683	398	409	559	m3/da (mm)
(h)	total service area with IV complete			1,450,980	1,450,980		1,450,980	1,450,980	decare (da)
(i)=(e)/(h)	water availability per decare with IV complete			429	579		330	480	m3/da (mm)

Source: (d) Water level for Scenario 1 and Scenario 2 was estimated by the Seyhan basin hydrology model (Tanaka et al. 2006).
Base water level is from DSI (2002) Briefing of WUA and Year 2002 Management Activity Report, DSI Region VI, Adana;
(f) from DSI (2003b) Transferred Irrigation Association Year 2002 Observation and Evaluation Report,
DSI Region VI, Lower Seyhan Irrigation Project, Operation and Maintenance Department.

a) Base case

The current conveyance efficiency in LSIP and on-farm application efficiency under furrow irrigation systems are considered to be 0.8 and 0.6 respectively. Then it yields 0.48 as the overall irrigation water efficiency in LSIP. The total volume of water available for LSIP in 2002 was 1,424 million cubic meters. The total service area in 2002 was 1,168,830 decares (116,883 hectares) including irrigated area without canal infrastructure in Region IV. By dividing the actual amount of water available for LSIP by the total service area in LSIP, the annual water availability of 585 mm for the base case was estimated.

b) Scenario 1: Global warming under low water development

By the 2070s, no significant investment in water development, i.e. additional canal networks and dams, is made. In the upper and middle basin of Seyhan River, the entire wheat and barley area is converted to pasture. Also, forest area remains the same as present condition. In LSIP, the downstream of Seyhan river basin, the conveyance efficiency decreases from 0.8 to 0.6 due to no investment on canal maintenance. Then it yields 0.36 as the overall irrigation water efficiency in LSIP. The precipitation will decrease according to future climate change from pseudo warming experiment. The decrease in precipitation in the 2070s is reflected in the reduction of estimated potential water available for LSIP. The irrigated area remains the same as the base case with 469 mm annual water availability. The reduction of precipitation will also increase irrigation water requirement for each crop.

c) Scenario 2: Global warming under high water development and increased irrigated area

By the 2070s, significant investment in water development, i.e. canal networks and dams, is made. In the upper basin, barley remains as present. About 25% of winter wheat in the middle basin is now converted to the irrigated agricultural area where citrus is cultivated. In LSIP the conveyance efficiency remains 0.8 the same as base case with investment on canal maintenance, and the application efficiency increases to 0.7 by improving on-farm irrigation technology. Then it yields 0.56 as the overall irrigation water efficiency in LSIP. The precipitation will decrease according to pseudo warming experiment. The decrease in precipitation in the 2070s is reflected in potential water available for LSIP. The reduction of precipitation will also increase irrigation water requirement for each crop. The irrigation infrastructure in region IV of LSIP is now completed with complete canal networks and the total service area of LSIP expands to 1,450,980 decares (45,098 hectares) with 429 mm annual water availability.

d) Scenario 3: Global warming under high water development with 150 mm groundwater use

In addition to the significant investment in water development in scenario 2, additional 150 mm of groundwater use is now available. In LSIP the conveyance efficiency remains the same as scenario 2. The precipitation will decrease according to pseudo warming experiment. The irrigation infrastructure in region IV of LSIP is now completed with concrete canal networks with 579 mm annual water availability.

Similarly, the water availabilities for CCSR-GCM are 398 mm for scenario 1, 330 mm for scenario 2 and 480 mm for scenario 3 as shown in Table 3.

3.3 *Data*

In the simulation analysis, the following data set was used. (See Appendix 1 for the models and data sets for simulation analysis.) The RCM (Regional Climate Model) prepared for ICCAP[3] project (Kimura et al., 2006) provides various regional climate information in 2070s. For downscaling to Seyhan basin by RCM, the forcing data for the boundary condition of RCM are given by MRI-CGCM2 (Yukimoto et al., 2001; Kitoh et al., 2005) and CCSR-CGCM with T42 in wave truncation, which approximately corresponds to 2.5 degree (250 km grid) horizontal resolution[4]. Control run (1991-2000) of MRI-CGCM2 simulates the current climate condition, while global warming run (2071-2080) is performed based on A2 scenario in Special Report on Emission Scenarios (SRES) of IPCC (IPCC, 2001). Monthly precipitation in Seyhan river basin will decrease 10-40mm/month during cold season. Figure 3 shows the results of MRI and CCSR projections of precipitation in 2070s in Adana. The reduction of precipitation during winter and surface temperature are higher in CCSR although summer precipitations are higher in CCSR.

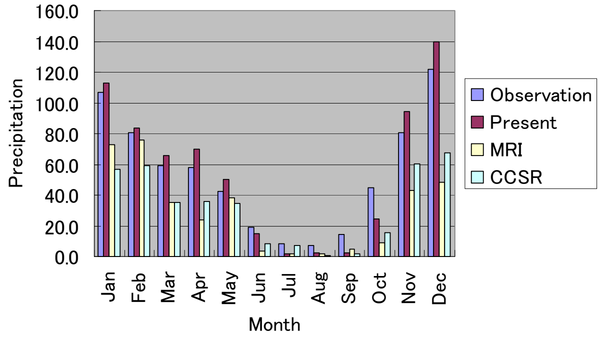

Fig. 3. Comparison of observed and projected precipitation in Adana

The potential total water availability at LSIP in the 2070s was estimated using SiBUC (Simple Biosphere including Urban Canopy) land surface model (Tanaka and Ikebuchi, 1994). This land surface model was designed to treat the land use condition (natural vegetation in forest area, cropland, urban area, water body) in detail including information on various irrigation schemes for different types of cropland in the entire Seyhan river basin. The SiBUC model utilizes the output of RCM. The RCM output includes seven meteorological components, i.e., precipitation, downward short-wave and long-wave radiation, wind speed, air temperature, specific humidity, and pressure. The simulation

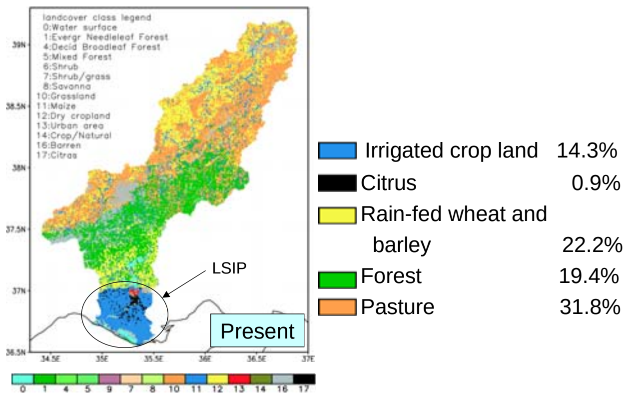

Figure 4. Present land use in Seyhan River basin

3 The Research Project on Impact of Climate Changes on Agricultural Production System in Arid Areas.

4 MRI-CGCM2 and CCSR-CGCM are coupled general circulation models developed by Meteorological Research Institute, Japan Meteorological Agency, Tsukuba, Japan, and Center for Climate Science Research, Tokyo University, Tokyo respectively.

Table 4. Irrigation water requirement of major crops in LSIP

crop	(a) 1990s irrigation water requirement (mm/year)	MRI-GCM (b) 2070s irrigation water requirement (mm/year)	MRI-GCM (b)-(a) future increase in water requirement (mm/year)	CCSR-GCM (c) 2070s irrigation water requirement (mm/year)	CCSR-GCM (c)-(a) future increase in water requirement (mm/year)
fruit	762.1	848.6	86.4	778.8	16.6
citrus	661.4	749.0	87.6	724.4	63.0
maize	569.0	611.0	42.0	594.2	25.2
soybean	539.0	559.9	20.9	546.2	7.2
cotton	524.2	583.0	58.8	569.3	45.1
II maize	391.4	385.9	−5.5	380.3	−11.1
vegetables	229.2	302.0	72.8	289.2	60.0
watermelon	195.9	195.2	−0.7	239.6	43.7

Source: (a) Nuran Özgenç, Faruk Cenap Erdoğan. (1988) DSI irrigated crop water consumption and irrigation water requirement.
(b),(c) Estimated from the average precipitation decrease in 2070s from peud-warming experiment (Kimura et al., 2006). We used the same level of evapotranspiration in 2070s based on the results that the decrease in duration days trade offs the increase in precipitation increse by climate change.

period for RCM is from 1994 to 2003 for the present climate condition. The future climate condition in the 2070s is simulated using pseudo warming experiment. The potential water available for LSIP was estimated using the data of inflow at Seyhan Dam, domestic water use, river maintenance flow, and irrigation water intake in the upper and middle basin. (For further information on SiBUC land surface model please see Tanaka et al. 2006.) Figure 4 indicates the present land use in Seyhan River basin. The total watershed area is 21,734 km^2 and the land cover class in upper and middle basin are dominated by rain-fed wheat and barley (22.2%), pasture (31.8%) and forest (19.4%).

The actual water released for LSIP in 2002 was obtained from the data reported in *Briefing of WUA and Year 2002 Management Activity Report* (DSI, 2002).

Eight major irrigated crops[5] in LSIP are chosen for the simulation analysis. Those are maize, citrus, cotton, vegetables, watermelon, soybean, fruit and 2nd crop maize (II maize). The first six crops covered about 94% in terms of area planted as well as the total gross revenue of production in LSIP during the 2002 cropping season as mentioned in the previous section (Table 1).

Table 4 indicates the current and future irrigation water requirement of major crops in LSIP. The information on current water requirement of crops (a) was obtained from *DSI irrigated crop water consumption and irrigation water requirement* (Özgenç and Erdoğan, 1988) that most of the WUAs follow when they estimate the total irrigation water required before the next cropping season. The highest water user is fruit (762 mm per annum) followed by citrus (661 mm per annum) and maize (569 mm per annum). The crop water requirement in the 2070s (b) was estimated using the average observed monthly rainfall data during 1970-2005 and the decrease of rainfall in the 2070s estimated by pseudo warming experiment (Kimura et al., 2006) as follows.

$$WR_i = \Sigma(U_i - r + \Delta) - K_i, \qquad (4)$$

where *WR* is the irrigation water requirement by crop *i*, *U* is monthly evapotranspiration of crop *i* (Özgenç and Erdoğan, 1988), *r* is the current monthly average rainfall (1970-2005), Δ is the

[5] Wheat is not included in this analysis because wheat is usually not an irrigated crop. The area cultivated by spring wheat in 2004 was about 21.9%. The second maize is usually cultivated after harvesting spring wheat.

monthly decrease in precipitation in the 2070s (Kimura et al., 2006), K_i is the maximum residual soil moisture for crop *i* (Özgenç and Erdoğan, 1988) at the beginning of the crop period in spring. We aggregated only the water deficit months and then subtracted the maximum residual soil moisture that soil can contain from the aggregate net water requirement. We used the same level of evapotranspiration in the 2070s based on the observation that the shortening growing period trade offs the increase in evapotranspiration by climate change. According to this estimation, the future increase in water requirement per annum is particularly high in citrus, fruit and vegetables by 87.6 mm, 86.4 mm, and 72.8 mm respectively for MRI-GCM. The future increase in water requirement for CCSR-GCM is less than the case for MRI-GCM due to the higher precipitation projection during the summer. Under the climate change with decreasing precipitation and rising temperature, it may be possible that the irrigation period may start earlier than the current irrigation period that normally stretches between April and October. However, this aspect was not considered in the analysis.

The gross revenue per decare from production of each crop in LSIP from 1996 to 2004 was obtained from the annual report of *Yield Census Results for Areas Constructed, Operated and Reclaimed by DSI* (DSI, 1997-2005)[6]. Because of limited information on production costs during this period, only gross revenue for each crop was used for simulation instead of net return. The value of gross revenue for each year was re-evaluated with 2005 price so that the high inflation during this period is taken into account. The real monetary value depreciated to one thirtieth during this period. Another concern was the gross revenue of watermelon. Watermelon is usually cultivated only once in five years in the same plot to avoid replant failure. Using the actual gross revenue may overestimate the gross revenue of watermelon in the long run. In order to take into account the actual crop rotation of watermelon, weighted average of watermelon (1 year) and maize (4 years) was used for simulation.

[6] Every year, water users associations report their cropping pattern, price, yield and gross revenue per decare for major crops to DSI. This data is aggregated to make a yield table for Seyhan (LSIP).

4. Simulation Results

4.1 *Results from MRI-GCM*

The amount of irrigation water available for LSIP in the 2070s is expected to decrease because of the decrease in precipitation by 5-90 mm in most of the months in Adana according to the pseudo warming experiment by ICCAP (Kimura et al., 2006). Given the availability of irrigation water in the 2070s from the SiBUC land surface model and future irrigation water requirement by crops, the simulation of E-V model was run with i) the base case under current water use level (585 mm per annum), ii) scenario 1 with the climate change case under low water development scenario (469 mm per annum), and iii) scenario 2 with the climate change case under high water development scenario when canal infrastructure in region IV at the downstream of Seyhan river is completed (429 mm per annum), iv) scenario 3 under high water development with 150 mm groundwater use (579 mm per annum).

Table 5-8 shows the simulation results of four cases. These tables indicate the land allocation to various crops in LSIP with risk aversion parameter (RAP) between 0 and 0.02. When RAP is 0, farmers do not avoid any risk. Higher the RAP, the risk averse attitude of farmers become stronger. Table 5 shows the base case under current water use level (585 mm water availability per annum). When farmers do not care any risk (when RAP=0), the area under citrus and vegetable is 82.3% and 17.7% of the total irrigated land of LSIP with average gross revenue of 1,981 YTL per decare. At the risk aversion level of 1%, area under citrus, cotton, vegetables and fruit is 22.0%, 59.3%, 7.0% and 11.6% respectively. This cropping pattern yielded average gross revenue of 718 YTL per decare at 2005 price. Considering that the actual gross revenue per decare was 707 YTL in 2002 at 2005 price (Table 1), the risk aversion level of farmers in LSIP may be close to 1%. In other words, farmers in LSIP will not likely to accept the gross revenue per decare lower than 2002 level. Higher risk aversion parameter of 2% yielded low gross revenue per decare because high risk aversion means more reduction of gross revenue from the annual variability between study periods. In the base case under risk aversion level of 1% and 2%, water resources are still under utilized resulting in redundant or idle water resources of 23.5 mm/year and 75.0 mm/year respectively. This indicates that in these two cases, water is not the constraining factor to allocate land in the model.

Similarly Table 6 shows the simulation results of the climate change case under low water development scenario in 2070s (469 mm water availability per annum). This case may be considered the pure impact of climate change by giving other social conditions remain the same except for the upper basin vegetation change from wheat/barley to pasture and deterioration of canal systems. The reduction of water availability and the increase of water requirement of crops resulted in lowering cotton production (49.7%) which are relatively water intensive, and increasing watermelon production (41.4%) which is relatively high value and high income variability with less water intensity, at 1% risk aversion level. At lower risk aversion level between 0 and 0.05%, citrus and vegetable cultivation expanded. Compared to the base case at the same risk aversion level of 1%, the gross revenue per decare decreased from 718 YTL to 707 YTL (both at 2005 price). This may indicate the situation that in face of climate change in 2070s when farmers want to avoid yielding lower gross revenue per decare, they may have to take a higher risk. At 1% and less risk aversion level, water resources are no more idle and generating positive shadow prices for water.

Table 7 shows the simulation results of the climate change case under high water development scenario in 2070s (429 mm water availability per annum). In this case, not only because of the climate change but also the expansion of irrigated area in middle watershed of Seyhan River in addition to region IV at the downstream, the entire LSIP has to endure with the irrigation water level of 429 mm per annum. As a result, at risk aversion level of 1% watermelon further expanded to 51.7% while cotton (15.1%) and vegetable (3.6%) reduced the acreage. Under the water constraint and variability of gross revenue, farmers are more likely to choose high value added crops relative to water requirement such as watermelon, citrus, cotton, fruit and vegetables. This trend has a similarity with the earlier Delphi forecast by WUA staff members that preferred high value crops such

Table 5. Land allocation in LSIP under base case (MRI)
(585 mm water availability)

RAP	0	0.001	0.005	0.01	0.02
citrus	82.27	82.27	57.45	22.00	4.12
cotton			17.91	59.33	70.31
vegetables	17.73	17.73	1.97	7.04	9.41
watermelon			11.72		5.43
fruit			10.95	11.63	10.74
gross revenue (YTL/da	1981	1770	1022	718	547
shadow price of water	2.926	2.313	0.085		
idle water (mm)				23.51	74.96

RAP: Risk Aversion Parameter

Table 6. Land allocation in LSIP under low water development scenario1(MRI)
(469 mm water availability)

RAP	0	0.001	0.005	0.01	0.02
citrus	37.36	46.73	49.44	22.05	4.23
cotton				23.96	47.76
vegetables	62.64	14.04		4.36	7.48
watermelon		39.23	50.56	41.35	31.78
fruit				8.28	8.75
gross revenue (YTL/da	1413	1303	983	707	543
shadow price of water	2.829	2.472	0.617	0.101	0.083
idle water (mm)					

RAP: Risk Aversion Parameter

Table 7. Land allocation in LSIP under high water development scenario2
with region IV complete (MRI)
(429 mm water availability)

RAP	0	0.001	0.005	0.01	0.02
citrus	28.41	39.34	42.05	22.09	4.27
cotton				15.11	38.91
vegetables	71.59	14.93	0.89	3.60	6.73
watermelon		45.73	57.07	51.69	42.12
fruit				7.50	7.97
gross revenue (YTL/da	1300	1203	952	703	539
shadow price of water	2.829	2.529	0.902	0.117	0.116

RAP: Risk Aversion Parameter

Table 8. Land allocation in LSIP under high water development scenario3
with region IV complete and 150mm GW use (MRI)
(579 mm water availability)

RAP	0	0.001	0.005	0.01	0.02
citrus	61.97	67.07	57.59	21.94	4.12
cotton			0.68	48.29	70.31
vegetables	38.03	11.58	0.19	6.44	9.41
watermelon		21.35	32.04	12.90	5.43
fruit			9.49	10.43	10.74
gross revenue (YTL/da	1724	1567	1016	716	547
shadow price of water	2.829	2.316	0.087	0.056	
idle					8.105

RAP: Risk Aversion Parameter

Table 9. Simulated cropping pattern of LSIP with MRI-GCM and CCSR-GCM

	2002	2070s MRI-GCM			2070s CCSR-GCM		
scenario	base	S-1	S-2	S-3	S-1	S-2	S-3
water availability (mm)	585	469	429	579	398	330	480
citrus	22.00	22.05	22.09	21.94	21.86	18.32	21.84
cotton	59.33	23.96	15.11	48.29	4.34		25.97
vegetables	7.04	4.36	3.60	6.44	2.98	3.17	4.74
watermelon (+maize)		41.35	51.69	12.90	64.03	78.51	38.82
fruit	11.63	8.28	7.50	10.43	6.80		8.64
gross revenue (YTL/da)	718	707	703	716	696	670	708
shadow price of water (YTL/m3)		0.101	0.117	0.056	0.164	0.796	0.116
idle water (mm)	23.51						

Risk aversion parameter = 1%

as citrus and vegetables. However this combination of crops will result in 703 YTL per decare, lower than the current (base) level of 718 YTL per decare at 2005 price.

Table 8 indicates the simulation results under high water development with 150 mm groundwater use. Because of additional groundwater is available, water availability in LSIP increased to 579 mm per annum. High water availability similar to base case allowed water intensive cotton production to expand (48.3%) and watermelon cultivation to decrease (12.9%). This combination of crops will result in annual gross revenue of 716 YTL per decare, which is similar to the base level of 718 YTL per decare at 2005 price.

The increasing shadow price of water by decreasing potential water availability in LSIP indicates the increasing scarcity of water resources

in the future. At 1% risk aversion level, shadow price of water is 0.101 YTL/m3 under low water development case (469mm). The shadow price further increases to 0.117 YTL/m3 under high water development case (429mm).

4.2 *Comparison of MRI-GCM and CCSR-GCM*

Figure 9 shows the comparison of simulation results with various results with MRI-GCM and CCSR-GCM. Because CCSR projected precipitation decrease and surface temperature increase in Seyhan River basin, the potential water available for downstream LSIP is also 70-100 mm smaller with CCSR climate outputs. As a result, comparing to MRI cropping patters, CCSR cropping pattern is more dominated by watermelon which is water efficient in terms of gross revenue generated per unit of water. Because the scarcity of water is intensified in CCSR, the shadow price of water increased to 0.796 YTL/m3.

5. Conclusions

This paper tried to assess the regional impacts of climate change on agricultural production systems by estimating the potential water availability and crop irrigation water requirement in the 2070s and simulating the possible cropping pattern and the farmer welfare in Lower Seyhan Irrigation Project (LSIP) in Turkey. We used expected value-variance (E-V) model that is used to analyze risk. The model maximizes total gross revenue of agricultural production in entire LSIP according to the risk aversion coefficient. Under the water constraint and variability of gross revenue, farmers are more likely to choose high value added crops relative to crop water requirement such as watermelon, citrus, cotton, fruit and vegetables. However in the case of climate change case under high water development scenario this combination of crops will result in 701 YTL per decare, lower than the current level of 718 YTL per decare at 2005 price. Also the future increases in variability of rainfall may affect negatively to the farmer welfare by decreasing gross revenue per unit of land.

Comparison of MRI-GCM and CCSR-GCM

outputs indicated that the results of future climate change projections in 2070s are sensitive to the type of Global Climate Models adopted for the analysis. In our analysis, CCSR-GCM showed less precipitation and higher surface temperature that resulted in intensifying water scarcity in downstream irrigated areas compared to MRI-GCM. It should be noted that these two sets of information should be considered as a range of constraining factors and possible adjustment for the future when we take any policy measures.

The future investment should target more efficient use of water resources by various alternative options. First, incentive mechanism is required for introducing on-farm technology and water pricing systems that save water substantially if the expansion of the irrigated area is continuing at the upstream as well as downstream of the Seyhan River basin. The current practice of furrow irrigation system for major field crops needs to be transferred to more efficient on-farm water technology if the water scarcity is going to be intensified. Second, the role of WUA for efficient use of irrigation water may be quite important and there is a potential for saving water substantially by improving management and organization of WUAs (Umetsu et al. 2005).

The option of cultivating high gross revenue generating crops such as citrus, fruit and vegetables needs to allow risk of annual gross revenue variability. However, this option may cause environmental pressure on land and water resources in LSIP by introducing more intensive use of pesticides and fertilizers. These options should be assessed carefully for the sustainability of agricultural production systems such as environmentally acceptable crop rotations and agronomic adaptations to prevent crop failure.

This paper did not take into account the following issues due to data limitations. The impacts of heat damages due to the increase in air temperature and the increase in CO_2 concentration in the atmosphere in the future was not considered. If the information on the impact of heat damages and CO_2 concentration on the decrease and/or increase of yield of various crops is available, it may be possible to include these factors into the simulation analysis. Especially for the heat damage, there is a possibility that the threshold level may be more important. For example, the tree crops such as citrus and fruit are more sensitive to heat damages at the stage of flowering. Also future price changes for each crop were not considered. If the future price projections for all crops are available for the 2070s, it may be possible to take into account the effect of price factors into the analysis. However, the future prices are more prone to future market availability and conditions such as Turkey integration into the EU agricultural market, which requires further investigation.

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Appendix 1. Schematic diagram of models and data sets for simulation analysis