The Pakistan Development Review
42 : 4 Part II (Winter 2003) pp. 823–838

Net Gains from Conjunctive Use of Surface and Ground Water

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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 ground water to augment their surface supplies. The quality of ground water in Pakistan varies from fit for irrigation to moderately saline to sodic. Thus the tubewell owners in the marginal quality ground water 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 ground water 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, ground water and salinity at irrigation subdivision level. To answer the issues of spatial differences in the trade offs between gross farm income, ground water and salinity at irrigation Subdivision level, this paper presents the results of the optimisation modeling at the Subdivisional level

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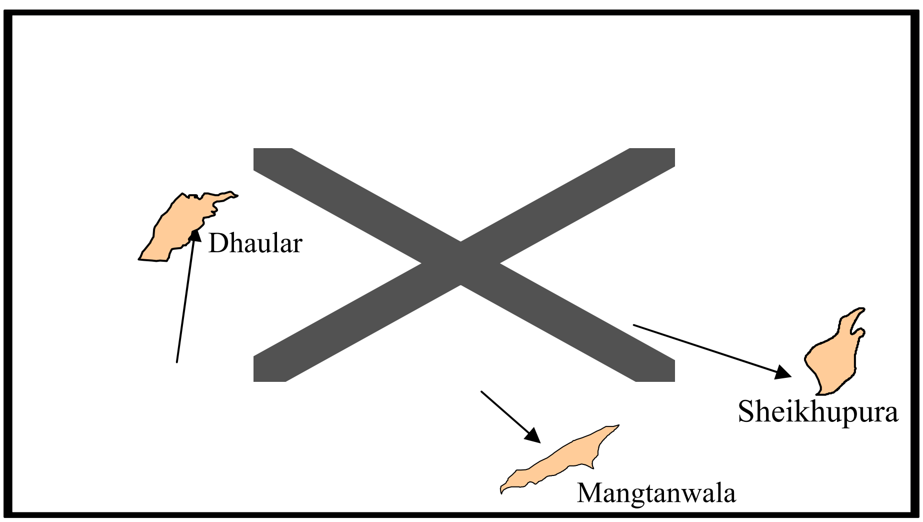
in the Rechna Doab (area between the Ravi and the Chenab Rivers). The Rechna Doab has a gross area of 2.98 million hectare (Mha), of which 2.319 Mha is the Gross Command Area (Figure 1). In the Rechna Doab, three types of irrigation sources are commonly used on farms i.e. canal irrigation, tubewell irrigation 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 ground water 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 ground water 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 analyse 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.

Fig. 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 ground water quality in the Rechna Doab;
— compare the net gains from rice crop, produced on farms under various irrigation management conditions; and
— select optimal land uses (by using SWAGMAN Farm Model), which maximises 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 Dhaular subdivisions are located in the upper, middle and the tail parts of the Rechna Doab (Figure 1). These subdivisions 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 5.08m in Sheikhupura, Mangtanwala and Dhaular subdivisions respectively. Water allocation for the Sheikhupura, Mangtanwala and Dhaular subdivisions 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 Organisation (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 subdivisions. 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 ground water. It also accounts on the economic returns from potential land uses, and maximises 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 subdivision.
S = Soil types across the farms in the subdivision.

The model was subjected to the constraints namely, area, salt balance, net water balance, pumping of ground water 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 ground water to supplement canal water supplies. The quality of the ground water differs spatially. The literature shows that ground water 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 ground water 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, ground water 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 ground water, especially at the tail ends of the canal irrigation system. Table 1 provides figures pertaining to the farmers' perception about the quality of ground water 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 ground water 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 ground water at their farm was saline and was not fit for irrigation. About eight percent of the farmers were not aware of the ground water 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 ground water, 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

	Quality of Ground Water				
Farm Category	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 ground water 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 salinisation.

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 ground water which may be unfit for irrigation. The prevailing rate of installation and use of tubewell water may cause problems relating to the over-

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.

exploitation of fresh ground water reservoir and salt imbalance, building up of salinity/sodicity. This may result in an increase in unproductive land, extra costs for ground water quality improvement and salinised soil reclamation, and permanent up-coning of saline ground water.

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 fertiliser on the farms using conjunctive water management accounted for about

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
Fertiliser	1630	2372	2157
Labour	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

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.

The main findings from the SWAGMAN Farm Model application for Sheikhupura, Mangtanwala, and Dhaular 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 Sheikhupura Subdivision, the optimisation 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 Sheikhupura Subdivision would increase from current level of Rs 10524 to 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 Sheikhupura 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 Sheikhupura Subdivision, ground water is of good quality that is why, besides overall canal water shortage, rice is still cultivated in the subdivision.

Fig. 2. Total Gross Margin in Sheikhupura, Mangtanwala and Dhaular Subdivisions.

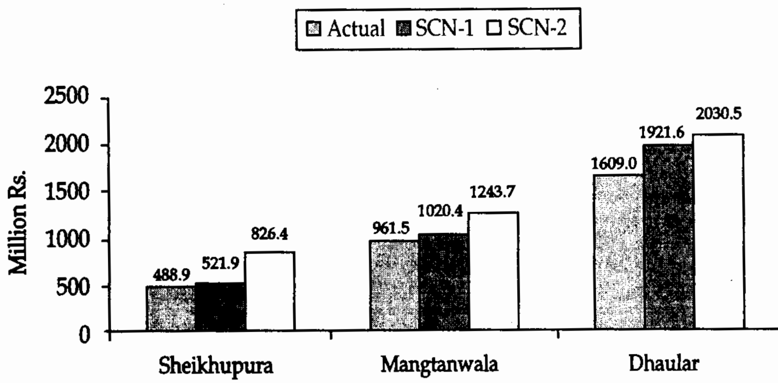


Fig. 3. Change in Depth to Water Table in Sheikhupura, Mangtanwala and Dhaular Subdivisions.

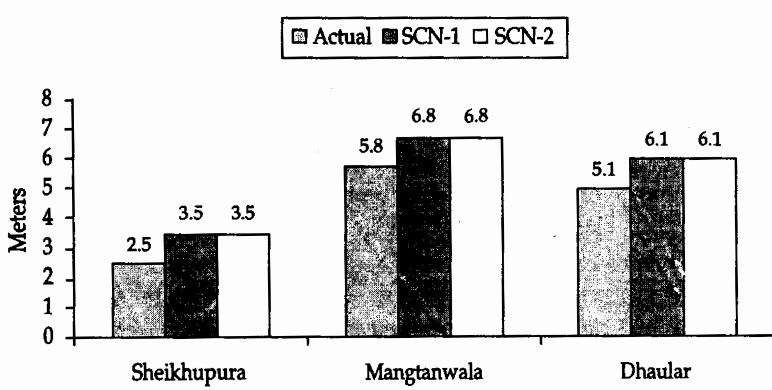


Fig. 4. Impact on Salinity in SCN-1 in Sheikhupura, Mangtanwala and Dhaular Subdivisions.

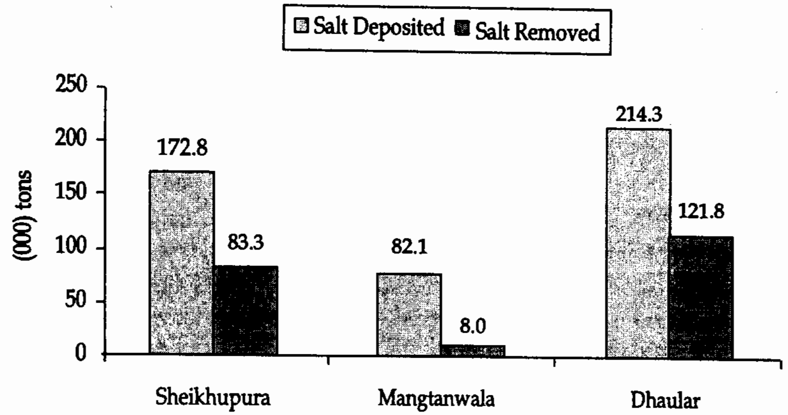
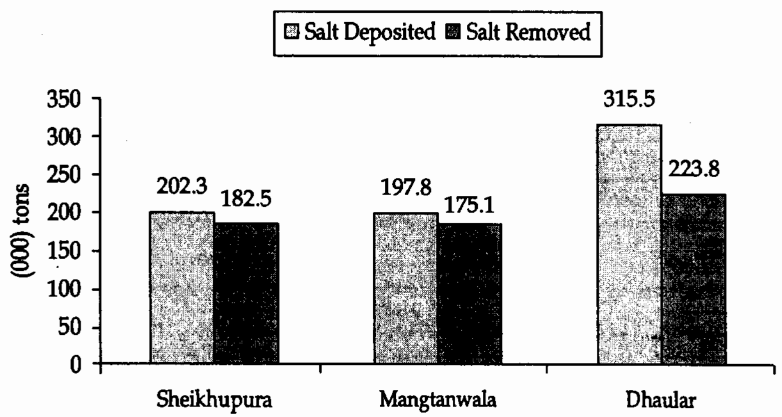


Fig. 5. Impact on Salinity in SCN-2 in Sheikhupura, Mangtanwala and Dhaular Subdivisions.



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 Sheikhupura Subdivision. Also, ground water 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 ground water 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	Dhaular
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	Dhaular
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 optimisation 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 ground water for fulfilling the demand of these high delta crops would lower the ground water level. As Mangtanwala Subdivision is situated in relatively fresh ground water zone, the use of good quality of water would help to leach down the salts and reduce soil salinity.

Dhaular 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 optimisation 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 ground water 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 ground water 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 ground water 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 minimise 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 Sheikhupura (upper Rechna Doab), where ground water is of good quality, farmers supplement canal water with ground water, 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 Dhaular (lower Rechna Doab) where farmers use tubewell water in lesser quantity. The reasons for low projected salinity level in the Sheikhupura Subdivision may be due to good quality of ground water. Secondly, in the Sheikhupura 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 Dhaular 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 ground water 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) programme and Punjab Ground water Sector Development Programme (PGSDP) may be strengthened to monitor aquifer depletion/recharge on a regular basis to ensure the sustainable supplies of ground water in the fresh ground water areas.

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