

# ECONOMICS OF CONJUNCTIVE WATER MANAGEMENT IN PAKISTAN

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## ABSTRACT

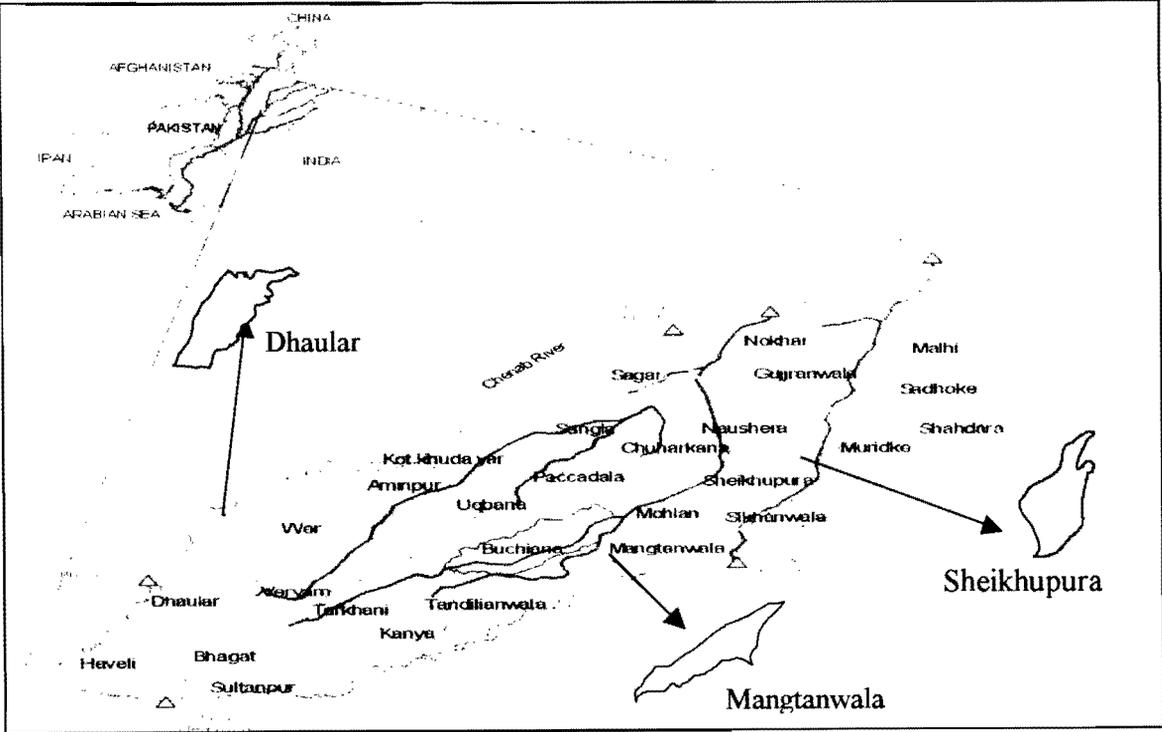
The paper assesses the on-farm financial gains for rice growing farms through different modes of irrigation and compares them with conjunctive water use. The data used in this study was collected from 544 farms located in the Rechna Doab. The results highlighted the problem of increased use of tubewell water in the saline groundwater zones that had resulted in the deterioration of the soils and groundwater quality, which has led to the problem of permanent upconing of saline groundwater. Conjunctive water management in rice crop increased the farm income by about Rs. 4400 and Rs. 10000 per hectare compared to only using the canal and tubewell water, respectively. The SWAGMAN Farm Model has also been used to evaluate the financial and environmental trade-offs for effective conjunctive water management in the Rechna Doab. The SWAGMAN Farm Model was developed by CSIRO (Australia) and was adapted for 28 sub-divisions in the Rechna Doab. Among 28 sub-divisions, this paper reports the results from three sub-divisions namely, Sheikhpura, Mangtanwala and Dhaur. The model optimization results showed that it is possible to increase the total gross margins while keeping the salinity levels and the changes in depth to water table in the acceptable limits through conjunctive water management at the sub-division level.

## 1. INTRODUCTION

Pakistan is fortunate enough because its soils, topography and climate are generally suitable for farming but its agriculture sector faces the problem of scarcity of the irrigation water. This paucity of irrigation supplies has forced the farmers to use the groundwater to augment their surface supplies. The quality of groundwater in Pakistan varies from fit for irrigation to moderately saline to sodic. Thus the tubewell owners in the marginal quality groundwater areas are bound to use the tubewell water in conjunction with the surface water on their farms. Currently the farmers are using about 65.75 BCM of groundwater in Pakistan (Halcrow, 2002). The international literature is filled with the studies on conjunctive water management and its impact on crop productivity and related issues [Gangwar and Toorn (1987), Bredehoeft and Young (1983); Gorelick (1988), Lingen (1988), O'Mara (1988); Shah (1988); Brewer and Sharma (2000), Datta and Dayal (2000), Raju and Brewer (2000), Sakhtivadivel and Chawala (2002) and Chaudhary and Shah (2003)]. In Pakistan, the review of literature shows that all of the previous studies conducted in the arena of water management reported the management problems leading to the inefficiencies in irrigation application and reduction in crop productivity, [Kijne and Velde (1991); Mustafa (1991) and Siddiq (1994)]. Few of the studies took into consideration the impact of waterlogging and salinity on productivity at farm level [Meyer *et al.* (1996), Prathaper *et al.* (1997) and O'Connell and Khan (1999)]. None of these studies have taken into consideration the trade-offs between gross farm income, groundwater and salinity at

irrigation Subdivision level. To answer the issues of spatial differences in the trade offs between gross farm income, groundwater and salinity at irrigation Subdivision level, this paper presents the results of the optimization modeling at the sub divisional level in the Rechna Doab (area between the Ravi and the Chenab Rivers). The Rechna Doab has a gross area of 2.98 million hectare (Mha), of which 2.319 Mha is the Gross Command Area (Figure 1). In the Rechna Doab, three types of irrigation sources are commonly used on farms i.e. canal irrigation, tubewell irrigation and the combination of both. Irrigated agriculture started in the Rechna Doab in 1892 via the Lower Chenab Canal. The designed cropping intensity of the irrigation system was pitched low, in the order of 60-70 percent at the start, but now the cropping intensity is more than 120 percent, indicating the increased water demand. This demand is being met through more than 180,000 tubewells in the fresh groundwater areas of the Rechna Doab (Jehangir *et al.* 2002). The physiography of the Rechna Doab consists of (a) Active flood plains, (b) Abandoned flood plains, (c) Bar Uplands and (d) Kirana Hills (longitudinal across the doab). Regarding the groundwater quality, the Rechna Doab is divided into three distinct zones (i) Fresh Water Zone (TDS < 1000 ppm) 1.36 Mha. (ii) Mixing Zone (TDS 1000-3000 ppm) and (iii) Saline Zone (TDS > 3000 ppm) 0.198 Mha. The soils are tertiary in nature and have recent alluvial deposits that consist of fine to very fine sand and silt. Soils are southwesterly sloped and the slope is 0.38 meter/kilometer (m/Km) and 0.29 m/Km in the upper and lower parts, respectively. Surface salinity is found in patches covering more than 20 percent of the cultivated area in the Rechna Doab (1.17 Mha). The meaning of conjunctive water management and its scope, practices and standards vary a great deal depending on the scarcity and quality of water in the Rechna Doab. This paper also attempts to analyze the economics of conjunctive water management practices in the Rechna Doab and provide the results of the SWAGMAN Farm Model for optimal land use in three of its irrigation Subdivisions.

Figure 1. Study Area in the Rechna Doab, Punjab, Pakistan



## 1.1 Objectives

The specific objectives of the paper are:

- to examine farmers' practices of irrigation and compare them with conjunctive water management and access their perceptions about the groundwater quality in the Rechna Doab;
- to compare the net gross margins from rice crop, produced on farms under various irrigation management conditions; and
- selection of optimal land uses (by using SWAGMAN Farm Model), which maximizes the economic returns under conjunctive water management at Subdivision levels.

This paper is subdivided into five sections. Methodology is discussed in the second part of the paper, followed by results and discussion in part three. The conclusions and policy implications are given in part four and five of the paper, respectively.

## 2. METHODOLOGY

### 2.1 Study Area

The Sheikhupura, Mangtanwala and Dhauhar sub-divisions are located in the upper, middle and the tail parts of the Rechna Doab (Figure 1). These sub-divisions had 46.45, 62.91 and 65.96 thousand hectares of cultivated area, respectively. The water table depths were reported to be 2.47, 5.78 and 5.08 m in Sheikhupura, Mangtanwala and Dhauhar sub-divisions respectively. Water allocation for the Sheikhupura, Mangtanwala and Dhauhar sub-divisions was 1.12, 1.01 and 5.29 million mega liters (ML), respectively.

### 2.2 Data Collection

The primary data sets were collected through a well-designed pre-tested questionnaire, which were used to collect the information from 544 sample farms located on 188 sample sites in the Rechna Doab. Physical and meteorological data were collected from secondary sources comprised of Punjab Irrigation Department (PID), Salinity Monitoring Organization (SMO) and Meteorological Department. Physical data includes soil texture, area under different soils, textural classes and water quality. The meteorological data included information about rainfall, humidity, sunshine, wind speed and temperature. The data about irrigation, infrastructure and the designed discharges were collected from the irrigation department.

### 2.3 Model Specification

The SWAGMAN Farm Model is an annual model that allocates land to different crops on annual basis, based on distribution of soils on farms within sub-divisions. The model takes into consideration the potential land uses, crop evaporative requirements, current irrigation practices, leaching requirements, annual rainfall, leakage to deep aquifer, depth to water table, capillary inflow from shallow water table, salt concentration of irrigation and groundwater. It also accounts on the economic returns from potential land uses, and maximizes total gross margins for the sub-divisions subject to the given economic and environmental constraints. In the Rechna Doab, the crops sown during the Rabi and the Kharif seasons were taken into account. The major crops during the Kharif season were rice, cotton and Kharif fodder while during the Rabi season the major crops were wheat and Rabi fodder. The sugarcane was an annual crop so it was treated as such in the Model. The specification of the model is given as follows:

$$TGM = \sum_C \sum_S X_{C,S} (GMLW_C - IRRN_{C,S} \times WPRICE)$$

Where:

- TGM = Total gross margin (Rs.)  
 X = Area under land use C and soil type S (ha.)  
 GMLW = Gross margin of a land use less cost of irrigation water (Rs./ha.)  
 IRRN = Irrigation water used for land C and across soil types S (ML/ha.)  
 WPRICE = Price of water (Rs./ML)  
 C = Land uses under various cropping patterns in the sub-division  
 S = Soil types across the farms in the sub-division

The model was subjected to the constraints namely, area, salt balance, net water balance, pumping of groundwater and water allocation. The total water requirements were not allowed to exceed the annual water allocation to the respective sub-divisions. The water allocation for a specific Subdivision was calculated by multiplying area under specific crops on different soil types and irrigation requirements on farms. The objective function was solved by using the integer programming solver GAMS, subject to given constraints. Two scenarios were generated. In the first scenario (SCN1) the actual allocation of irrigation supplies were used while the second scenario (SCN2) was generated by using the maximum surface supplies required for crop use.

### 3. RESULTS AND DISCUSSION

In the Rechna Doab, the farmers exploit groundwater to supplement canal water supplies. The quality of the groundwater differs spatially. The literature shows that groundwater of good quality is found in the upper parts of the Doab in a 24 to 48 Kilometer wide belt along the flood plains of the Chenab and Ravi rivers. Highly saline groundwater is found in the lower and central parts of the Doab. The Upper Rechna Doab contains fresh water of 500 parts per million (ppm), but in the central and lower portions, groundwater salinity concentration varies from 3,000 to 18,000 ppm. In the central and lower parts of the Doab, majority of the tubewells are pumping marginal to poor quality groundwater, especially at the tail ends of the canal irrigation system. Table 1 provides figures pertaining to the farmers' perception about the quality of groundwater in the Rechna Doab. Out of 535 rice-growing farms, about 47 percent farmers (majority of which is located in the Upper Rechna Doab) perceived the groundwater quality at their farms to be good, while about 38 percent of the sample farms were located in the central and lower part of Rechna Doab, who responded that the groundwater at their farm was saline and was not fit for irrigation. About eight percent of the farmers were not aware of the groundwater quality because they either have just installed the tubewell on the farms or they had taken the land on lease for the first year. About seven percent of the farmers believed that they had the marginal quality groundwater, which they were using by mixing it with canal water for irrigation purposes.

Table 1. Farmer's perceptions about the quality of irrigation water in the Rechna Doab

Farm Category	Quality of ground water				
	Good	Saline	Marginal	Not Known	All Categories
Small	39	24	1	6	70
Medium	79	80	11	31	201
Large	135	97	24	8	264
Total	253	201	36	45	535
	(47)	(38)	(7)	(8)	(100)

Note: The figures in parenthesis are percentages.

Out of total sample farms, 93 percent farms were using groundwater through tubewells on their farms (Table 2). About 29 percent of farms were using tubewell water as the only source of irrigation supplies and 59 percent of the total sample farms were using tubewell water to supplement their canal water supplies. It was observed that in the whole sample farm area, farmers have never had a laboratory test for their tubewell water quality. Thus, it is likely that they might be applying poor quality tubewell water to their fields. This would result in problems of salinity or sodicity in their fields and increased area under secondary salinization.

The impression one gets by examining these numbers is that the farmers are heavily dependent upon tubewell irrigation to bring more area under cultivation. The tubewells at the middle and the tail ends of the irrigation network are pumping poor quality groundwater which may be unfit for irrigation. The prevailing rate of installation and use of tubewell water may cause problems relating to the over-exploitation of fresh groundwater reservoir and salt imbalance, building up of salinity/sodicity. This may result in an increase in unproductive land, extra costs for groundwater quality improvement and salinized soil reclamation, and permanent up-coning of saline groundwater.

Table 2. Farmers' mode of irrigation in the Rechna Doab

Farm Category	Canal	Private Tubewell	Canal + Tubewell	Drain	Canal + Public T/w	Drain+ Pvt. T/w	All Categories
Small	7	30	27	1	1	4	70
Medium	16	60	104	2	7	12	201
Large	8	63	169	1	9	14	264
Total	31	153	300	4	17	30	535
	(6)	(29)	(56)	(1)	(3)	(6)	(100)

Note: The figures in parenthesis are percentages.

The resource use pattern of rice and output under different types of water management conditions is presented in Table 3. The expenditure on seed and fertilizer on the farms using conjunctive water management accounted for about 14 percent of the total cost for rice production. The farms using only canal or tubewell water invested 17 percent and 13 percent of the total cost on seed, respectively. Table 3 also shows that land preparation accounts for about 16 percent of the total cost of rice production. The farmers using only canal or tubewell water invested 20 and 12 percent of the total cost on land preparation, respectively, to produce rice. While the farmers using canal and tubewell water conjunctively invested 15 percent of the total cost for land preparation. The table also reveals that aggregate resource use per hectare on rice was about Rs. 7000 less on farms using only canal water as compared to the farms using the canal and tubewell water conjunctively. In the case of the farms using tubewell only the farmers

invested Rs. 3000 more as compared to the farms using both these irrigation sources conjunctively. The rice crop yields estimates show that it was 8 and 21 percent higher on the farms using conjunctive water management as compared to the farms using only canal irrigation or only tubewell irrigation, respectively. The estimates show that the net income was about 62 percent higher on the farms using conjunctive water management as compared to the farms using only tubewell irrigation.

Table 3. Input use and output for rice under different irrigation practices in the Rechna Doab (Rs./Ha)

Items	Source of Irrigation		
	Canal	Tubewell	Canal+ Tubewell
Seed	166	167	179
Fertilizer	1630	2372	2157
Labor	1382	1786	1535
Land preparation	2121	2432	2558
Farm yard manure	1071	1549	1856
Irrigation	291	7935	4701
Cost of chemicals	955	965	1425
Harvesting Threshing	2668	2809	2663
Total cost	10286	20016	17075
Yield (Kg/Ha)	2491	2785	2831
Gross income	22452	26272	26313
Net income	12166	6257	16607

The main findings from the SWAGMAN Farm Model application for Sheikhpura, Mangtanwala, and Dhauhar Subdivisions are shown in Figures 2-5. These figures compare the actual model results with the two scenarios generated by the model. The changes in average and total gross margins, impact on salinity, changes in watertable level at the Subdivision level, due to proposed cropping patterns are presented in the following section.

In the case of Sheikhpura Subdivision, the optimization results suggested by the SWAGMAN Farm Model for the cropping pattern would increase the gross margins by about 6.7 and 69.00 percent from the current level of Rs. 488.86 million to the expected level of Rs. 521.90 and Rs. 826.39 million for both scenarios, SCN1 and SCN2, respectively. The model results showed that the average gross margin per hectare in Sheikhpura Subdivision would increase from current level of Rs. 10524 to

Figure 2. Total Gross Margin in Sheikhpura, Mangtanwala and Dhaur Subdivisions

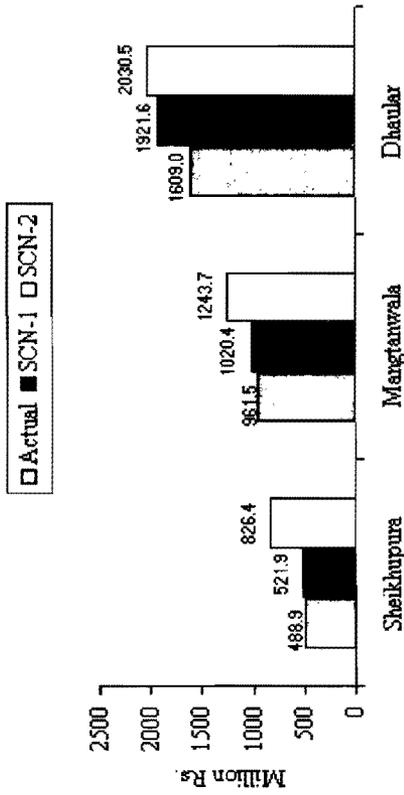


Figure 3. Change in Depth to water table in Sheikhpura, Mangtanwala and Dhaur Subdivisions

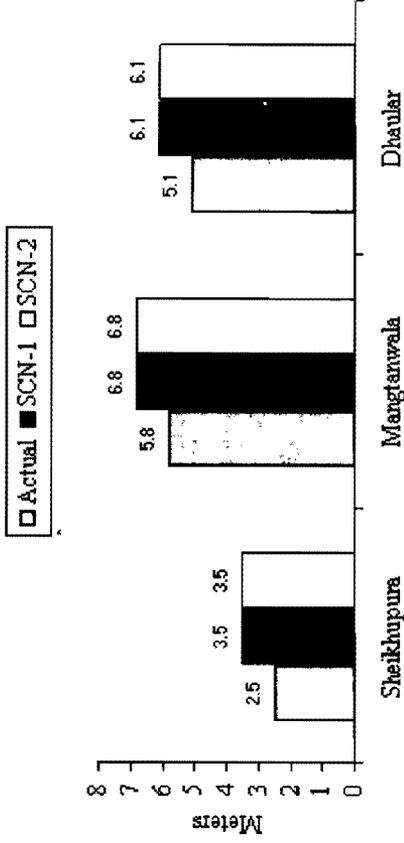


Figure 4. Impact on Salinity in SCN-1 in Sheikhpura, Mangtanwala and Dhaur Subdivisions

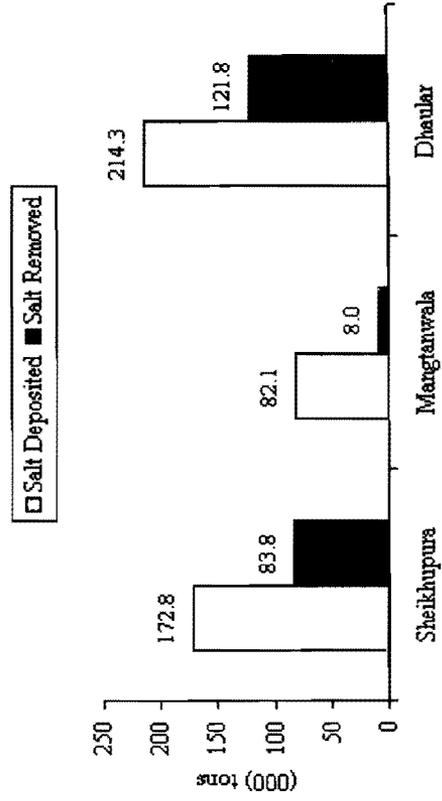
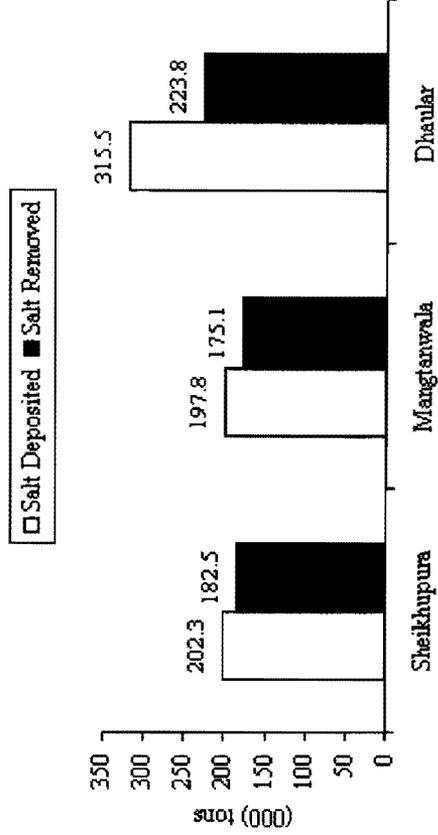


Figure 5. Impact on Salinity in SCN-2 in Sheikhpura, Mangtanwala and Dhaur Subdivisions



Rs. 11236 and Rs. 17791 in case of SCN1 and SCN2, respectively. This increase in the total gross margin was resulted due to the selection of cropping rotation, which yielded maximum returns. In the case of Sheikhpura Subdivision, more than fifty percent of the area is classified as having loamy soils, and other half consists of clay loam and sandy loam soils.

The major crops of the area are rice, wheat, Kharif fodder and Rabi fodder. Currently, about 9.04 thousand-hectare land is cultivated under rice-wheat cropping pattern, 6.04 thousand hectares under Rabi fodder-rice rotation, and 15.07 thousand hectares under Kharif fodder-wheat rotation. There was 0.41 thousand hectares of land under sugarcane, and 15.89 thousand hectares of land was kept fallow. In Sheikhpura Subdivision, groundwater is of good quality that is why, besides overall canal water shortage, rice is still cultivated in the subdivision.

The SWAGMAN Farm Model results for SCN1 suggested reducing the area under cropping patterns like rice-wheat and Rabi fodder-rice under limited water conditions to about 7.00 and 4.29 thousand hectare, respectively. Thus, allocating land to low delta crop i.e. Kharif fodder-wheat and wheat alone to 15.86 and 18.69 thousand hectares, respectively. The model results also predicted to grow sugarcane on 0.61 thousand hectares of land, which was currently being grown on 0.41 thousand hectares. In case of SCN2, the model suggested to grow 25.50 thousand hectares under rice-wheat, 8.56 thousand hectares under Kharif fodder-wheat cropping rotation, 1.93 thousand hectares under sugarcane crop, and 10.50 thousand hectares under Rabi fodder-rice cropping system. The model proposed to cultivate 25.46 and 10.5 thousand hectare under rice-wheat and Rabi fodder-rice crop rotation, respectively in SCN2. The cropping pattern proposed by the model requires 392789 ML of irrigation water in SCN1 and 769707 ML in SCN2. The model also predicted a watertable fall in Sheikhpura Subdivision. Also, groundwater table might go down by one meter from the current level of 2.47 meter to a predicted level of 3.47 meter.

The salts brought into soils of the Subdivision by capillary upflow through irrigation, and rainfall during cropping season would be 122.85 and 202.30 thousand tons for both the scenarios, SCN1 and SCN2 respectively. Whereas, the salts removed by deep drainage in the growing season and was estimated to be about 83.80, and 182.50 thousand tons for both the scenarios, respectively. The model estimated the total salts brought into the root zone as 39.05 and 19.80 thousand tons over one year in the case of SCN1 and SCN2, respectively. The decrease in groundwater table and rise in salinity level might be due to cultivation of high delta crop like rice and Rabi fodder and contamination of soil and water from different industrial waste.

Table 4. Land use proposed by SWAGMAN Farm Model under SCN-1 (000 Ha)

Land use pattern	Sheikhupura	Mangtanwala	Dhauhar
Rice-Wheat	7.00	0.00	0.11
Cotton-Wheat	0.00	0.00	10.26
Sugarcane	0.61	18.50	10.95
Kharif Fodder-Wheat	15.86	15.99	20.96
Rabi Fodder- Rice	4.29	2.21	7.74
Wheat	18.69	24.55	15.93
Fallow	0.00	1.67	0.00

Table 5 Land use proposed by SWAGMAN Farm Model under SCN-2 (000 Ha)

Land use pattern	Sheikhupura	Mangtanwala	Dhauhar
Rice-Wheat	25.46	39.46	21.44
Cotton-Wheat	0.00	0.00	10.26
Sugarcane	1.93	7.50	16.21
Kharif Fodder-Wheat	8.56	7.10	11.50
Rabi Fodder- Rice	10.50	8.85	6.55

The entire Subdivision of Mangtanwala has a mixture of medium to moderately fine soils. These soils are having mainly silty clay; clay loam in abundance, while a considerable quantity of silt loam; loam and sandy loam is also present. The optimization of Model resulted in changes for the cultivated areas under different crops being raised in Mangtanwala Subdivision. This shifting of area under different crop rotations gave 6.1 and 29.36 percent increase in gross margins of the Subdivision, raising it from the current level of Rs. 961.45 millions to Rs. 1020.38 and Rs. 1243.70 millions for SCN1 and SCN2, respectively. The average gross margin per hectare in Mangtanwala Subdivision increased from the current level of Rs. 15283 to Rs. 16219 and Rs. 19769 in SCN1 and SCN2, respectively.

The main crops of Mangtanwala include rice, wheat, sugarcane and fodder. At present, rice-wheat is grown under the area of about 25.68 thousand hectares followed by 13.54 thousand hectares under Kharif fodder-wheat. The sugarcane, Rabi fodder-rice and maize-wheat covered the land by 6.67, 4.67 and 2.54 thousand hectares, respectively. Remaining of the 9.82 thousand hectares was kept fallow. In SCN1, the model results showed that rice-wheat and maize-wheat crop rotations were dropped but increased the area under sugarcane and Kharif fodder-wheat by 18.50 and 15.99 thousand hectares, respectively. Due to water constraint, the model adopted wheat for 24.55 thousand hectares and reduced Rabi fodder-rice to 2.21 thousand hectares from the current area of 4.67 thousand hectares.

The model results for SCN2 showed the cropping pattern of rice-wheat by readjusting the area being cultivated under different cropping pattern. The model suggested that for maximum total gross margins, 39.46 thousand hectares of land should be cultivated under rice-wheat, 7.50 thousand hectares under sugarcane, 7.10 thousand hectares under Kharif fodder-wheat, and 8.85 thousand hectares under Rabi fodder-rice cropping rotation. This

readjustment of the land under different cropping patterns was mainly due to the difference in gross margins of these cropping patterns. In the case of Mangtanwala, sugarcane has the highest gross margin but for providing the food security to population living in the Subdivision a limit was set for the land under sugarcane. Otherwise, the whole area might have gone under sugarcane cultivation. Rice-wheat was an important crop rotation of the Subdivision, and the model also predicted to cultivate this rotation on maximum area (about 62.70 percent of 62911 hectares of cultivated area of Mangtanwala Subdivision).

For the whole year, the crop water requirement of the cropping pattern proposed by the model was 408281 ML for SCN1 and 991725 ML for SCN2. The model predicted that the watertable in the Subdivision would go down to 6.78 meters from 5.78 meters, thus, falling by one meter from the current level. The salts brought to the root zone by irrigation water and rain over the year would be 82.05 and 197.80 thousand tons under SCN1 and SCN2, respectively. The rice and sugarcane in Mangtanwala Subdivision was proposed to be cultivated on a large area, and thus, use of more groundwater for fulfilling the demand of these high delta crops would lower the ground water level. As Mangtanwala Subdivision is situated in relatively fresh groundwater zone, the use of good quality of water would help to leach down the salts and reduce soil salinity.

Dhauhar Subdivision is located in the lower Rechna Doab, and has cultural command area of 65.96 thousand hectares. The model proposed significant changes based on estimated gross margins. It predicted 19.43 and 26.19 percent increase in total gross margins through optimization of land use under different cropping patterns. Existing gross margins were estimated to be Rs. 1609.02 million while projected gross margins would be Rs. 1921.64 and Rs. 2030.49 millions for both SCN1 and SCN2, respectively. The average gross margins per hectare were predicted to increase by the model from the actual scenario with Rs. 24394 to Rs. 29133, and Rs. 30784 in SCN1 and SCN2, respectively.

The SWAGMAN Farm Model redistributed the existing cropping patterns and their areas under cultivation. In SCN1, about 20.96 thousand hectares of land for Kharif fodder-wheat was proposed by the model, which was only 9.55 thousand hectares in the actual scenario. This major shift was due to low delta cropping pattern since water supply was equal to crop water requirement in SCN1. The model increased the area under sugarcane to about 10.95 thousand hectares, which was 3.84 thousand hectares in the existing scenario, and adopted wheat crop to about 15.93 thousand hectares. But it decreased the area under Rabi fodder-rice to about 7.74 thousand hectares, which was grown on an area of 12.73 thousand hectares. The model dropped Rabi fodder-rice in SCN1 and SCN2. In the actual scenario, there was 14.27 thousand hectares of fallow land but it dropped to zero in SCN1 and SCN2.

In SCN2, under unlimited water availability, the rice-wheat was proposed to grow on 21.44 thousand hectares, which was actually grown on 12.73 thousand hectares. But due to water constraints in SCN1, the model proposed only 0.11 thousand hectares. Due to high gross margin of cotton-wheat, the model proposed to grow on 10.26 thousand hectares, in both the scenarios. The area under sugarcane was increased to 16.21 thousand hectares in SCN2 from its current level of 3.84 thousand hectares. The model decreased

the area under Rabi fodder-rice cropping patterns, mainly, due to its low gross margin as compared to the other cropping patterns. The Kharif fodder was increased to 11.50 thousand hectares of land in SCN2, which was 20.96 thousand hectare in SCN1 as compared to 9.56 thousand hectares in the actual scenario.

The annual crop water requirement of the cropping pattern proposed by the model was 607099 ML for SCN1 and 947396 ML for SCN2, thus having a difference of 340297 ML. The groundwater table would fall from 5.08 meter to 6.08 meter. The model results showed that 213.7 thousand tons of salt in SCN1 and 333.51 thousand tons of salts in SCN2 would be deposited in root zone through irrigation water while the rain would add 0.59 thousand tons of salts in both the scenarios. Salts removed from root zone through deep drainage were 121.84 and 241.60 thousand tons in SCN1 and SCN2, respectively. The net additions of salts remained positive and were 92.36 and 92.50 thousand tons in both the scenarios, respectively. The increase in soil salinity was due to the pumpage of saline groundwater for rice crop.

#### **4. CONCLUSIONS**

In this paper, the farmer's mode of irrigation on their farms and their perception about the quality of water in the Rechna Doab is presented. The study shows that about 93 percent of the farms were using groundwater in the Rechna Doab. Among these users about 47 percent were exploiting saline and marginal aquifers. These farmers were also facing the major threat of salinity on their farms. They needed to be educated about the conjunctive use of irrigation water to minimize the effect of salinity on their farms. The above results are stark evidence of on-farm gains due to the conjunctive use of canal and tubewell water. These gains call for more efficient conjunctive water use on farms. The financial analysis showed that potential farm benefits could be 63 percent higher in case of rice provided judicious use of canal and tubewell irrigation were applied on the farms. The results of SWAGMAN Farm Model showed that the gross margins vary in different irrigation Subdivisions due to different cropping patterns, and input and output prices. In Sheikhpura (upper Rechna Doab), where groundwater is of good quality, farmers supplement canal water with groundwater, which is quite an expensive input for crop production. Therefore, the cost of production for crops go high and gross margins are very low as compared to Dhauhar (lower Rechna Doab) where farmers use tubewell water in lesser quantity. The reasons for low projected salinity level in the Sheikhpura Subdivision may be due to good quality of groundwater. Secondly, in the Sheikhpura Subdivisions the model proposed rice-wheat cropping pattern, which needs more water intensively. Rice crops play important role in leaching down the salts especially if irrigation is fresh and of good quality. In Mangtanwala Subdivision the model suggested that for maximum total gross margins, 39.46 thousand hectares of land should be cultivated under rice-wheat, 7.50 thousand hectares under sugarcane, 7.10 thousand hectares under Kharif fodder-wheat, and 8.85 thousand hectares under Rabi fodder-rice cropping rotation in the case of SCN2. In the case of Dhauhar Subdivision the model proposed to grow 10.26 thousand hectares under cotton wheat rotation, in both the scenarios. The area under sugarcane was increased to 16.21 thousand hectares in SCN2 from its current level of 3.84 thousand hectares.

## **5. POLICY IMPLICATIONS**

In the past, government invested heavily to get rid of Waterlogging and salinity menace in the Rechna Doab. Currently government is encouraging farmers to install community tubewells in the areas where the groundwater is of better quality. It is also necessary to formulate some legal framework to regulate tubewell operations in areas where the recharge problem exists. The existing institutions like the On Farm Water Management (OFWM) program and Punjab Groundwater Sector Development Program (PGSDP) may be strengthened to monitor aquifer depletion/recharge on a regular basis to ensure the sustainable supplies of groundwater in the fresh groundwater areas.

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