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OPTIMUM CROP DESIGN UNDER LIMITED AND ADEQUATE IRRIGATION POSSIBILITIES IN SMALL SCALE FARMING ENTERPRISES OF GAP-TAHILALAN IRRIGATION UNION

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ABSTRACT - The GAP region enjoys a rather high agricultural potential in terms of its climatic and soil characteristics. Approximately 1.8 million hectares of land will be brought under irrigation in this region. In order to utilise the existing water and land resources of the region in most efficient way, studies on post-irrigation crop patterns and their respective shares are critical in the process of transition from rainfed to irrigated farming. The objective of the present study is to determine the crop design that will ensure maximum returns in a small-scale farm (30 decares) in the Tahılalan Irrigation Union in the Harran Plain under adequate and deficit irrigation conditions. In this context the study determines plant water needs for crops cultivable under given conditions, irrigation plans under adequate and deficit irrigation conditions, necessary inputs and costs gross profit margins. On the basis of this information, the optimum crop design is obtained by linear programming.
Key words: irrigation, land resources, crop pattern, deficit irrigation

INTRODUCTION

In the GAP region we observe irrigation water as the scarcest resource among all necessary inputs for agricultural production. Consequently, the optimum utilisation of this scarce resource is taken as the basis of selecting the most appropriate approach to farming. At present, irrigation unions in the region make their plans for the most economic use of available water resources.

In cases where there is plenty of irrigable land whereas irrigation water capacity is limited and irrigation water is costly, preference can be made for more up-to –date irrigation technologies and restricted irrigation practices. In the latter, instead of seeking maximum yield, some fall in yield is tolerated by restricting the volume of water used for irrigation. Nevertheless, it is still possible, in these cases, to irrigate larger tracts of land with a given water availability and to get higher returns per unit of water used. (1,2). Researchers in this field assert that considerable saving can be made in energy, water and capital and returns to the enterprise can be increased in case the irrigation system is planned with respect to limited water availability (3). It is further stated that farming enterprises working with limited water supply enjoy higher returns per unit of water used despite a fall in returns per unit of land compared to cases where sufficient water is used (4,5).

The irrigation programming envisages determining the number of irrigation, timing and volume of water to be used in each irrigation under given soil, crop and climate conditions. These programmes are important in that they can help use resources optimally and enhance production under both adequate and deficit irrigation conditions (6, 7).

In an enterprise where deficit irrigation is applied, such questions as which crops can tolerate deficit irrigation, which others require full irrigation, possible profit margins, water and labour needs etc. can be answered through the linear programming method in order to achieve the highest possible return on limited water supply (8).

The objective of this study is to determine that particular crop design, which would ensure the maximum return under both adequate and deficit irrigation conditions in a small-scale farming enterprise in Tahılalan Irrigation Union selected as the field of study.

MATERIAL AND METHOD

Material

The survey covers agricultural enterprises comprising the Tahılalan Irrigation Union located in the 1st part of Şanlıurfa-Harran Plains where irrigation was introduced in 1995. There are 12 villages in the union and total irrigated area is 6,538 hectares (Figure 1). Climatic data as measured by Akçakale meteorology station were used in the study. According to these data the average annual temperature in the area is 17.9 ºC and total annual precipitation is 214.8 mm.

Although the Harran Plain is conducive to policulture, low precipitation and its seasonal distribution which does not coincide with the growth period of many crops as well as low relative humidity restricts the culture of some crops. In those parts of the plain where dry farming is practiced, common crops include wheat in the first place followed by lentil, barley and sesame as well as some pistachio orchards and vineyards. In the irrigated parts of the plain the leading crop is cotton followed by vegetables (eggplant, pepper and tomato) and fruits (apricot, prune and pomegranate) (9).

Method

After examining the size of agricultural enterprises in the area, it was decided to work on small farms up to 50 decares (average size is 30 decares) (9).

Considering the climatic features and marketing outlets of the area 20 crops were selected including those grown under both rainfed and irrigated conditions as well as secondary crops.

A single type of soil is assumed since the dominant pattern is clayish soil in the area. The usable water holding capacity of soil is assumed as 150 mm/m, and infiltration rate as 13 mm/h (10).

Calculation of Reference Water Consumption (ETo) Values

The reference water consumption values for Akçakale were calculated through the Penman method (as modified by the FAO) ad the computer software IRSIS was used for this purpose (11).

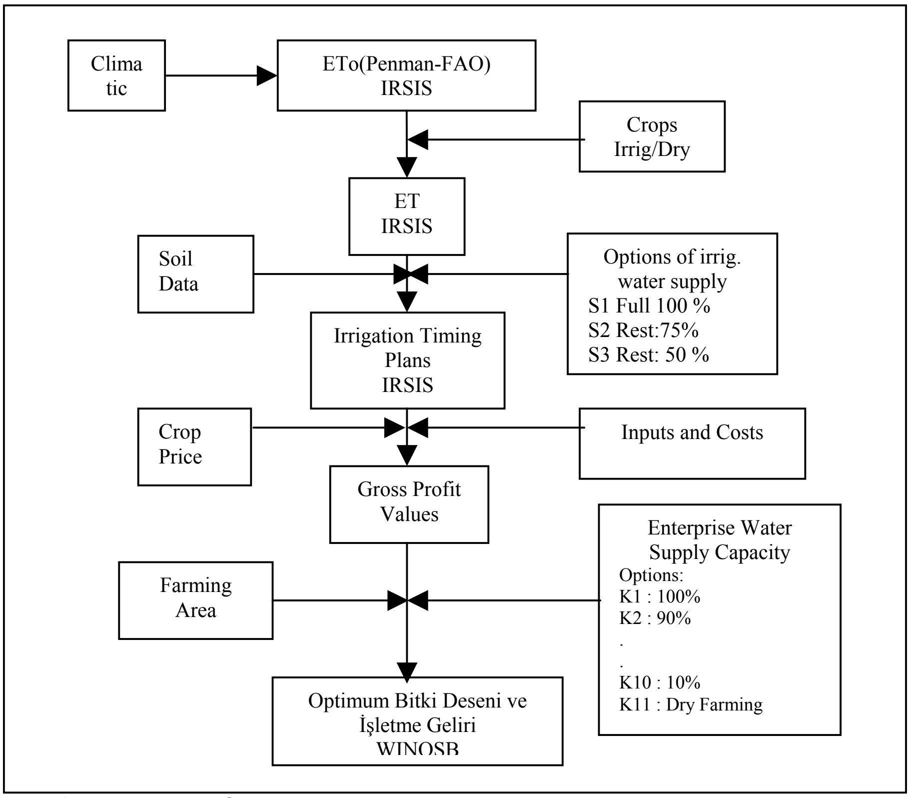

Fig. 1: Work Flow Chart

Developing Crop Water Consumption and Irrigation Programmes under Adequate and Deficit Irrigation

The study sought to obtain plant water consumption and irrigation programmes under deficit irrigation in addition to cases where plant water need is fully met. With respect to the level of satisfying given water needs the following three options were developed as shown in table below.

Table 1. Options Relating to the Volume of Irrigation Water Used in the Model

Symbol	Rate	Comment
S1	100%	The case where full water need of the plant is met
S2	75%	The case where 75 % of water need of the plant is met
S3	50%	The case where 50 % of water need of the plant is met

By using the IRSIS computer software in relation to water supply options given in Table 1, estimates of plant water consumption and irrigation programmes were developed. Firstly, the full satisfaction of plant water need is calculated (100 %) and values related to deficit irrigation are then calculated by taking 75 5 and 50 % of the earlier figure.

Plant file information including kc plant coefficients, ky yield factors, plant root depth and soil moisture level was prepared by referring to the FAO 24, FAO 33 and FAO 56. Seasonal water restriction is applied in the study (12, 13, 14).

Calculation of Gross Profit for the enterprise under Adequate and Deficit Irrigation

Gross profit from individual crops are calculated by subtracting specific variable costs incurred during the production of the crop concerned from gross value of output relating to that crop (9).

Gross profit for crops was calculated on the assumption that family labour would be sufficient and thus no labour cost was considered. However, considering that hiring labour might be necessary in cases where family labour fell short of need, additional labour cost variables were also added to the model (15).

Optimum Crop Design for the enterprise under Adequate and Deficit Irrigation

Linear programming technique was used to reach the optimum crop design in both adequate and deficit water supply conditions (16, 17, 18, 19, 20, 21, 22). The WINQSB computer software was used in the finalisation of linear programming models developed.

Table 2 below gives the 11 options emerging with respect to the irrigation water capacity of the enterprise. As can be seen in this table, K1 stands for the enterprise which is endowed with water capacity needed by the optimum crop design yielding the maximum return. Symbols from K2 to K10 stand for those enterprises where existing water capacity is variably below what is needed. Finally, K11 denotes the enterprise engaged in dry farming. Outcomes were obtained by developing linear programming models for each water capacity level. (15).

Table 2. Water Source Capacity Options Used in the Study

Symbol	Rate	Comment	Symbol	Rate	Comment
K1	100%	Enterprise with required cap.	K7	40%	40% Capacity
K2	90%	90% Capacity	K8	30%	30% Capacity
K3	80%	80% Capacity	K9	20%	20% Capacity
K4	70%	70% Capacity	K10	10%	10% Capacity
K5	60%	60% Capacity	K11	Rainfed	Rainfed farming
K6	50%	50% Capacity			

FINDINGS AND DISCUSSION

Irrigation Programmes Developed under Adequate and Deficit Irrigation

Table 3 gives as an example one of the irrigation programmes for cotton under adequate and deficit irrigation conditions. In adequate irrigation conditions the total volume of water applied is 872 mm and the proportion of actual water use to maximum use is 1.00. Hence, the actual yield (Ya) is equal to maximum yield (Ym). While working on S2, the volume of irrigation water is made equal or close to 872.0 * 0.75 = 654.0 mm. The irrigation programme developed denotes the use of 650.6 mm of irrigation water. Since the crop is confronted with water stress, Eta/Etm = 0.77 and Ya/Ym = 81.4%.

Table 4 summarizes the results of irrigation programmes. The table gives actual yield (Ya) values basing on the volume of seasonal irrigation water (I), number of irrigations (N) and Ya/Ym values. Examining these values we find that as lesser and lesser water is given to the crop, there are parallel decreases in the number of irrigations and yield.

Table 3. Irrigation Programmes Developed for Cotton Farming Under Adequate and Restricted Irrigation Possibilities

Irrigation Conditions	Irrigation	Irrigation Date	Water Used (mm)	Irrigation Interval (day)	Yield (%)
	1	22.05	66.5	-	
	2	05.06	60.7	14	100
	3	15.06	61.3	10	
	4	23.06	59.6	8	
S1	5	30.06	58.3	7	
(100%)	6	07.07	63.7	7	
	7	14.07	64.9	7	
	8	21.07	64.5	7	
	9	29.07	73.1	8	
	10	07.08	78.1	9	
	11	17.08	80.6	10	
	12	28.08	80.5	11	
	13	14.09	60.1	17	
	1	25.05	31.9	-	
	2	04.06	35.7	10	81.4
	3	13.06	39.5	9	
	4	21.06	42.8	8	
S2	5	29.06	47.6	8	
75 (%)	6	06.07	49.0	7	
	7	14.07	54.7	8	
	8	23.07	61.1	9	
	9	01.08	64.3	9	
	10	12.08	72.7	11	
	11	24.08	74.1	12	
	12	08.09	77.3	15	
	1	30.05	26.5	-	
	2	10.06	32.2	11	62.0
	3	21.06	39.1	11	
	4	02.07	46.3	11	
	5	13.07	52.8	11	
S3	6	26.07	62.3	13	
50 (%)	7	10.08	60.4	15	
	8	25.08	57.5	15	
	9	11.09	58.5	17	

Gross Profit of the Enterprise under Adequate and Deficit Irrigation

Gross profit values corresponding to adequate and deficit irrigation conditions were calculated by considering costs varying or not varying with respect to yield (9,15). Production costs independent of yield were calculated under adequate water supply conditions and then applied to other conditions. On the other hand, production costs variable with yield were calculated with respect to the case S1 where actual yield overlapped with maximum yield. Then, for deficit irrigation conditions (S2, S3), this value and ratio (Ya/Ym) were used to obtain production costs variable with real yield.

Table 4 gives gross profit values calculated for all crops and irrigation conditions covered in the study. When these values are examined by taking adequate irrigation as given, it is observed that in

2000 prices eggplant stands as the most profitable crop, followed by green pepper, tomato and water melon.

Table 4: Results of Irrigation Programmes for All Crops Covered in the Study and Corresponding Gross Profit

	Crop and Water	I (mm)	N (no)	Ya (kg/da)	Gross Profit 10^6Tl/da		Crop and Water	I (mm)	N (no)	Ya (kg/da)	Gross Profit 10^6Tl/da
X1	Barley Opt.	131	2	500	35.1	x28	Eggplant Opt.	939	21	5000	366.2
X2	75%	100	1	473	32.8	x29	75%	702	14	3805	274.7
X3	50%	65	1	426	28.9	x30	50%	474	8	2530	175.8
X4	Wheat Opt.	131	2	600	49.6	x31	Onion Opt.	278	6	2500	157.3
X5	75%	97	1	563	46.1	x32	75%	205	3	2300	143.9
X6	50%	65	1	510	41.1	x33	50%	135	2	1995	123.3
X7	Pepper Opt.	883	21	2400	330.8	x34	Clover Opt.	1012	10	10000	116.4
X8	75%	661	10	1858	251.4	x35	75%	761	8	7470	69.1
X9	50%	439	6	1200	154.3	x36	50%	508	8	5390	30.1
X10	Tomato Opt.	1007	24	4500	278.2	x37	Soya II Opt.	543	5	250	41.8
X11	75%	753	14	3344	201.1	x38	75%	406	3	204	28.2
X12	50%	503	9	2174	121.9	x39	50%	270	2	147	10.7
X13	Spinach Opt.	84	4	2500	185.8	x40	S.flower II Opt	568	8	244	29.4
X14	75%	64	2	2173	158.2	x41	75%	437	7	193	19.3
X15	50%	31	1	1548	103.8	x42	50%	284	6	128	6.2
X16	Cabbage Opt.	527	10	1150	131.1	x43	Corn II Opt.	573	8	1000	50.2
X17	75%	395	5	957	103.4	x44	75%	422	6	692	23.9
X18	50%	263	5	719	69.0	x46	Sesame II Opt.	514	4	70	16.7
X19	Water m. Opt.	711	15	4500	264.7	x47	75%	386	3	57	10.2
X20	75%	528	8	3276	176.7	x48	50%	276	3	42	2.7
X21	50%	352	5	2268	104.3	x49	Barley Dry	-	-	250	14.8
X22	Lentil Opt.	138	2	250	45.1	x50	S.flower Dry	-	-	113	5.0
X23	75%	102	1	240	42.6	x51	Wheat Dry	-	-	200	11.6
X24	50%	69	1	224	38.5	x52	Sesame Dry	-	-	30	0.7
X25	Cotton Opt.	872	13	350	100.8						
X26	75%	651	12	285	77.0						
X27	50%	436	9	217	52.1						

Examining gross profit values with respect to irrigation water used, it is observed that gross profit values tend to fall as the volume of irrigation water applied falls. Since negative gross profit emerges in corn (second crop) under S3 mode of deficit irrigation, this was excluded from the model.

Optimum Crop Designs for the Enterprise under Adequate and Deficit Irrigation

The linear programming model for an enterprise with adequate irrigation water capacity (K1) is given in Table 5.

Values relating to maximum cultivation possible for crops under dry and irrigated farming conditions were derived from values given by Dernek and Erdem (1993) (23) as well as information provided by the Urfa Directorate of Rural Services and faculty staff from the Department of Agricultural Economics, Faculty of Agriculture, Ankara University. The model was further refined in terms of given capacity by considering second crops and rotation.

As far as restrictions relating to labour force capacity, relevant variable coefficients were the labour force need of each crop and the sum of family labour force capacity and the variable relating to the availability of temporary labour in the period concerned. Variable coefficients relating to irrigation water restrictions in 10-day periods were irrigation water need of each crop corresponding to each period and, in terms of capacity, a value greater than what is needed for adequate water supply. Following the solution of the model and obtainment of optimum crop design, the volume of irrigation water needed for this optimum design under adequate water supply conditions (K1) was calculated in terms of values corresponding to enhanced capacity in peak periods.

Table 5: Linear Programming Model for Adequate Water Capacity

Function
$35.1*10^6 X1 + 32.8*10^6 X2 + \ldots + 0.7*10^6 X52 - (0.5*10^6 X53 + \ldots + 0.5*10^6 X61)$
II. **Restrictions**
A. Restrictions relating to cultivation area (da)
1. I. Cultivation area
X1..X6 + X22..X24 + X49 + X51 <= 0.50*30
2. II. Cultivation area
–(X1..X6) – (X22..X24) – X49 – X51 + (X37..X48) <=0
3. Rotational restriction
X7..X21 + X25..X36 + X50 + X52 <= 0.50 * 30
4. Restriction on clover culture area
X34 + X35 + X36 <= 0.10 * 30
5. Restriction on vegetable culture area
X7..X18 + X28..X33 <= 15
6. Restriction on dry farming land
X49 + X51 <= 0.50 * 30
X52 + X50 <= 0.50 * 30
B. Labour restrictions (sa)
1. March. 2.95 X1 + 2.95 X2+....+ 11.08 X33 + 0.05 X49 + 0.06 X51 <= 559
2. April. 8.1 X7 + 8.1 X8+.....+ 2.05 X32 + 5.42X34 +..+ 5.42X36 <= 559
..
11. November. 80.62 X13 +....+44.63 X15 + 0.19X31+....+0.50 X36 +...+ 0.86 X52<=674
C. Irrigation water restrictions (m^3)
1. April1. 61.3 X31 <= 5000
2. April2. 67.9 X1 + 67.9 X4 +......+ 55.0 X36 <= 5000
.....
.22. November1. 5.6 X13 <= 5000

In cases where there is shortage in irrigation water capacity (K2, K3, K4, K5, K6, K7, K8, K9, K10 and K11), values obtained by multiplying the K1 value by ratios given in Table 2 stand for irrigation water capacity values in the model. Table 6 gives optimum crop designs and enterprise revenues under adequate and deficit irrigation conditions as obtained from the solution of linear programming models constructed through similar methods.

The optimum crop design in K1 (100% water capacity) gives wheat culture on 15 decares of land and eggplant on another 15 decares of land. Both of these crops make up the crop design possible under the culture area restriction adopted in the model. Corn culture on 15 decares of land finds its place in the design as the second crop. This optimum crop design under adequate water supply is based on S1 where all water need of the crop concerned is satisfied. In K3 where the irrigation water capacity of the enterprise falls to 80 %, the crop design envisages both adequate and deficit irrigation conditions. In K10 where irrigation water capacity is as low as 10 %, dry farming finds its place in the design and furthermore, uprooting and cleaning spinach in November make it necessary to find additional labour force in this month when labour supply capacity is actually low. Finally, in K11 where dry farming is practiced, the crop design allowed by given restrictions includes barley and sunflower, each grown on 15 decares of land.

Table 6: Optimum Crop Designs under Adequate and Deficit Irrigation

Variable No	Crop Type and Water	K1	K2	K3	K4	K5	K6	K7	K8	K9	K10	K11
x4	Wheat Opt.	15.0	15.0	15.0	15.0	15.0	15.0	11,14	8,35	5,57		
x5	Wheat 75%							3,86	6,65	6,3	3,15	
x6	Wheat 50%										2,69	
x7	Pepper Opt.						0,7	3,13	2,34	1,56	0,78	
x13	Spinach Opt.							1,03	4,52	8,01	11,51	
x23	Lentil 75%									0,54		
x24	Lentil 50%									2,59	4,43	
x28	Eggplant Opt.	15	15	15	15	15	14,3	10,85	8,13	5,42	2,71	
x37	Soya II Opt.		2,52	3,4	2,13	0,86						
x39	Soya II 50%					1,85	1,7	2,37	1,78	1,19	0,59	
x43	Corn II Opt.	15	12,48	9,86	6,92	3,97	1,11					
x44	Corn II 75%			0,13	0,86	1,59	1,62					
x46	Sesame II Opt.			1,12	2,34	1,48	0,76					
x49	Barley Dry										4,73	15
x50	S.flower Dry											15
x61	Labour, Nov.										253,7	
Total area under the culture of the first crop (da)		15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0
Total area under the culture of the second crop (da)		15.0	15.0	14.51	12.25	9.76	5.17	2.37	1.78	1.19	0.59	-
Enterprise Revenue (10^9 TL)		6.99	6.97	6.90	6.77	6.56	6.34	5.95	5.33	4.69	3.77	0.30
Water Source Capacity (m^3/10 day)		3058	2754	2448	2142	1836	1530	1224	918	612	306	-
Total Irrigation Water Used (m^3)		26475	26090	25394	23669	21369	18463	15498	12278	9038	5150	-

Examining Table 6 in terms of enterprise revenues, we observe that as a response to falling irrigation capacity enterprise revenues first fall very slowly and then rather rapidly. It is interesting to note that returns to an enterprise working with 10 % irrigation capacity are equivalent to 50 % of the revenue of an enterprise working with 100 % irrigation water capacity while the former enjoys 12 times as much return as a dry farming enterprise can obtain. It should still be noted that it is essential, to attain these results, to apply limited irrigation water at times and volumes specified in the irrigation timing plan. There may be significant falls in both yield and returns if an enterprise with limited irrigation water supply opts for a crop design other than what is found optimum and makes mistakes in the timing of irrigation and volume of water applied.

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