Chapter 6 Climate Change and Alternative Cropping Patterns in Lower Seyhan Irrigation Project: A Regional Simulation Analysis

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1. Introduction †

The recent development in climate change forecast using global and regional climate models (GCM and RCM) made it possible to provide more detailed information on regional precipitation and temperature changes in face of global warming. There is a strong concern over the impacts of future climate changes on the agricultural production. Thus it is important to provide 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) the base case under current water use level, ii) the climate change case under low water development scenario, and iii) the climate change case under high water development scenario.

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

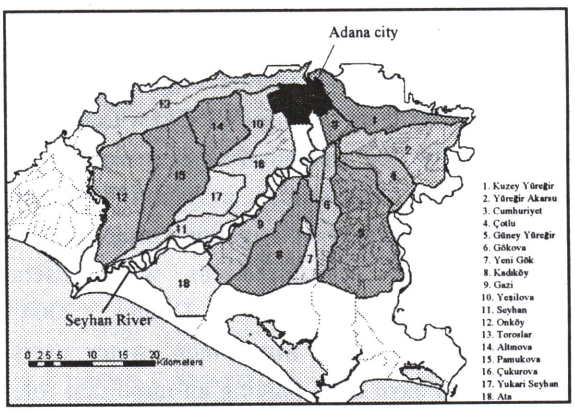

Figure 1. Lower Seyhan Irrigation Project and Water Users Associations

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The Lower Seyhan Irrigation Project in Adana was initiated by the Turkish government as one of the 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.

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.

So far, area only up to stage 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 the end-use in addition to DSI.

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.

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 (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).

3. Method and Data

3.1 *Method*

In order to estimate the optimal land resource allocated to various crops under different risky alternatives, expected value-variance (E-V) model was used. This model is used to analyze decision making in risky

[1] decare (da) = 0.1 hectare

[2] New Turkish Lira

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 (Harwood et al., 1999). In other words, if you are risk-averse farmer, you want to maximize expected return while choosing the low variance of return. 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:

$$\text{Max } Z = \sum_j \bar{c}_j X_j - \Phi \sum_j \sum_k s_{jk} X_j X_k \quad (1)$$

(1)

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

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

and X_j >= 0 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. 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.

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

		Base 2002	Scenario 1 climate change with low water development 2070s	Scenario 2 climate change with high water development 2070s	
(a)	conveyance efficiency	0.8	0.6	0.8	
(b)	application efficiency	0.6	0.6	0.7	
(c)=(a)x(b)	total efficiency	0.48	0.36	0.56	
(d)	actural water released for LSIP	1424	1882	1116	million m3
(e)=(d)x(c)	actural water available for LSIP	683.5	677.5	625.0	million m3
(f)	total service area of LSIP	1,168,830	1,168,830	1,168,830	decare (da)
(g)=(e)/(f)	water availability per decare	585	580	535	m3/da (mm)
(h)	total service area with IV complete			1,450,980	decare (da)
(i)=(e)/(h)	water availability per decare with IV complete			431	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.

3.2 *Scenarios*

For assessing the regional impacts of climate change on agricultural production systems in the 2070s, we used three cases for simulation as shown in Table 3.

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). By dividing the actual amount of water available for LSIP by the total service area in LSIP, the annual water availability of 585mm 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, the agricultural area remains the same with rainfed wheat production as a major agricultural practice. About 10% of wheat area now changed to pasture in the upper and middle basin. In LSIP the conveyance efficiency decreases 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 potential water available for LSIP. The irrigated area remains the same as the base case with 580 mm annual water availability. The reduction of precipitation will also increase water requirement for each crop.

c) Scenario 2: Global warming under high water development

By the 2070s, significant investment in water development, i.e. canal networks and dams, is made. In the upper and middle basin, about 25% of rainfed agricultural area is converted to the irrigated agricultural area in which maize (75%) and citrus (25%) are cultivated. In LSIP the conveyance efficiency remains 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 increase water requirement for each crop. The irrigation infrastructure in region IV of LSIP is now completed with concrete canal networks and the total service area of LSIP expands to 1,450,980 decares (45,098 hectares) with 421 mm annual water availability.

3.2 *Data*

In the simulation analysis, the following data set was used. (See Appendix 1 for the flow of data sets and models used.) The RCM (Regional Climate Model) prepared for ICCAP[3] project (Kimura et al., 2006) provides various regional climate information in the 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) with T42 in wave truncation, which approximately corresponds to 2.5 degree (250km grid) horizontal resolution. 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) (IPCC, 2001).

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, 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 period for RCM is from 1994 to 2003 for the present climate condition. The future climate condition in the 2070s is simulated using

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

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.)

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

Eight major irrigated crops[4] 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).

Table 4. Irrigation water requirement of major crops in LSIP

crop	(a) 1990s irrigation water requirement (mm/year)	(b) 2070s irrigation water requirement (mm/year)	(b)-(a) future increase in water requirement (mm/year)
fruit	762.1	843.9	81.7
citrus	661.4	769.2	107.7
maize	569.0	570.8	1.7
soybean	539.0	538.3	-0.7
cotton	524.2	561.4	37.2
II maize	391.4	381.2	-10.2
vegetables	229.2	290.8	61.6
melon	195.9	217.6	21.7

Source: (a) Nuran Özgenç, Faruk Cenap Erdoğan. (1988)
DSI irrigated crop water consumption and irrigation water requirement.
(b) 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.

4 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.

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.

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

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 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 is particularly high in citrus, fruit and vegetables by 108 mm per annum, 82 mm per annum, and 62 mm per annum respectively. 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 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)[5]. Because of limited information on production cost 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.

4. Simulation Results

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. High risk aversion parameter of 2% yielded low gross revenue per decare because high risk aversion parameter 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 mm/year respectively. This means that in

[5] 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).

these 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 the 2070s (580 mm water availability per annum). This case may be considered the pure impact of climate change by giving other social conditions remain the same. The reduction of water availability and the increase of water requirement of crops resulted in lowering citrus production (21.8%) and cotton production (49.7%) which are relatively water intensive, and increasing watermelon production (11.3%) 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%, 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 716 YTL (both at 2005 price). This may indicate the situation that in face of climate change in the 2070s when farmers want to avoid yielding lower gross revenue per decare, they may have to take a higher risk. The impacts of climate change with other conditions remains the same is not very substantial. At 1% and less risk aversion level, water resources are no more idle resource generating positive shadow prices for water.

Table 7 shows the simulation results of the climate change case under high water development scenario in the 2070s (535 mm water availability per annum). In this case, not only because of the climate change but also the expansion of irrigated area in middle and upper watershed of Seyhan River, the potential water availability for LSIP is further reduced substantially compared to the previous two cases. As a result, at risk aversion level of 1% watermelon further expanded to 24.3% while cotton (38.6%) and vegetable (5.7%) reduced the acreage. When the canal infrastructure in region IV at the downstream is completed in the 2070s, the entire LSIP has to endure with the irrigation water level of 431 mm per annum (see Table 8). In this case, watermelon (54.4%), citrus (21.9%), cotton (12.9%), fruit (7.3%) and vegetables (3.6%) are cultivated. Under the water constraint

Table 5. Land allocation in LSIP under base case (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 (580 mm water availability)

RAP	0	0.001	0.005	0.01	0.02
citrus	60.38	60.71	56.94	21.84	4.12
cotton				49.68	70.31
vegetables	39.62	37.14	0.32	6.63	9.41
watermelon		2.15	35.11	11.32	5.43
fruit			7.63	10.53	10.74
gross revenue (YTL/da	1704	1538	1014	716	547
shadow price of water	2.644	2.319	0.151	0.06	
idle water (mm)					23.48

RAP: Risk Aversion Parameter

Table 7. Land allocation in LSIP under high water development scenario2 (535 mm water availability)

RAP	0	0.001	0.005	0.01	0.02
citrus	50.98	52.34	55.71	21.86	4.13
cotton				38.57	65.00
vegetables	49.02	38.83	0.13	5.71	8.97
watermelon		8.84	42.60	24.32	11.64
fruit			1.56	9.54	10.27
gross revenue (YTL/da	1585	1433	1003	713	547
shadow price of water	2.644	2.382	0.333	0.083	0.022
idle water (mm)					

RAP: Risk Aversion Parameter

Table 8. Land allocation in LSIP under high water development scenario2 with region IV complete (431 mm water availability)

RAP	0	0.001	0.005	0.01	0.02
citrus	29.25	32.97	38.17	21.90	4.17
cotton				12.89	39.32
vegetables	70.75	42.73	3.56	3.58	6.84
watermelon		24.30	58.27	54.38	41.70
fruit				7.25	7.98
gross revenue (YTL/da	1310	1177	934	701	539
shadow price of water	2.644	2.529	1.031	0.137	0.129

RAP: Risk Aversion Parameter

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 as citrus and vegetables. However this combination of crops will result in 701 YTL per decare, lower than the current 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 0.06 YTL/mm or 3.48 YTL per decare under low water development case (580mm). The shadow price further increases to 44.4 YTL per decare (535mm) under high water development case and 59 YTL/da (431mm) under high water development case with completed canal networks in region IV.

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.

The future investment should target more efficient use of water resources by introducing on-farm technology and water pricing system that save water substantially if the expansion of the irrigated area is continuing at the upstream and downstream of the irrigation project. The option of taking more risk, i.e. allowing risk of gross revenue variability, yields higher average gross revenue per unit of land in most of the case. However, this option may cause environmental pressure on land resources by introducing more intensive use of pesticides and fertilizers. These options should be assessed carefully for the sustainability of agricultural production systems in LSIP.

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 such as Turkey integration to the EU agricultural market.

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