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Optimization of multi-objective cropping pattern using linear and goal programming approaches

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सार – सिंचाई पर आधारित कृषि के लिए सिंचाई योजना तथा उसकी समय–सारणी तैयार करना जल प्रबंधन के आवष्यक पहलू हैं। इस उद्‌देष्य की पूर्ति के लिए एक निर्धारित सीमा के अंतर्गत फसल चक्र आषा के अनुरूप बनाने के लिए भूमि और जल का समुचित वितरण अपेक्षित है। इस षोध पत्र में बारना सिंचाई परियोजना के लिए फसल चक्र को आषा के अनुरूप बनाने हेतु रैखिक एवं लक्ष्याभिमुखी दृष्टिकोण (एल. पी. एवं जी. पी.) अपनाया गया है। इसमें फसल चक्र को आषा के अनुरूप बनाने के लिए तीन विभिन्न लक्ष्यों पर विचार किया गया है जैसेः– कुल उत्पाद, प्रोटीन तथा कैलोरी की मात्रा में अधिकतम वृद्धि। इस परियोजना के अंतर्गत फसल चक्र को आषा के अनुरूप बनाने के लिए सर्वश्रेष्ठ दृष्टिकोण के चयन हेतु कुल उत्पाद, प्रोटीन एवं कैलोरी की मात्रा तथा सिंचाई के लिए प्रयुक्त रैखिक कार्यक्रम (एल. पी.) तथा लक्ष्य अभिमुखी कार्यक्रम (जी. पी.) के तहत जल की मात्रा जैसे कारकों पर विचार किया गया है। इस षोध पत्र में रैखिक कार्यक्रम (एल. पी.) तथा लक्ष्य अभिमुखी कार्यक्रम (जी.पी.) के सिद्धान्त का प्रयोग करते हुए फसल चक्र को आषा के अनुरूप बनाने के लिए अपनाए गए तरीकों पर प्रकाष डाला गया है तथा अध्ययन के आधार पर निष्कर्ष निकाले गए हैं। प्राप्त हुए निष्कर्षों के अनुसार फसल चक्र को आषा के अनुरूप बनाने के लिए जी. पी. का सिद्धान्त इस परियोजना के लिए सर्वोत्तम पाया गया है।

ABSTRACT. Irrigation planning and scheduling are essential components of water management in irrigated agriculture. For this purpose, optimal allocation of land and water is required for optimization of cropping pattern under a set of limitations. In this paper, an attempt was made to optimize the cropping pattern for Barna irrigation project using Linear and Goal Programming (LP and GP) approaches. Three different objectives such as maximization of net return, protein and calorie values were considered for optimization of cropping pattern. The factors like amount of net return, values of protein and calorie, and quantum of water utilized for irrigation by LP and GP were considered for selection of best approach for optimization of cropping pattern for the project. The paper presents the methodology adopted in optimizing the cropping pattern using LP and GP approaches and the results obtained from the study. GP approach was found to be best for optimization of cropping pattern for the project.

Key words – Barna Irrigation Project, Cropping Pattern, Goal Programming, Linear Programming, Optimization.

1. Introduction

Irrigation planning and scheduling are essential components of water management in irrigated agriculture. For this purpose, optimal use of land and water is required for optimization of cropping pattern under a set of limitations. The availability of land and water are more or less static in nature whereas our need for food from these two resources is dynamic in nature because of growing population. Under these circumstances, vertical expansion of cultivable land is considered as suitable method to increase food production. This can be achieved by adopting a proper and suitable cropping pattern in such a manner so that it optimizes the available resources, gives maximum net return, protein and calorie values with minimum land and water for the project under study. The approaches like Benefit-Cost, Functional and Programming are commonly used for optimization of cropping pattern with optimal allocation of land and water to different crops considered in the study.

Dorfon *et al*. (1958) expressed that Benefit-Cost (BC) approach could be used to test the economic feasibility of the project and to allocate scare resources among different alternatives. They also expressed that computation of BC ratio becomes extremely complex due to inter relations and feedbacks between different alternatives. Due to the inadequacy of BC approach, Charnes and Cooper (1967) used functional approach to combine the crop production with LP to estimate water demand of various crops. They described that the functional approach has a limited but quite significant role in water resources system analysis estimating product response to a number of inputs. Because of such limitations of BC and functional approaches, programming approach was used to determine optimal production plan when large number of alternatives are associated with equally large number of resource restrictions of different kinds and magnitude (Maji and Earl, 1978). Programming approach may be classified as Linear Programming (LP), Non-linear Programming (NLP), Geometric Programming (GP), Dynamic Programming (DP), Stochastic Programming (SP), etc. When a large number of crop enterprises are to be considered under an equally large number of constraints, LP and GP approaches are considered as an effective tool for optimization of cropping pattern and used in the study.

Ignizio (1983) used multi-period LP model for temporal and spatial allocation of irrigation water in Krishnarajsagar irrigation project. Jain *et al*. (1998) used LP and identified the most profitable crop combination in Tungbhadra irrigation project under twelve different situations for each of four selected representative farms from the alternative sets of land and water. Agrawal and Agrawal (1985) applied LP in combination with water budgeting to optimize agricultural production, based on an area under irrigation of winter crops, crop yields per unit area and the total irrigation water actually applied by canals in Hissar district. Srinivasa Raju and Nagesh Kumar (2000) employed Fuzzy LP irrigation planning model for evaluation of management strategies for Sri Ram Sagar project. Valunjkar (2002) used Fuzzy LP model for optimum utilization of water resources in relation to cropping pattern for Pench irrigation project, Maharashtra.

Anderson and Farle (1983) applied GP approach to select diets to meet the specific nutritional requirements. They expressed that the nutritional balance is difficult to achieve in diets while applying LP owing to the complex inter-relationship of its constraints. They also expressed that the nutritional balance of the raw materials selected by GP showed marked improvements over that selected by LP. Soni (1985) developed Goal Programming Model (GPM) for Debra block of Midnapore district with objectives to maximize net return, agricultural production, and protein and calorie requirements for the existing population of the project area. Romero and Tahir (1984) used GP for formulation of optimal cropping pattern for Kansabhal irrigation project.

The paper presents the cropping pattern of LP and GP that optimizes the net return, protein and calorie requirements for the existing population of the project area under study. The methodology adopted in LP and GP approaches and the results obtained from the study are briefly described in the ensuing sections.

2. Methodology

2.1. *Model description of LP and GP*

Charnes and Cooper (1967) expressed that LPM is concerned with the optimization of a given objective subject to a number of environmental and/or system constraints. They described that the type of maximization and minimization models of LP are in the direction of inequalities of the system constraints. The system constraints may be of (≤), (=) or (≥) type, decision variables may be non-negative or unrestricted in sign.

The general form of LPM with '*n*' decision variables and 'm' constraints is given by :

Maximize or Minimize

$$Z = C_1 X_1 + C_2 X_2 + \ldots\ldots\ldots\ldots\ldots C_n X_n$$

Subject to,

$$a_{11} X_1 + a_{12} X_2 + \ldots . + a_{1n} X_n \le \text{ or } = \text{ or } \ge b_1$$

$$a_{21} X_1 + a_{22} X_2 + \ldots . + a_{2n} X_n \le \text{ or } = \text{ or } \ge b_2$$

$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$$

$$a_{m1} X_1 + a_{m2} X_2 + \ldots + a_{mn} X_n \le \text{ or } = \text{ or } \ge b_m ;$$

$$X_1, X_2, \ldots\ldots\ldots\ldots, X_n \ge 0$$

GPM is a linear mathematical model in which the optimum attainment of multiple goals is sought within the given decision environment. The decision environment determines the basic components of the model, namely, decision variable, goal and non-goal constraints and

TABLE 1

Objective function of different objectives considered in LP and GP

S. No.	Objective (s)	Objective function
1	Maximization of net return (MNR)	Maximize $Z = \sum_{i=1}^{n} A_i \times N_i - \left[\sum_{j=1}^{NOM} C_s * S_{wj} + \sum_{i=1}^{NOM} C_G * G_{wj} \right]$
2	Maximization of protein value (MPV)	Maximize $Z = \sum_{i=1}^{n} A_i * Y_i * P_i$
3	Maximization of calorie value (MCV)	Maximize $Z = \sum_{i=1}^{n} A_i * Y_i * C_i$

[A_i = Area allocated to i^{th} crop; N_i = Net return per Ha. (Excluding water charges) from i^{th} crop; NOM = Number of months; C_s = Cost of unit volume of surface water; C_G = Cost of unit volume of ground water; S_{wj} = Gross surface water released through canal head in j^{th} month; G_{wj} = Gross ground water released through canal head in j^{th} month; Y_i = Yield of i^{th} crop; P_i = Protein value of i^{th} crop; C_i = Calorie value of i^{th} crop; n = number of decision variables or crops]

objective function. The generalized form of GPM may be expressed as:

Minimize $Z = d^- + d^+$

Subject to $f(x) + d^- + d^+ = g_1$ and

$$\sum_{j=1}^{n} a_{ij} * X_j \le b_i \,;\; i = 1,2, \ldots, m;\; X_j \ge 0,\; d^- \ge 0,\; d^+ \ge 0$$

Here, g_1 is the goal desired which is expected from the objective function $f(x) = \sum_{j=1}^{n} C_j X_j = CX$ to achieve as closely as possible subject to the given constraints.

2.2. *Model formulation of LP and GP*

Model formulation is the process of transforming a real world decision problem into a management science model. The model formulation of LP requires selection of decision variable, system constraints and objective function. The decision variables considered in LPM and GPM are optimal cropping areas (A_i), optimal surface water releases (S_{wj}), and ground water releases (G_{wj}).

Model formulation is considered as one of the most important activity for obtaining the solution to the GP problem and as it is the most difficult part in the application of management science to a particular problem. Because of the recent advances in the use of computers, finding of solution is not difficult when compared to model formulation. However, the matrix used in GP consists of two types of constraints like goal and non-goal constraints. Each goal constraint may be assigned a positive or negative deviational variable or both depending on the three situations regarding acceptance of achievement of desired goal (Locuks *et al*., 1981). In GP, three possibilities exist for each goal or constraint equation. The left hand side can be less than or equal to, greater than or equal to, or exactly equal to the right hand side. In GP, the constraints of net return, protein and calorie requirements are described as goal constraints. Likewise, the constraints of land and water availability, and minimum area required for each crop are described as non-goal constraints of GP. The objective function and system constraints used in LPM and GPM are described in the following sections.

2.2.1. *Objective function*

The objective function of three different objectives such as maximization of net return, maximization of protein and calorie values considered in LPM and GPM as per the proposed cropping pattern is given in Table 1.

2.2.2. *System constraints*

2.2.2.1. *Water availability constraint*

The water utilization by any crop in any month should not be more than the surface water (SW) and

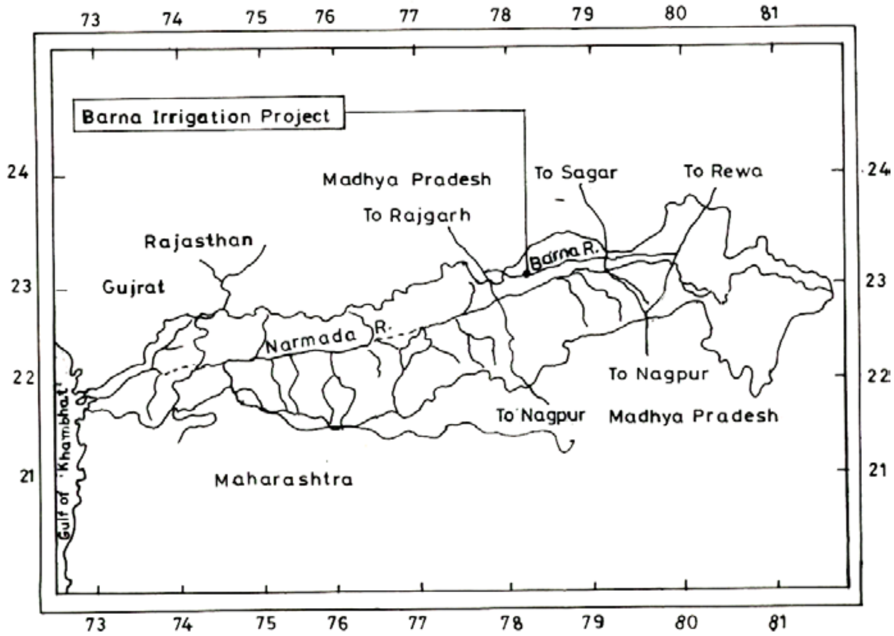

Fig. 1. Location map of the study area

ground water (GW) available in the particular month. The general form of constraint equation is defined by : $\sum_{i=1}^{n} A_i * \mathrm{GIR}_{ij} \leq S_{wj} + G_{wj}$. The maximum SW utilization by crops during any month cannot exceed the net SW available in that month for utilization subjected to the live capacity of reservoir or conveyance capacity of canal whichever is having minimum value. For SW availability, the constraint equation is defined as $S_{wj} \leq$ Min [C_{cj} or W_{Rj}]. In similar manner, GW withdrawal for irrigation in any month should not exceed the 20% of utilizable balance annual GW recharge for which the constraint equation may be given as $G_{wj} \leq NGW_j$. In GPM, the water availability constraint equation is defined as $\sum_{i=1}^{n} A_i * \mathrm{GIR}_{ij} - \mathrm{S}_{W\,j} + \mathrm{G}_{W\,j} + d_4^- - d_4^+ = 0$ Similarly, the constraints for SW and GW availability are defined as $S_{wj} + d_5^- - d_5^+ =$ Min [C_{cj} or W_{Rj}] and $G_{wj} + d_6^- - d_6^+ = NGW_j$ respectively.

2.2.2.2. *Land availability constraint*

Area under different crops during any month cannot exceed the cultivable command area (CCA) of the study area. Hence, total area under Kharif crops cannot exceed the CCA. Similarly, total area under Rabi crops also cannot exceed the CCA. During the overlapping period of Kharif and Rabi crops, the total area in that month should be less than CCA. So, the land availability constraint is defined as $\sum_{i=1}^{n} A_{ij} \leq T_A$. For GPM, the land availability constraint is expressed as $\sum_{i=1}^{n} A_{ij} + d_7^- - d_7^+ = T_A$.

2.2.2.3. *Minimum area constraint*

In order to avoid excessive transportation expenditure on food items required for the existing population for the area under study, by considering their food habits, their minimum nutritional requirement and to make study area self sufficient in food production, a minimum area was fixed for different crops. The minimum area constraint is expressed as $A_i \geq T_{(\min)i}$. Similarly, in GPM, minimum area is fixed for various crops and the constraints for the same is defined as $A_i + d_8^- - d_8^+ = T_{(\min)i}$.

3. Application

3.1. *Study Area*

Barna project is the first river valley and also major irrigation project of Madhya Pradesh, which envisages

TABLE 2

Objective function of different objectives for Barna irrigation project

Approach	Objective	Objective function
LP	MNR	$(17{,}600*A_1 + 29{,}605*A_2 + 26{,}995*A_3 + 10{,}100*A_4 + 8{,}185*A_5 + 6{,}845*A_6 + 23{,}800*A_7 + 9{,}500*A_8 + 5{,}900*A_9 + 17{,}510*A_{10} + 11{,}620*A_{11} + 19{,}750*A_{12} + 29{,}600*A_{13}) - 1{,}152(S_{wi}) - 15{,}921(G_{wi}) = 50*10^8$ (where, i = 1,2,3,6,7,9,10,11,12)
	MPV	$148.50*A_1 + 444*A_2 + 260*A_3 + 691.20*A_4 + 156.10*A_5 + 192*A_6 + 400*A_7 + 363*A_8 + 205.20*A_9 + 304.50*A_{10} + 295.50*A_{11} + 441*A_{12} + 480*A_{13} + d_2^- = 80*10^6$
	MCV	$6{,}850.80*A_1 + 13{,}680*A_2 + 8{,}725*A_3 + 6{,}912*A_4 + 2{,}345*A_5 + 2{,}776*A_6 + 8{,}000*A_7 + 10{,}230*A_8 + 4{,}320*A_9 + 7{,}950*A_{10} + 4{,}725*A_{11} + 7{,}854*A_{12} + 9{,}600*A_{13} + d_3^- = 30*10^8$
GP	MNR	Maximize $Z = (17{,}600*A_1 + 29{,}605*A_2 + 26{,}995*A_3 + 10{,}100*A_4 + 8{,}185*A_5 + 6{,}845*A_6 + 23{,}800*A_7 + 9{,}500*A_8 + 5{,}900*A_9 + 17{,}510*A_{10} + 11{,}620*A_{11} + 19{,}750*A_{12} + 29{,}600*A_{13}) - 1{,}152(S_{wi}) - 15{,}921(G_{wi})$ (where, i = 1,2,3,6,7,9,10,11,12)
	MPV	Maximize $Z = 148.50*A_1 + 444.00*A_2 + 260.00*A_3 + 691.20*A_4 + 156.10*A_5 + 192.00*A_6 + 400.00*A_7 + 363.00*A_8 + 205.20*A_9 + 304.50*A_{10} + 295.50*A_{11} + 441.00*A_{12} + 480.00*A_{13}$
	MCV	Maximize $Z = 6{,}850.80*A_1 + 13{,}680*A_2 + 8{,}725.00*A_3 + 6{,}912.00*A_4 + 2{,}345.00*A_5 + 2{,}776.00*A_6 + 8{,}000.00*A_7 + 10{,}230.00*A_8 + 4{,}320.00*A_9 + 7{,}950.00*A_{10} + 4{,}725.00*A_{11} + 7{,}854.00*A_{12} + 9{,}600.00*A_{13}$

[where, A_1, A_2, A_3........, A_{13} are assigned to areas (in ha) for different crops respectively. The crops like Paddy (A_1), Maize (A_2), Jowar (A_3), Soyabean (A_4), Red Gram (A_5), Black Gram (A_6) and Kharif seasonal Vegetables (A_7) are called Kharif crops. Likewise, the crops like Wheat (A_8), Gram (A_9), Linseed (A_{10}), Peas (A_{11}), Groundnut (A_{12}) and Rabi seasonal Vegetables (A_{13}) are called Rabi crops]

TABLE 3

SW and GW availability constraints for different months for LPM and GPM

S. No.	Month	Water availability constraints for different months for LPM		GPM	
		SW	GW	SW	GW
1	January	$S_{w1} \le 9{,}776.16$	$G_{w1} \le 2{,}131$	$S_{w1} + d_{5a}^- = 9{,}776.16$	$G_{w1} + d_{6a}^- = 2{,}131$
2	February	$S_{w2} \le 6{,}514.40$	$G_{w2} \le 2{,}131$	$S_{w2} + d_{5b}^- = 6{,}514.40$	$G_{w2} + d_{6b}^- = 2{,}131$
3	March	$S_{w3} \le 5{,}841.80$	$G_{w3} \le 2{,}131$	$S_{w3} + d_{5c}^- = 5{,}841.80$	$G_{w3} + d_{6c}^- = 2{,}131$
4	June	$S_{w6} \le 3{,}634.80$	$G_{w6} \le 2{,}131$	$S_{w6} + d_{5d}^- = 3{,}634.80$	$G_{w6} + d_{6d}^- = 2{,}131$
5	July	$S_{w7} \le 7{,}564.10$	$G_{w7} \le 2{,}131$	$S_{w7} + d_{5e}^- = 7{,}564.10$	$G_{w7} + d_{6e}^- = 2{,}131$
6	September	$S_{w9} \le 9{,}460.80$	$G_{w9} \le 2{,}131$	$S_{w9} + d_{5f}^- = 9{,}460.80$	$G_{w9} + d_{6f}^- = 2{,}131$
7	October	$S_{w10} \le 9{,}776.16$	$G_{w10} \le 2{,}131$	$S_{w10} + d_{5g}^- = 9{,}776.16$	$G_{w10} + d_{6g}^- = 2{,}131$
8	November	$S_{w11} \le 9{,}460.80$	$G_{w11} \le 2{,}131$	$S_{w11} + d_{5h}^- = 9{,}460.80$	$G_{w11} + d_{6h}^- = 2{,}131$
9	December	$S_{w12} \le 9{,}776.16$	$G_{w12} \le 2{,}131$	$S_{w12} + d_{5i}^- = 9{,}776.16$	$G_{w12} + d_{6i}^- = 2{,}131$

(where $d_{5a}^-, d_{5b}^-, d_{5c}^-, d_{5d}^-, d_{5e}^-, d_{5f}^-, d_{6g}^-, d_{5h}^-, d_{5i}^-, d_{6a}^-, d_{6b}^-, d_{6c}^-, d_{6d}^-, d_{6e}^-, d_{6f}^-, d_{6g}^-$, d_{6h}^- and d_{6i}^- are negative deviational variables)

TABLE 4

Land availability constraints for Kharif and Rabi crops for different seasons for LPM and GPM

S. No.	Type of crops	Cultivation period	Land availability constraints for Kharif and Rabi crops for different seasons for LPM	GPM
1	Kharif	Jun - Oct	$A_1+A_2+A_3+A_4+A_5+A_6+A_7 \le 45{,}000$	$A_1+A_2+A_3+A_4+A_5+A_6+A_7+d_{7a}^- = 45{,}000$
2	Kharif and Rabi	Oct	$A_1+A_2+A_3+A_4+A_5+A_6+A_7+A_{12}+A_{13} \le 45{,}000$	$A_1+A_2+A_3+A_4+A_5+A_6+A_7+A_{12}+A_{13}+d_{7b}^- \le 45{,}000$
3	Rabi	Mar	$A_5+A_8+A_{11} \le 45{,}000$	$A_5+A_8+A_{11}+d_{7c}^- \le 45{,}000$
4	Rabi	Jan and Feb	$A_5+A_8+A_9+A_{10}+A_{11}+A_{12} \le 45{,}000$	$A_5+A_8+A_9+A_{10}+A_{11}+A_{12}+d_{7d}^- \le 45{,}000$
5	Rabi	Nov and Dec	$A_5+A_8+A_9+A_{10}+A_{11}+A_{12}+A_{13} \le 45{,}000$	$A_5+A_8+A_9+A_{10}+A_{11}+A_{12}+A_{13}+d_{7e}^- \le 45{,}000$
6	Rabi	Nov - Mar	$A_8+A_9+A_{10}+A_{11}+A_{12}+A_{13} \le 45{,}000$	$A_8+A_9+A_{10}+A_{11}+A_{12}+A_{13}+d_{7f}^- \le 45{,}000$

(where d_{6a}^-, d_{6b}^-, d_{6c}^-, d_{6d}^-, d_{6e}^- and d_{6f}^- are negative deviational variables)

construction of dam across river Barna, a major tributary of river Narmada. The project is designed to provide annual flow irrigation to 75,000 ha. area comprising of 30,000 ha. for Kharif crops and 45,000 ha. for Rabi crops. The total command area of the project is 75,000 lakh ha, out of which 58,000 ha. is CCA. The project provides water to Bareli-Tehsil of Raisen district and Budhani-Tehsil of Sehore district of Madhya Pradesh through canal system. The right bank main canal is 9.36 km long having head discharge of 22 cumecs providing irrigation to 18,158 ha. (31.31% of CCA) land in Kharif season and 27,237 ha. (46.96% of CCA) land in Rabi season. The left bank main canal with a head discharge of 14.50 cumecs runs for a distance of 28 km provides water to 11,842 ha. (20.42% of CCA) land during Kharif season and to 17,763 ha (30.63% of CCA) land during Rabi season. Therefore, command area of 30,000 ha. (51.72% of CCA) is brought under irrigation during Kharif season and command area of 45,000 ha. (77.58% of CCA) is considered for irrigation during Rabi season. Thus, the total cropping intensity considered in the present study is 129.30%. Fig. 1 gives the location map of the study area.

3.2. *Data availability*

The primary data of rainfall, evaporation and monthly water available in Barna reservoir, cost of input and price of output, and yield data in respect of different crops as per existing and proposed cropping pattern were collected from the report of Barna irrigation project. The

TABLE 5

Minimum area constraints for Kharif and Rabi crops for LPM and GPM

S. No.	Crop	Minimum area constraints for Kharif and Rabi crops for LPM	GPM
1	Paddy	$A_1 \ge 6{,}080$	$A_1 - d_{8a}^+ = 6{,}080$
2	Maize	$A_2 \ge 760$	$A_2 - d_{8b}^+ = 760$
3	Jowar	$A_3 \ge 608$	$A_3 - d_{8c}^+ = 608$
4	Soyabean	$A_4 \ge 1{,}520$	$A_4 - d_{8d}^+ = 1{,}520$
5	Red Gram	$A_5 \ge 1{,}738$	$A_5 - d_{8e}^+ = 1{,}738$
6	Black Gram	$A_6 \ge 1{,}520$	$A_6 - d_{8f}^+ = 1{,}520$
7	Vegetables (K)	$A_7 \ge 1{,}520$	$A_7 - d_{8g}^+ = 1{,}520$
8	Wheat (T&H)	$A_8 \ge 8{,}107$	$A_8 - d_{8h}^+ = 8{,}107$
9	Gram	$A_9 \ge 1{,}014$	$A_9 - d_{8i}^+ = 1{,}014$
10	Linseed	$A_{10} \ge 2{,}606$	$A_{10} - d_{8j}^+ = 2{,}606$
11	Peas	$A_{11} \ge 608$	$A_{11} - d_{8k}^+ = 608$
12	Groundnut	$A_{12} \ge 912$	$A_{12} - d_{8l}^+ = 912$
13	Vegetables (R)	$A_{13} \ge 1{,}267$	$A_{13} - d_{8m}^+ = 1{,}267$

(where, d_{8a}^+, d_{8b}^+, d_{8c}^+, d_{8d}^+, d_{8e}^+, d_{8f}^+, d_{8g}^+, d_{8h}^+, d_{8i}^+, d_{8j}^+, d_{8k}^+, d_{8l}^+ and d_{8m}^+ are positive deviational variables)

TABLE 6

Total area allocated, available water for utilization, net return, total protein and calorie from existing, LP and GP cropping pattern

S. No.	Cropping pattern	Total area allocated (ha)	Available water for utilization (ha m.)		Net return (10^8 Rs)	Total protein (10^6 kg)	Total calorie (10^8 cal.)
			SW	GW			
1	Existing	75,000	34,055.00	0.00	5.47	30.40	4.43
2	LP	75,000	32,194.63	1,257.93	17.15	30.45	8.40
3	GP	75,000	31,294.63	1,157.93	17.34	30.78	8.53

secondary data on available quantities of SW for the project was also retrieved from the irrigation project report (1984). The available quantity of GW for the project was calculated by adopting the norms of GW Estimation Committee. Crop wise monthly water requirement was estimated on the basis of consumptive use of individual crop using modified Penman method (Doorcnbos and Pruitt, 1977). The protein and calorie requirements were computed on the basis of per capita average daily requirement (Ghei and Ghei, 1973).

3.3. *Optimization of cropping pattern using LP and GP*

3.3.1. *Objective function*

Using the methodology of LP and GP, as given in Section 2, an attempt has been made to optimize the cropping pattern with the available resources for the Barna irrigation project. The objective function of different objectives used for optimization of cropping pattern for the project are given in Table 2.

3.3.2. *System constraints*

3.3.2.1. *Water availability constraints*

The month wise gross irrigation requirement (GIR) for each crop was used for computation by considering the assumption that the value of GIR should not be more than the SW and GW available for utilization in that month. Likewise, net month wise net SW available in reservoir for irrigation releases, after deducting all the losses, were calculated. Further, month wise canal's conveyance capacity to carry the water for irrigation was worked out and minimum of the two were considered as the monthly net SW available for irrigation use. Since there was no crop activity in the month April, May and August, the values for the respective months were not considered in the computation.

By using the water data in respect of Barna reservoir for the period from 1960-61 to 1991-92, the quantum of 75 % of dependable monthly water available in the reservoir was computed and used to formulate the SW constraints for different months for LPM and GPM, and are given in Table 3. Likewise, the GW availability constraints of LPM were formulated by satisfying the conditions that the total annual GW utilization for irrigation should not more than the 20% of total utilizable balance GW recharge per year. The GW availability constraint for annual period may be expressed as $G_{w1}+G_{w2}+G_{w3}+G_{w6}+G_{w7}+G_{w9}+G_{w10}+G_{w11}+G_{w12} \leq 10{,}653$ with each value of $G_{wi} \leq 2{,}131$. The GW constraints for different months for LPM and GPM are also determined and are given in Table 3.

3.3.2.2. *Land availability constraints*

For the present study, the cropping intensity was considered and fixed to a limit of 200% (100% for Kharif and 100% for Rabi) so that area under Kharif or Rabi crops may not increase the minimum CCA and designed area of Kharif or Rabi crops. Therefore, designed area for Kharif and Rabi crops are 30,000 ha and 45,000 ha. respectively. So, designed area of 45,000 ha of Rabi crops is considered as CCA and accordingly constraints were formulated in such a way that the area under Kharif or Rabi or overlapping crops should not exceed the total of 45,000 ha. Table 4 gives the land availability constraints for Kharif and Rabi crops for different seasons for LPM and GPM.

3.3.2.3. *Minimum area constraints*

Minimum area for each of thirteen crops considered in proposed cropping pattern was fixed as per food habits, and protein and calorie requirements for the existing population of the study area. By considering the minimum area assigned to different crops, the minimum area

TABLE 7

Available water for utilization for different months for cropping pattern of LP and GP

S. No.	Month	Available water (ha m.) for utilization for different months for cropping pattern of			
		LP		GP	
		SW	GW	SW	GW
1	January	7,776.16	5.44	7,476.16	5.44
2	February	5,514.40	1,252.49	5,414.40	1,152.49
3	March	1,064.79	0.00	1,064.79	0
4	June	636.50	0.00	636.50	0
5	July	1,909.12	0.00	1,809.12	0
6	September	2,558.82	0.00	2,358.82	0
7	October	3,075.34	0.00	3,075.34	0
8	November	3,154.30	0.00	3,054.30	0
9	December	6,505.20	0.00	6,405.20	0
	Total	32,194.63	1,257.93	31,294.63	1,157.93

TABLE 8

Optimal allocation of land (ha) and water (ha m.) for different crops under cropping pattern of LP and GP

S. No.	Crop	Minimum required area (ha)	Existing cropping pattern		Proposed cropping pattern of			
					LP		GP	
			Area	SW	Area	SW	Area	SW
1	Paddy	6,080			6,180	4,061.44	6,180	4,261.25
2	Maize	760			16,235	2,533.14	16,429	2,337.64
3	Jowar	608			608	156.86	608	156.86
4	Soyabean	1,900	30,000	6,600	1,900	418.00	1,900	618.00
5	Red Gram	1,738			1,832	2,497.51	1,738	2,493.81
6	Black Gram	1,520			1,725	103.36	1,520	103.36
7	Vegetables (K)	1,520			1,520	253.84	1,625	233.64
8	Wheat (T)	1,013	15,000	11,760	1,675	2,379.51	1,738	2,928.46
	Wheat (H)	7,094	5,000	3,920	7,094	924.26	7,094	875.31
9	Gram	1,014	25,000	11,775	1,014	477.59	1,014	497.59
10	Linseed	2,606			32,408	16,488.31	27,212	14,937.31
11	Peas	608			608	514.37	632	514.37
12	Groundnut	912			934	633.84	943	633.84
13	Vegetables(R)	1,267			1,267	752.60	1,367	703.19
Total		28,640	75,000	34,055	75,000	32,194.63	75,000	31,294.63
Area (ha) under Kharif crops			30,000		30,000		30,000	
Area (ha) under Rabi crops			45,000		45,000		45,000	
Total cropping intensity (%)			129.30		129.30		129.30	
Average water utilized per ha (m)			0.454		0.429		0.417	

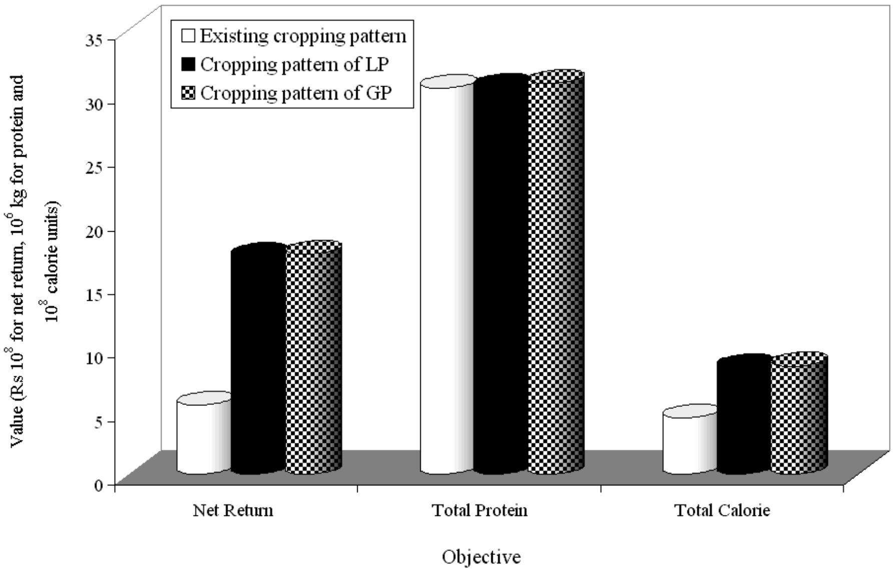

Fig. 2. Net return, total protein and calorie from existing, LP and GP cropping pattern

constraints for Kharif and Rabi crops for LPM and GPM were formulated and are given in Table 5.

A computer programme was developed and used to obtain a solution for the formulated LPM and GPM. Existing cropping pattern was considered for comparison with the cropping pattern of LP and GP to select the best approach for optimization of cropping pattern for the project under study.

4. Results and discussions

In this paper, three specific objectives, namely, maximization of net return, maximization of protein and calorie values was considered under various resource constraints. Accordingly, LPM and GPM were formulated and run to achieve the maximum value of net return, high values of proteins and calories for the existing population of the project area. Table 6 gives the values for the defined objectives like available net return, total protein and calorie, SW and GW utilized by different cropping patterns of LP and GP. The available water for utilization for different months using LP and GP approaches were also computed and is given in Table 7.

From Table 6, it may be noted that net return obtained from LP and GP are Rs $17.15*10^8$ and Rs $17.34*10^8$ respectively. From Table 6, it may also be noted that the cropping pattern of GP gives the values for protein and calorie as $30.78*10^6$ kg and $8.53*10^8$ calorie units respectively. On the other hand, the cropping pattern of LP gives the values for protein and calorie as $30.45*10^6$ kg and $8.40*10^8$ calorie units respectively against the minimum requirement of protein of $7.42*10^6$ kg and calorie of $2.78*10^8$ calorie units. Fig. 2 gives the values of net return, total protein and calorie from existing, LP and GP cropping pattern.

From Table 7, it may be noted that the cropping pattern of LP utilized 32,194.63 ha m. of SW and 1,257.93 ha m. of GW. Likewise, the cropping pattern of GP utilized 31,294.63 ha m. of SW and 1,157.93 ha m. of GW. Again from Table 7, it may also be noted that the SW and GW utilized for irrigation by GP is less by 900 ha m. and 100 ha m. respectively when compared to the quantum of SW and GW utilized by LP. Table 8 gives the details on land and water allocated to different crops, total area under Kharif and Rabi crops, total cropping intensity and average water of utilization per ha m. of land for cropping pattern of LP and GP.

From Table 8, it may be noticed that the cropping pattern of LP and GP gave total cropping intensity of 129.30% with allocation of similar area of 30,000 ha for Kharif and 45,000 ha for Rabi. So, best approach for cropping pattern was selected on the basis of average water of utilization per ha of land in addition to the values of net return, total calorie and protein obtained from both LP and GP approaches. Also from Table 8, it may be observed that the cropping pattern of LP and GP allocated different areas for different crops.

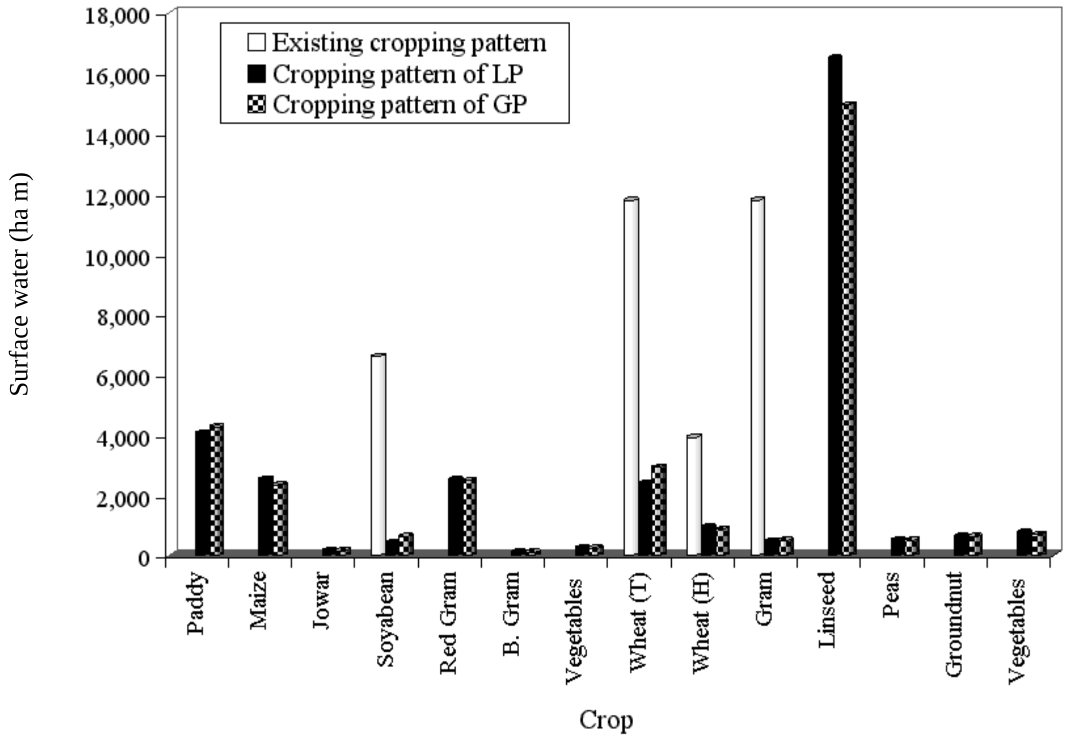

Fig. 3. Surface water available for utilization for different crops under existing, LP and GP cropping pattern

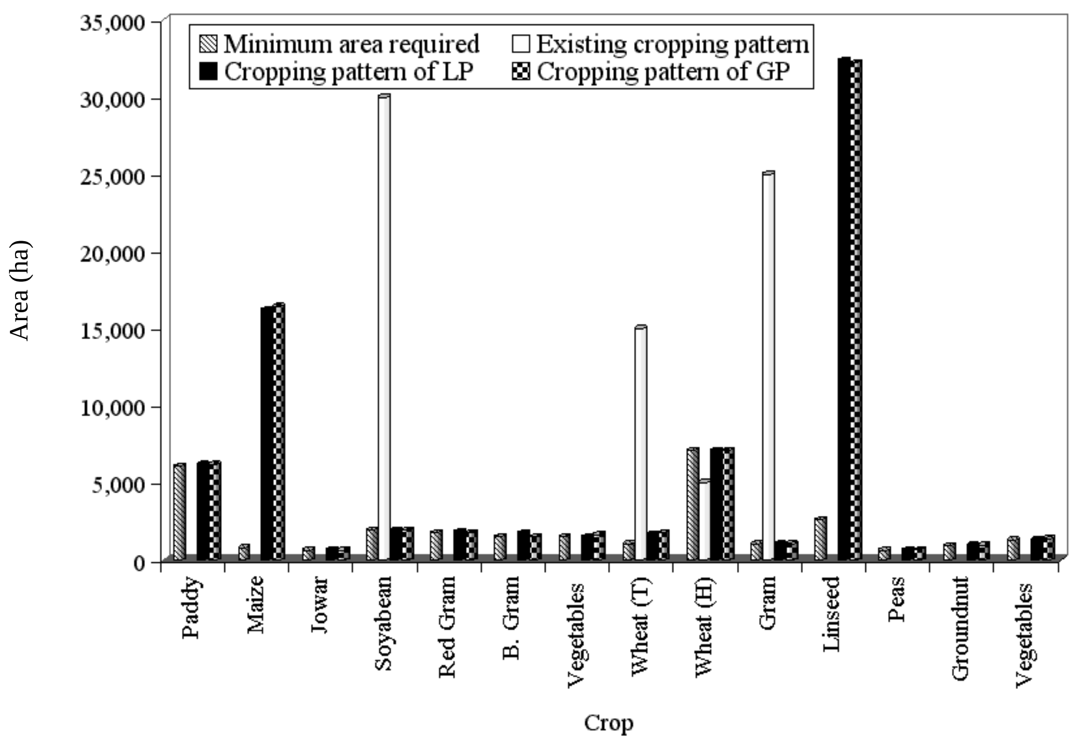

Fig. 4. Area allocated for different crops under existing, LP and GP cropping pattern

Again, from Table 8, it may be noticed that the cropping pattern of LP allocated more area for Paddy, Maize, Red Gram, Black Gram, Wheat (Tall), Linseed and Groundnut as 6,180 ha, 16,235 ha, 1,832 ha, 1,725 ha, 1,675 ha, 32,408 ha and 934 ha against the minimum required area of 6,080 ha, 760 ha, 1,738 ha, 1,520 ha, 1,013 ha, 2,606 ha, and 912 respectively. Similarly, the cropping pattern of GP allocated more area for Paddy, Maize, Vegetables (K), Wheat (Tall), Linseed, Peas, Groundnut and Vegetables (R) as 6,180 ha, 16,429 ha, 1,625 ha, 1,738 ha, 27,212 ha, 632 ha, 943 ha and 1,367 ha against the minimum required area of 6,080 ha, 760 ha, 1,520 ha, 1,013 ha, 2,606 ha, 608 ha, 912 ha and 1,267 ha respectively.

From Table 8, it may be noticed that the average water utilized per ha by GP and LP are 0.417 m and 0.429 m respectively. From these results, it may also be noticed that the cropping pattern of GP requires less quantum of water as when compared to LP. Figs. 3 and 4 give the available SW for utilization and area allocated for different crops under existing, LP and GP cropping pattern respectively.

From Tables 7&8 and also from Figs. 3&4, it may be noticed that the cropping pattern of GP approach gave maximum net return and fulfilled the requirement of protein and calorie values for the existing population of the project area with minimum utilization of land, SW and GW. By considering the specific objectives, as mentioned above, GP approach was found to be best for optimization of cropping pattern for the project under study.

5. Conclusions

The paper presents the results of cropping patterns of LP and GP that are considered for selection of best one for optimization of cropping pattern of the Barna irrigation project. The paper gives the amount of net return, total protein and calorie values from cropping pattern of LP are Rs $17.15*10^8$, $30.45*10^6$ kg and $8.40*10^8$ calorie units respectively. The paper also gives the corresponding values from cropping pattern of GP are Rs $17.34*10^8$, $30.78*10^6$ kg and $8.53*10^8$ calorie units. The paper shows the total cropping intensity obtained from cropping pattern of LP and GP is 129.30%. The paper also shows the average water utilized per ha by GP and LP are 0.417 m and 0.429 m. By considering high values of net return, protein and calorie, and food requirements for the existing population of the study area, the cropping pattern of GP is found to be best and GP approach is recommended for optimization of multi-objective cropping pattern for Barna irrigation project.

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Notations/Symbols used

A_i = Area (ha) allocated to i^{th} crop
A_K = Area (ha) under Kharif crops
A_R = Area (ha) under Rabi crops
A_{ij} = Area (ha) allocated to the i^{th} crop in j^{th} month
a_{ij} = Technological or structural coefficient
B = (m*1) Column vector of right hand side constant
b_i = Available resources or linear vector stipulation
C = (1*n) Row vector of objective function coefficient
C_i = Calorie value (calorie/kg) of i^{th} crop
C_j = Unit contribution rate or cost coefficient
C_s = Cost of unit volume (ha m) of surface water
C_G = Cost of unit volume (ha m) of ground water
C_{cj} = Conveyance capacity (ha m) of canal in j^{th} month
CR = Total calorie requirement (calorie units)
d^-, d^+ = Deviational variable in negative and positive directions
d_1^-, d_1^+ = Under and over achievement of NR
d_2^- d_2^+ = Under and over achievement of PR
d_3^-, d_3^+ = Under and over achievement of CR
d_4^-, d_4^+ = Under and over achievement of water releases
d_5^-, d_5^+ = Under and over achievement of surface water utilization
d_6^-, d_6^+ = Under and over achievement of ground water utilization
d_7^-, d_7^+ = Under and over achievement of total land
d_8^-, d_8^+ = Under and over achievement of minimum area for i^{th} crop
G_{wj} = Gross ground water (ha m) released through canal head in j^{th} month
G_{w1}, G_{w2},.....G_{w12} = Utilizable ground water recharge (ha m) from January to December
GIR_{ij} = Gross irrigation requirement in excess of effective rainfall for the i^{th} crop in j^{th} month
g_l = Goal level set by the decision maker
m = Number of system constraints
N_i = Net return (Rs) per ha (Excluding water charges) from i^{th} crop
NGW_j = Utilizable balance ground water recharge (ha m) in j^{th} month
n = Number of decision variables or crops (1, 2,………..13)
NR = Total net return (Rs) expected from the area (ha)
P_i = Protein value (gm/kg) of i^{th} crop
PR = Total protein requirement (gm/kg)
S_{wj} = Gross surface water (ha m) released through canal head in j^{th} month
S_{w1}, S_{w2},......S_{w12} = Surface water (ha m) released from January to December
$T_{(min)i}$ = Minimum area (ha) allocated to i^{th} crop
T_A = Total available cultivable command area (ha)
X = (n*l) Column vector of real variables
X_j = Decision (or activity) variable
Y_i = Yield (kg/ha) of i^{th} crop
W_{Rj} = Water available in reservoir (ha m) in j^{th} month