International Journal of Agricultural Engineering, Vol. 3 No. 1 (April, 2010) : 5-10

Research Paper :

Optimal cropping pattern in command area

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Accepted : ***November, 2009***

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ABSTRACT

The irrigation water requirement of major crops and total water available in the Natuwadi dam located in Konkan region of Maharashtra was estimated. A linear programming model was formulated to suggest optimal cropping pattern giving the maximum return at different water availability levels. The objective function of the model was subject to following constraints: total water available and land during *Rabi* season, minimum area under rice and sugarcane for local food requirement and preference to grow particular crop in a specific area. This model has given the optimal cropping pattern for a command area of 2050 ha at water availability levels of 100, 90, 80 and 70 per cent and net returns of 120,109.50, 99.10 and 88.64 million rupees, respectively. It is found that, the water available in the command area may support optimally 36.50, 1018, 50, 273, 45, 98 and 127 ha of rice, banana, sugarcane groundnut, chilli, brinjal and maize for fodder, respectively, to get maximum returns of 120 million rupees at 100% water availability levels. Banana appears to provide the most consistent profit in the command area.

Key words : Water requirement of crops, Water availability levels, Cropping pattern, Linear programming model, Net benefit

Efficient management of irrigation system is becoming key issue for agricultural development. There will be increasing need for more extensive water supply systems to meet ever-increasing agriculture, domestic and industrial demand due to population pressure. Water is not found when and where it is needed and also it may not be of good quality. Optimum development and efficient utilization of water resources, therefore, assumes great significance in the country. Important aspect of water management includes optimal allocation of water for irrigation purposes over an irrigation season and selection of cropping pattern for a given land area and water availability. This is usually achieved through the application of optimization techniques. Linear programming (LP) has been one of the widely used technique for solving water resources problems (Yeh, 1985; Benedini, 1988). Bahauddin and Hussain (1995) evolved a methodology for optimal surface irrigation practices, which aimed at maximizing the benefits of crop production per unit water applied to a case study of Sri Ram Sagar project. Linear programming technique was employed to evolve optimal allocation of water to crops. Singh (1996) developed a linear programming model to obtain optimum crop combination for maximum net benefit with available land and water in Bijnor district. She concluded that by optimum utilization of land and water resources it would be possible to increase the agricultural income of the district by almost 80 per cent. Cheng Yun (2008) proposed a linear programming model to study the consumptive use of surface water and groundwater for optimum water allocation in Taiwan.

METHODOLOGY

In the present study, a LP model was formulated for arriving at an optimal cropping pattern for Natuwadi Project in Konkan region, Maharashtra. The model was solved for different availability levels of inflows *viz.*, 100, 90, 80 and 70 per cent, to obtain various possible cropping patterns under coastal conditions.

Study area:

Natuwadi project is the state sector medium irrigation project on Choriti river, situated in southern Konkan region of Ratnagiri district of Maharashtra, India between the latitude $17^0 50'$ N and $73^0 24'$ E. The location map of Natuwadi medium irrigation project is shown in Fig. 1. The salient features of Natuwadi Project are presented in the Table 1.

Inflow data:

The daily inflow data for 20 years *i.e.* from 1988 to 2007 for Choriti river at Natuwadi dam site were collected from the office of the Irrigation Department. The average monthly inflow discharges were obtained by adding up

Table 1 : Salient features of Natuwadi Medium Irrigation Project

Sr. No.	Particulars		Value
1.	Location	:	Village –Natuwadi, N.H. 17, Tal-Khed, Dist-Ratnagiri, Maharashtra, India.
2.	Type of dam	:	Earthen dam with masonry gated spillway on left bank.
3.	SOI Toposheet No.	:	47/G-5 and 6
4.	Latitude	:	$17^{0}50^{'}$ N
	Longitude	:	$73^{0}24^{'}$ N
5.	Catchments area	:	16.32 sq. km.
6.	i) Mean annual rainfall	:	3632 mm
	ii) Average annual runoff	:	49.98 M cum.
	iii) 75 % dependable runoff	:	36.3 M cum.
7.	Dam and Reservoir		
	i) Gross capacity of reservoir	:	28.08 M cum.
	ii) Capacity of dead storage	:	0.85 M cum.
	iii) Capacity of live storage	:	27.23 M cum.
	iv) Evaporation losses	:	2.21 M cum.
	v) Area under submergence at FRL	:	217.2 ha.
	vi) Max. height of dam	:	45.27 m
	vii) Total length of dam	:	900 m
	viii) Type of spillway	:	Masonry gated ogee type spillway on left gate
8.	Canals		
	i) Length of canal	:	Left bank canal, 12 km. Right bank canal, 24 km.
	ii) Discharge at head	:	Left bank canal, 0.88 cu.m./sec Right bank canal, 5.66 cu.m./sec
9.	Commanded area		
	i) Gross commanded area	:	2343 ha.
	ii) Cultivable area	:	2006 ha.
	iii) Irrigable area	:	2050 ha.
	iv) Cropped area	:	4621 ha.
10.	Intensity of irrigation to gross commanded area	:	76.17 %
13.	Cost per ha of irrigable area	:	Rs. 1.6 lakh/ha
14.	Benefit cost ratio	:	1.74 : 1

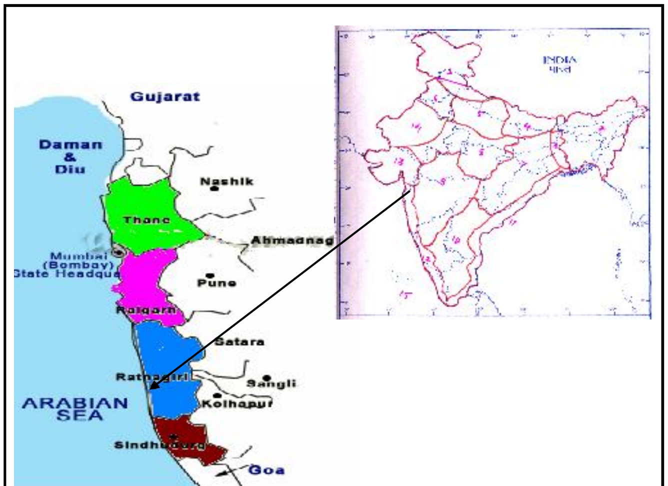

Fig. 1 : The location map of Natuwadi medium irrigation project

daily inflows and used for model building. The total annual inflow was then calculated from the collected data. The water year was considered from June to May, with June, July, August, September and October as wet season and November to May as dry season.

The statistics of the monthly inflow are presented in Table 2. From the Table 2, it can be observed that 95 per cent of annual inflow occurred during the months June to October. There was no major variation in the standard deviation. There was no major variation in skewness and kurtosis coefficients. Therefore, the distribution of inflow in each month may be assumed same.

The climate of the area is characterized by humid sub-tropical monsoon with three-district season *i.e.* summer (March to May), rainy (June to October), winter (November to February). On an average annual precipitation of 2800 to 3500 mm is received, of which about 95 % of the rainfall occurs during June to October. During rainy season, the humidity is as high as 90 to 98 per cent. The mean daily maximum and minimum temperatured varies between 30^{0}C to 23^{0}C, respectively. The soils of the study area were lateritic moderately fine textured and well drained. The soils were having acidic reaction (pH=4.75 to 6.50). The CEC ranges between 8.1 to 23.55-me/100 g of soil. The lateritic soils are dominant in the region having field capacity of 28 % and wilting point of 17.4 %. The basic infiltration rate is 4.4 to 7.7 cm/hr having soil depth of 30 to 100 cm (Anonymous, 1990).

The main crops grown in the command area are *Rabi* rice (Jan. to April), banana (Oct. to June), sugarcane (Oct. to June), groundnut (Nov. to April), watermelon (Nov. to March) and chilly (Nov. to March). Monthly

Table 2 : The statistics of the monthly inflows

Month	Mean $\overline{X}$ M cum.	Standard deviations M cum.	Variance s^2	Coefficient of Variation c.v.	Coefficient of Skewness C_s	Kurtosis	Lag one serial correlation coefficient r_1
June	5.41	3.43	11.76	0.63	1.86	2.88	0.136
July	15.39	3.62	13.12	0.23	-1.058	0.154	0.184
Aug.	23.07	1.73	3.0	0.075	-0.82	0.41	0.571
Sept.	27.05	2.10	4.39	0.077	-3.57	13.95	0.917
October	27.28	1.74	3.03	0.064	-3.24	11.34	0.945
Annual	98.20	6.61	43.68	0.067	0.44	1.87	0.196

water requirements for crops grown in the command area were worked out considering 75 per cent dependable rainfall for effective rainfall computation, based on the guidelines given by the Water Management Division (1971) and are listed in Table 3. The computations of net benefit in rupees per hectare for each crop was worked out based on data collected from the site and are given in Table 4. Storage at different availability levels was calculated and reported in Table 5.

Brief details about linear programming and its

Table 3 : Monthly crop water requirement (mm)

Month	*Rabi* rice	Banana	Sugarcane	Groundnut	Watermelon	Green chilli	Brinjal	Cucumber	Tomato	Fodder maize	Total
Jan.	294	49	39	100	95	84	109	114	122	78	1084
Feb.	327	58	56	99	105	116	161	140	140	132	1334
March	335	81	185	130	32	138	175	166	168	190	1600
April	156	119	188	116	-	-	-	-	176	-	755
May	-	155	191	-	-	-	-	-	-	-	346
June	-	48	47	-	-	-	-	-	-	-	95
July	-	-	-	-	-	-	-	-	-	-	-
Aug.	-	-	-	-	-	-	-	-	-	-	-
Sept.	-	-	-	-	-	-	-	-	-	-	-
Oct.	-	113	121	-	-	-	-	-	-	-	234
Nov.	-	106	102	14	14	24	-	-	-	-	260
Dec.	343	47	78	45	52	68	75	80	64	-	852
Total	1455	776	1007	504	298	430	520	500	670	400	**6560**

Table 4 : Details of net benefit from crops

Sr. No.	Crops	Yield q/ha	Support price, Rs/q	Market value Rs./ha	Cost of cultivation Rs./ha	Net benefit Rs./ha.
1.	*Rabi* rice					
	1.Paddy	40	580	23200	18808	8392/-
	2.By produce	40	100	4000		
2.	Banana	300	600	180,000	99069	80931/-
3.	Sugarcane main produce	1000	100	10,0000	42137	62863/-
	By produce					
4.	Groundnut main produce	20	1600	32000	19269	15931/-
	By produce	40	80	3200		
5.	Watermelon	150	500	75000	44068	30932/-
6.	Green chilli	100	1500	150000/-	35131/-	1,14,869/-
7.	Brinjal	200	600	12000/-	37627/-	82373/-
8.	Cucumber	200	800	16000/-	35406/-	1,24,594
9.	Tomato	100	100	100000/-	64063	35937/-
10.	Maize for fodder	420	100	42000	29357	12643/-

application (mathematical modelling) to the present case are discussed below.

Linear programming (LP) :

Linear Programming (LP) deals with that class of programming problems for which the constraints as well as the function to be optimized are linear relations among the variables. When the resources are scarce, there is a need for allocation of limited resources to priorities or activities. This technique is used either to maximize or minimize a given objective function. The solution to the linear programming (LP) model was obtained using simplex method with a TORA computer software.

In a more convenient matrix notation, a typical LP problem (Maji and Heady, 1980) can be written as,

In a more convenient matrix notation, a typical LP problem (Maji and Heady, 1980) can be written as,

$$\text{Max/(Min)} \quad Z = C^T x \qquad \ldots (1)$$

Subject to the constraints

$$Ax \geq B \qquad \ldots(2)$$

and $x \geq 0$ …. (3)

where, C is a (nx1) vector known constant,

x is a (nx1) vector of decision variables,

A is a (mxn) matrix of known constant and

B is a (mxn) vector of constants.

The problem is to find asset of x, the decision variables, that maximize (or minimize) the objective function Z (Eq. 1) and satisfies the equation 2 and 3.

Assumptions :

The following assumptions were considered in developing the model.

– The relationship between the variables in the objective function and the constraints are linear.

– All parts of the land under consideration are put to the same management practices.

– Soil of the project area is homogenous.

– Time and period of crop sown is same in every year.

– Crop yield considered is same throughout the command area inspite of variation in management practices.

The model has been developed considering the stochastic nature of the inflows to the dam. The model was solved for different storage water availability levels of inflows *viz.*,70%, 80%, 90% and 100% to obtain various cropping pattern.

Objective function:

– The objective function has been formulated to allocate land resource for the existing crops, so as to maximize the net benefit and is given by:

$$\text{Max}Z = \sum_{j=1}^{12} B_j A_j \qquad (4)$$

where, Z = Net benefits from the command area (Rs.)

B_j = Net benefits from j^{th} crop (Rs./ha)

A_j = The area under j^{th} crop in the command (ha)

Constraints:

The objective function is subjected to the following constraints:

Capacity constraints:

The storage in the dam at any month should not exceed the maximum storage, S_{max} and storage should be greater than dead storage, S_{min} for all months.

$S_t \leq S_{max}$, t = 1, 2,…………,12

$S_t \geq S_{min}$, t = 1, 2,…………,12

where, S_t represents storage in the dam at time t (ha-cm).

Water requirement constraints:

The release in each month should be greater than or equal to the amount of water needed in that month.

$$R_t - \sum_{i=1}^{m}\sum_{j=1}^{n} CWR_{j_t} . A_{ij} \geq 0, \qquad t = 1,2,\ldots,12 \qquad ..(5)$$

where, R_t represents release from the dam during month t (ha-cm) and CWR_{jt} represents crop water requirement for the crop j during the month t.

Continuity constraints:

The continuity equation can be written as follows:

$$S_{t+1} = S_t + I_t - R_t - E_t - PL_t \qquad t = 1,2\ldots12 \qquad . (6)$$

where, S_t = Storage in the dam at time t

S_{t+1} = Storage in the dam at time t +1

I_t = Inflow into the dam at time interval Δt.

R_t = Release from the dam at time interval Δt.

E_t = Evaporation from the dam at time interval Δt.

PL_t = Percolation losses from the dam at time interval Δt.

In the above equation the combined evaporation and percolation losses were assumed to be 15 per cent of the average storage for the period Δt as suggested by Loucks *et al.* (1981).The time period Δt was taken as a month in this model.

$$E_t + PL_t = 0.15\,[(S_t + S_{t+1})/2] \qquad ..(7)$$

Land availability constraints:

The sum of area under each crop should not exceed the total available land. This can be represented by the following equations.

$$\sum_{j=1}^{n} A_{ij} \le A_i \qquad i = 1, \ldots, \ldots, m \qquad (8)$$

where, A_i represents total available land in the command of i^{th} canal (ha).

RESULTS AND DISCUSSION

Optimization of objective function was performed with a linear programming (LP) model. Storage at different availability levels is shown in Table 5. Area allocated to different crops and net benefits from the planning model formed the command area of Natuwadi Project is shown in Table 6, so as to maximize the net returns.

Table 5 : Storage at different availability levels, ha-cm

Gross storage	Availability levels (%) 70	80	90	100
1,18,700	83,090	94,960	1,06,830	1,18,700

The maximum total area of 1834 ha was allocated at 100 % water availability level, which decreased as 1583, 1453, 1323 ha at 90, 80 and 70 per cent water availability levels, respectively.

As regards the area allocated to individual crops, maximum area was allocated to banana crop, as it was most profitable crop. Rice crop was allocated the restricted area of 36.5 ha, as it was not profitable and needs more water. However, due to sustainability constraint rice has taken the minimum area, which was necessary to meet the staple food requirement of the existing population. Sugarcane took more area than rice, as this is annual crop. Though the returns from sugarcane are more, but due to the non-availability of sugar factories in the nearby locality, area under sugarcane has not gone up much.

Groundnut crops are now gaining popularity in Konkan region. Hence, this crop was introduced for meeting the oil requirement of existing population.

As regards to number of bullocks and buffalos, it was necessary to have 2100 bullocks for performing various farming operations and 800 buffalos, which gave additional returns of Rs.4 millions from milk and F.Y.M. production in the area. For meeting the feed requirement the fodder maize was introduced in the command.

The other vegetable crops like water melon, chilli, brinjal, cucumber and tomato have been introduced not only for meeting the nutritional requirement of the population but also due to the vicinity of Mumbai-Goa highway to the command population and this provided a good market avenue for receipt generation.

It is also observed from Table 6 that the maximum net benefits of 120 million rupees were obtained in 100 % water availability level indicating the importance of water availability from the point of view of receipt generation. The maximum net benefits decreased as 109.5, 99.1, 88.64 million rupees, at 90, 80 and 70 per cent water availability, respectively in the command area.

Conclusion:

Based on the analysis of the results following conclusions are drawn,

– Irrigation plan for 100 % availability level with maximum net benefits of 120 million rupees can be implemented in the command area.

– Net benefit at100% water availability level is 35 % more than 70% availability level.

– Banana crop appears to provide the most consistent profit in the command area.

– Comparison of results indicates that, the

Table 6 : Area allotted to the different crops and net benefit from the planning model at different water availability levels

Sr. No.	Crop	Unit	Solution for maximization of net benefit at availability levels 100%	90%	80%	70%
1.	*Rabi* rice	ha	36.50	36.50	36.50	36.50
2.	Banana	ha	1018.60	823.00	627.35	431.70
3.	Sugarcane	ha	50.00	50.00	50.00	50.00
4.	Groundnut	ha	273.50	273.50	273.50	273.50
5.	Watermelon	ha	10.00	10.00	10.00	10.00
6.	Chilli	ha	45.00	45.00	45.00	45.00
7.	Brinjal	ha	98.10	163.30	228.50	293.70
8.	Cucumber	ha	50.00	50.00	50.00	50.00
9.	Tomato	ha	5.00	5.00	5.00	5.00
10.	Maize for fodder	ha	127.60	127.60	127.60	127.60
Net benefit (million rupees)			120.00	109.50	99.10	88.64
Total area		ha	1834.30	1583.90	1453.45	1323.00

methodologies are quite versatile and can be used in other similar situations with suitable modifications.

Acknowledgement:

The author is thankful to the Irrigation Department, Govt. of Maharashtra, for providing necessary data.

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