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Irrigation Scheduling and Optimum Cropping Pattern with Adequate and Deficit Water Supply for Mid-sized Farms of Harran Plain

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Abstract: The aim of this study was to determine the optimum cropping pattern with adequate and deficit water supply for mid-size (100 da) farm in Harran Plain Firat Irrigation District. The best cropping patterns corresponding to water source capacities of 100, 80, 60, 40, 20 and 0% ; crop water demands of 100, 80, 60% were determined. The results of the study shows that even with very low water supply, it is possible to keep the farm income at high levels.

Key words: Optimization, linear programming, deficit water, deficit irrigation, irrigation scheduling, cropping pattern

INTRODUCTION

Maximum yield is obtained if humidity is ensured in required amounts in the root section of plants during the growth season and if other production inputs are kept at optimum. In case where irrigation water capacity is sufficient, the highest production value per unit area is generally targeted. In the applications called optimum irrigation, irrigation is made in a manner not to decrease the plant yield and at times required by plants and sufficient irrigation water is applied. Using a suitable irrigation scheduling, water utilization usefulness can be increased. In cases where there is plenty of agricultural land suitable for irrigation, but irrigation water capacity is insufficient or irrigation is expensive, it becomes more important to determine the most suitable irrigation scheduling. In such cases where a certain water deficiency is risked, the purpose is not to obtain maximum yield, but to ensure more area is irrigated with the same amount of water. Thus, more income is obtained from unit water. In these applications called deficit irrigation, operation income can be increased by achieving significant reductions in energy, water and capital requirements[1,2].

Although the existing water sources are sufficient in quantity, the fact that acquisition of water is in fact difficult and not economical emphasizes the importance of deficit irrigation in our country. In a farm where irrigation water is insufficient or expensive, which plants can be given deficit water and at what rates and which plants should be irrigated without any restriction can be determined using linear programming techniques[2,3].

In deficit water applications, with the help of optimum distribution, the entire field can utilize from irrigated agriculture even with the lowest water supply. For a farm implementing a deficit water scheme to obtain the highest income with deficit water supply, the plant types that can be subjected to deficit water application and the rates of such application or the plant types that should be given adequate water without any restriction can be found out using linear programming methods. Such studies concerning the optimization of deficit irrigation have gained importance in recent years when water sources are adversely affected in terms of both quantity and quality[3].

The irrigation programming made under the existing soil, vegetation and climatic conditions is important for, both under deficit and adequate water supply conditions, optimal utilization from water and soil sources, increasing production, increased utilization from precipitation and minimizing water losses. In particular, in cases where water supply is deficit and water is expensive, a proper irrigation scheduling can secure significant increases in yield[4,5].

The purpose of this study was to determine the optimum cropping pattern that will maximize income with adequate and deficit water supply in a mid-size (100 da)

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farm in Harran Plain Firat Irrigation District that is selected as the study area.

MATERIALS AND METHODS

Firat Irrigation District (FID) is located to the south of Sanliurfa city center and its elevation is approximately 450 m. The net surface area of FID is 78 410 da (consisting of 64 724 da irrigated agricultural area and 583 da dry agricultural area). FID is located upstream of the main canal system with a capacity of about 40 m^3 that supplies water to a net irrigation area of 337 000 da in Harran Plain.

Only 5 villages have dry agricultural areas where wheat and pistachio are cultivated. In irrigated areas, cotton is cultivated at the highest level, which is followed by wheat. Vegetable production is made generally in small areas.

In order to carry out irrigation scheduling, optimization analyses and cropping pattern planning in adequate and deficit irrigation conductions in a locality selected as the study area, it is necessary first to select a mid-size farm and then, to determine the plants that will be cultivated in this farm[2].

The plants cultivated in mid-size farms that are included in Sanliurfa-Harran Plain irrigation were determined taking into consideration the records the farms. In the study, the cropping pattern established by the state hydraulic works (SHW) within the framework of the irrigation project was examined as well and selection of the plants that can be cultivated in both watery and dry conditions was decided. In the selection of the plants, the cropping pattern established by the SHW for the region, the plants recommended by the Rural Service Research Institutes, wheat, barley, cotton, watermelon, pepper, eggplant, tomato as approved by the Provincial Directorate of Agriculture and the District Directorates of Agriculture and sunflower and soybean as secondary products were taken into consideration.

Given the fact that sowing of plants not on a single date, but on several different successive dates is a requirement for the plants with larger sowing area and at the same time, it is useful for extending the need for irrigation water to a longer period in peak periods in case the irrigation water is not adequate, 2 or 3 sowing dates with a 10 day interval were determined in the study for each plant depending on the sowing area. In the determination of plant sowing or planting dates, local data were utilized.

Penman-Monteith method was used in determining the water consumption of the plants recommended for the region.

The relations between water and yield are examined by researchers in terms of parabolic relations between irrigation water quantity and yield or plant water consumption and yield as well non-dimensional relations. Non-dimensional water-yield relation is given[6]:

$$[1-Ya/Ym] = ky\ [1-E\,Ta/E\,Tm]$$

where:
Ya : Actual yield (kg/ha)
Ym : Maximum yield (kg/ha)
ky : Coefficient of yield
Eta : Actual water consumption (mm)
ETm : Actual water consumption (mm)

In this education, ky, called as the yield factor, varies depending on types and development phases of the plants and shows whether a plant is sensitive to water deficit in that period.

When the field to be irrigated is deficit and the irrigation water is adequate, generally maximum production per unit area is targeted. In this practice called as optimum irrigation, plants are irrigated whenever they need so as not to decrease the plant yield and the amount of irrigation water is so adjusted to raise the soil humidity to the field capacity. In the practice of less irrigation water needed for various reasons, the actual water consumption of the plant will be lower than its maximum water consumption. Therefore, the actual yield will be less than the maximum yield. The decrease in yield will be little or much depending on time, duration and magnitude of the tension created by the deficit water. In this case, development of irrigation scheduling that will ensure highest yield with existing deficit water is important.

In case irrigation water is not adequate, deficit water application for the whole season of plant development (seasonal deficit) or deficit water application at one or several stages when the plant is less sensitive to water (intra-seasonal deficit) can be performed.

In cases where the agricultural area that can be irrigated is abundant, yet the irrigation water capacity is not sufficient or economical, a more contemporary irrigation technology may be selected and at the same time, deficit irrigation may be carried out. In deficit irrigation, irrigation water amount is decreased to a certain extent allowing a decrease in yield, yet it is possible to irrigate more area with the same amount of water and obtain more income per unit water[7,8].

Plant coefficients kc and yield factors ky, plant effective root depth, humidity level of the soil to be irrigated and other data as required for these calculations,

were prepared using the publications. In the study, seasonal water deficit was applied[9,10].

In addition to the case where the water requirement of plants is completely met, the irrigation water options whereby 80 and 60% of the water requirement of plants are provided were considered and accordingly, three different irrigation schedules were obtained for each plant.

In an irrigated agriculture farm, in order to obtain maximum operation income, it is necessary to find out the optimal cropping pattern for both the cases where irrigation water capacity is adequate and deficit. To this end, linear programming techniques can be utilized[2].

Linear programming methods operate with linearly progressing equations. It is necessary to determine the planning values that are proportional to the elimination of the values disturbing the linearity and to the narrowing and expansion of production issues. Therefore, "gross profit" that is generally calculated separately for each production activity is a value free from the values that disturb the linearity and it has great significance as a factor in decision-making in operational planning[2].

The gross profit values considered in this study were calculated using the following equation[2,3].

$$BK = (Y_a xSF)-[(DM_1)+(k_y xY_a / Y_m)+(k_v xV_t)+(k_e x_t)+(k_n x N)]$$

where:

BK = Gross profit (TL/da)
Y_a = Actual yield (kg/da)
SF = Sales price (TL/kg)
DM_1 = Production costs that do not change depending on yield level (TL/kg)
k_y = Production costs that change depending on yield for maximum yield (TL/kg)
Y_m = Maximum yield (kg/da)
k_v = Unit price of irrigation water (TL/m^3)
V_t = Total (gross) amount of irrigation water applied to the plant (m^3/da)
k_e = Energy costs for transmission, distribution and application to soil per unit water (TL/m^3)
kn = Labor costs for an irrigation (TL/unit/da)
N = Irrigation coefficient

Gross profit values for the plants were calculated assuming that family labor would be sufficient and therefore, labor costs were not taken into consideration. However, in order to make provisions for labor outsourcing in cases where family labor is not sufficient, the model included additional labor variables[2].

In the study, optimum cropping patterns for an average year for cases where water source capacity is adequate (K_1 = 100%) and is not adequate (K_2=80%, K_3=60%, K_4=40%, K_5=20%, K_6=0%) in a farm with an agricultural area of 100 da were obtained using the linear programming technique[11-13]. In the solution of the linear programming models, WINQSB computer software was utilized.

RESULTS AND DISCUSSION

As an example, one of the irrigation schedules established for adequate and deficit water conditions is given in Table 1. In optimum irrigation conditions (S_1), total applied irrigation water amount is 799 mm and the yield rate is 100%. While S_2 solution is taken, the irrigation water was ensured to be equal or close to 799x0.80 = 639 mm. In this case, the yield rate is 83%. The results of the irrigation schedules obtained in the study are summarized in Table 2.

Table 1: Irrigation schedules developed for watermelon plant in adequate and deficit irrigation conditions

Irrigation conditions	Irrigation No.	Irrigation Dates	Water amount (mm)	I (mm)	SA (day)	VO (%)
	1	10-05	32	799		100.0
	2	22-05	38		12	
	3	30-05	42		8	
	4	07-06	45		8	
	5	15-06	52		8	
	6	22-06	52		7	
S_1	7	28-06	49		6	
(%100)	8	04-07	51		7	
	9	11-07	52		7	
	10	18-07	52		7	
	11	25-07	51		7	
	12	02-08	57		8	
	13	10-08	56		8	
	14	18-08	53		8	
	15	27-08	57		9	
	16	06-09	58		10	
	1	10-05	32	639		83.5
	2	22-05	38		12	
	3	04-06	44		13	
S_2	4	13-06	51		9	
(%80)	5	22-06	50		9	
	6	01-07	67		9	
	7	11-07	70		10	
	8	21-07	68		10	
	9	01-08	71		11	
	10	12-08	69		11	
	11	24-08	70		12	
	1	10-05	32	479		61.6
	2	22-05	38		12	
S_3	3	06-06	46		15	
(%60)	4	17-06	59		11	
	5	28-06	71		11	
	6	10-07	78		12	
	7	23-07	78		13	
	8	05-08	76		13	

I: Total water amount, SA: Irrigation interval, VO: Yield rate (Y_a/Y_m)

Table 2: Irrigation schedule results and gross profit values obtained in the study for all plants

Variables	Plant type and water amount	I (mm)	N (unit)	Y (kg/da)	Gross profit (10^6 TL/da)
X_1	Wheat Opt.	365	6	600	50.0
X_2	Wheat 80%	292	4	553	45.2
X_3	Wheat 60%	220	3	486	38.9
X_4	Wheat 40%	146	2	413	32.0
X_5	Barley Opt.	157	3	500	35.1
X_6	Barley 80%	125	2	477	33.2
X_7	Barley 60%	94	1	453	31.1
X_8	Barley 40%	63	1	423	28.6
X_9	Cotton Opt.	909	13	350	100.8
X_{10}	Cotton 80%	727	8	294	80.3
X_{11}	Cotton 60%	545	7	234	58.3
X_{12}	Watermelon Opt.	799	16	4500	213.0
X_{13}	Watermelon 80%	639	11	3758	211.4
X_{14}	Watermelon 60%	479	8	2772	140.5
X_{15}	Pepper Opt.	960	30	2400	335.5
X_{16}	Pepper 80%	768	15	1973	271.4
X_{17}	Pepper 60%	576	15	1433	190.4
X_{18}	Eggplant Opt.	1000	32	5000	366.2
X_{19}	Eggplant 80%	800	19	4005	290.1
X_{20}	Eggplant 60%	600	12	2875	202.7
X_{21}	Tomato Opt.	1061	24	4500	278.0
X_{22}	Tomato 80%	849	14	3645	221.3
X_{23}	Tomato 60%	637	12	2525	145.8
X_{24}	Sunflower II Opt.	574	8	244	29.6
X_{25}	Sunflower II 80%	459	6	208	22.4
X_{26}	Sunflower II 60%	344	6	162	13.7
X_{27}	Soybean II Opt.	486	6	250	41.8
X_{28}	Soybean II 80%	389	4	215	28.2
X_{29}	Soybean II 60%	292	3	172	18.7

For the average year and adequate water capacity, the linear programming model was formed as shown below:

- Objective function

$$50 \times 10^6 X_1 + 45.2 \times 10^6 X_2 + \ldots + 18.7 \times 10^6 X_{29} - 0.5 \times X_{30} - \ldots - 0.5 \times 10^6 X_{38}$$

- Constraints

A: Sowing area constraints

1. Total sowing area constraint

   $X_1 + \ldots + X_{23} \le 100$

2. Second harvest sowing area constraint

   $X_1 + X_2 + X_3 + X_4 + X_5 + X_6 + X_7 + X_8 - X_{24} - X_{25} - X_{26} - X_{27} - X_{28} - X_{29} \ge 0$

3. Maximum sowing area constraints

   $X_1 + X_2 + X_3 + X_4 \le 50$

   $X_5 + X_6 + X_7 + X_8 \le 30$

   $X_1 + X_2 + X_3 + X_4 + X_5 + X_6 + X_7 + X_8 \le 50$

   $X_9 + X_{10} + X_{11} \le 50$

   $X_{12} + X_{13} + X_{14} \le 10$

   $X_{15} + X_{16} + X_{17} \le 10$

   $X_{18} + X_{19} + X_{20} \le 10$

   $X_{21} + X_{22} + X_{23} \le 10$

B: Labor constraints

1. March: $0.06X_1 + 0.06X_2 + \ldots + 0.00X_{29} - X_{30} \le 666$

2. April: $5.8X_1 + \ldots + 0.00X_{29} - X_{31} \le 666$

Table 3: Optimum cropping pattern

Plants			K_1	K_2	K_3	K_4	K_5	K_6
			Farm water capacity					
Wheat	X_1	S_1	50	46.87	29.21	10.56	1.71	0
	X_2	S_2		3.13	20.79	21.26	7.68	0
	X_3	S_3						0
	X_4	S_4				13.97	13.14	0
Barley	X_5	S_1					7.37	0
	X_6	S_2				4.20	1.31	0
	X_7	S_3					18.78	0
	X_8	S_4						0
Cotton	X_9	S_1	10	10.00	10.00	4.25		0
	X_{10}	S_2						0
	X_{11}	S_3						0
Watermelon	X_{12}	S_1	10	7.87	7.09	8.71	0.66	0
	X_{13}	S_2		2.13	2.91	1.29	3.76	0
	X_{14}	S_3						0
Pepper	X_{15}	S_1	10	10.00	10.00	10.00	10.00	0
	X_{16}	S_2						0
	X_{17}	S_3						0
Eggplant	X_{18}	S_1	10	10.00	10.00	10.00	4.83	0
	X_{19}	S_2					2.12	0
	X_{20}	S_3					3.05	0
Tomato	X_{21}	S_1	10	10.00	10.00	10.00	0.71	0
	X_{22}	S_2						0
	X_{23}	S_3						0
Sunflower II	X_{24}	S_1						0
	X_{25}	S_2						0
	X_{26}	S_3						0
Soybean II	X_{27}	S_1	50	32.82	14.16			0
	X_{28}	S_2						0
	X_{29}	S_3		10.57	6.73	0.85	0.81	0
1st harvest total sowing area (da)			100	100.00	100.00	94.24	75.12	0
2nd harvest total sowing area (da)			50	43.39	20.89	0.85	0.81	0
Income (10^9 TL)			16	15.33	14.60	13.40	9.11	0

1. November: $0.25X_1 + \ldots + 0.00X_{29} - X_{38} \le 760$

C: Irrigation water constraints

1. April (1. ten days) $72X_1 + 78X_2 + \ldots + 0.0X_{29} \le 500000$

2. April (2. ten days) $0.0 \, X_1 + \ldots + 0.0X_{29} \le 500000$

3. October (1. ten days) $0.0X_1 + \ldots + 0.0X_{29} \le 500000$

As coefficients of the variables for the deficits relating to labor capacity, total of labor capacities required monthly by each plant and the variable concerning the provision of temporary labor for the relevant period was used. As coefficients of the variables for the irrigation water deficits concerning ten-day period, irrigation water amounts required by each plant for the relevant period were taken and as capacity values, a value greater than the amount that may be need for the adequate water condition was taken. Following the solution of the model and obtaining the optimal cropping pattern, the water source capacity required for this pattern in the peak

period (K_1) was obtained. K_1 was multiplied by 0.8 to obtain K_2, by 0,6 to obtain K_3, by 0,4 to obtain K_4, by 0.2 to obtain K_5 and by 0 to obtain K_6.

The optimum cropping pattern given for K_1 (100%, adequate water capacity) shows 50 da for wheat, 10 da for eggplant, 10 da for cotton, 10 da for watermelon, 10 da for pepper, 10 da for tomato and 50 da for 2nd harvest soybean (Table 3). Vegetables and wheat are at the higher limit as possible. In the optimal cropping pattern obtained for the adequate water, S_1 subject in which water requirements of all plants are met was included. For K_2 where it fell to 80%, water deficit is in question for wheat, watermelon and soybean. For pepper, eggplant and tomato, no water deficit is in question until K_5, where, however, they are included in the pattern to a certain extent. Soybean is included to a very low extent in S_3 following K_4. Sunflower is not included to the pattern for any condition. While included in the pattern for K_4 and K_5, barley reaches its highest value for K_5.

When examined in terms of the incomes of the farms with different water sources, if the irrigation water capacity of the farm decreases, the incomes of the farm also decreased. The amount of such decrease is small initially while it becomes more intense afterwards. An interesting point here is that even if the water source capacity decreases to 20%, the income is higher than the half. When the maximum income is around 16 billion TL, it is around 9.11 billion TL for K_5.

The results of the study show that even with very low water supply, it is possible to keep the farm income at high levels. However, for this, the water-yield relations of these plants should be well-known and the types of plants and irrigation scheduling that should be used depending on the existing irrigation water, labor and field capacities should be determined using analyses of linear programming technique.

With the emergent water problems in the world, countries prefer the methods for optimum utilization from their water potentials. Obviously, provision of agricultural irrigation water to plants according to their requirements will ensure maximum production per unit area. However, unnecessary irrigation by farmers in adequate water conditions lead to soil salination and an increase in water table. Instead, deficit irrigation will ensure an increase in income by providing effective water utilization and extending irrigation to a larger area.

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