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

N. VIVEKANANDAN and K. VISWANATHAN*
Central Water and Power Research Station, Pune – 411 024, India
*NGM College, Pollachi – 642 001, India
(Received 28 July 2006, Modified on 15 November 2006)
e mails : anandan@rediffmail.com and visu_ngm@yahoo.com

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, protein and calorie values, 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 scarce 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

\[ Z = C_1 X_1 + C_2 X_2 + \ldots \ldots \ldots + C_n X_n \]

Subject to,

\[ a_{11} X_1 + a_{12} X_2 + \ldots + a_{1n} X_n \leq \text{or } = \text{or } \geq b_1 \]

\[ a_{21} X_1 + a_{22} X_2 + \ldots + a_{2n} X_n \leq \text{or } = \text{or } \geq b_2 \]

\[ \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \]

\[ a_{m1} X_1 + a_{m2} X_2 + \ldots + a_{mn} X_n \leq \text{or } = \text{or } \geq b_m \]

\[ X_1, X_2, \ldots, X_n \geq 0 \]

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

| S. No. | Objective (s) | Objective function |
|--------|---------------|--------------------|
| 1      | Maximization of net return (MNR) | \[
\begin{align*}
Z = \max & \sum_{i=1}^{n} A_i * N_i - \left[ \sum_{j=1}^{NOM} C_j * S_{kj} + \sum_{j=1}^{NOM} C_j * G_{kj} \right] \\
& \text{subject to } f(x) + d^+ + d^- = g_1 \text{ and } \\
& \sum_{j=1}^{NOM} a_{ij} * X_j \leq b_i ; \quad i = 1,2, \ldots, m; X_j \geq 0, d^+ \geq 0, d^- \geq 0 \\
& \text{Here, } g_1 \text{ is the goal desired which is expected from the objective function } f(x) = \sum_{j=1}^{n} C_j X_j = CX \text{ to achieve as closely as possible subject to the given constraints.}
\end{align*}
\]
| 2      | Maximization of protein value (MPV) | \[ Z = \max \sum_{i=1}^{n} A_i * Y_i * P_i \] |
| 3      | Maximization of calorie value (MCV) | \[ Z = \max \sum_{i=1}^{n} A_i * Y_i * C_i \] |

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

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

\[
\text{Minimize } Z = d^- + d^+
\]

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

\[
\sum_{j=1}^{NOM} a_{ij} * X_j \leq b_i ; \quad i = 1,2, \ldots, m; X_j \geq 0, d^- \geq 0, d^+ \geq 0
\]

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
ground water (GW) available in the particular month. The general form of constraint equation is defined by:

\[ \sum_{i=1}^{n} A_i * \text{GIR}_{ij} \leq S_{wj} + G_{wj}. \]

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 \( S_{wj} \leq \text{Min} \left[ C_{cj} \text{ or } W_{j} \right] \). 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

\[ \sum_{i=1}^{n} A_i * \text{GIR}_{ij} - S_{wj} + G_{wj} + d_5^- - d_5^+ = 0 \]

Similarly, the constraints for SW and GW availability are defined as \( S_{wj} + d_5^- - d_5^+ = \text{Min} \left[ C_{cj} \text{ or } W_{j} \right] \) 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 \( A_i \geq T_{(\text{min})} \). Similarly, in GPM, minimum area is fixed for various crops and the constraints for the same is defined as \( A_i + d_8^- - d_8^+ = T_{(\text{min})} \).

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 |
|----------|-----------|--------------------|
| MNR      | \(17,600* A_1 + 29,605* A_2 + 26,995* A_3 + 10,100* A_4 + 8,185* A_5 + 6,845* A_6 + 23,800* A_7 + 9,500* A_8 + 5,900* A_9 + 17,510* A_{10} + 11,620* A_{11} + 19,750* A_{12} + 29,600* A_{13} - 11,152(S_w) - 15,921(G_w) = 50*10^6\) (where, \(i = 1,2,3,6,7,9,10,11,12\)) |
| LP       | \(148.50* A_1 + 444* A_2 + 260* A_3 + 691.20* A_4 + 156.10* A_5 + 192* A_6 + 400* A_7 + 363* A_8 + 205.20* A_9 + 304.50* A_{10} + 295.50* A_{11} + 441* A_{12} + 480* A_{13} + d_2^2 = 80*10^6\) |
| MCV      | \(6,850.80* A_1 + 13,680* A_2 + 8,725* A_3 + 6,912* A_4 + 2,345* A_5 + 2,776* A_6 + 8,000* A_7 + 10,230* A_8 + 4,320* A_9 + 7,950* A_{10} + 4,725* A_{11} + 7,854* A_{12} + 9,600* A_{13} + d_3^3 = 30*10^8\) |
| MNR      | Maximize \(Z = (17,600* A_1 + 29,605* A_2 + 26,995* A_3 + 10,100* A_4 + 8,185* A_5 + 6,845* A_6 + 23,800* A_7 + 9,500* A_8 + 5,900* A_9 + 17,510* A_{10} + 11,620* A_{11} + 19,750* A_{12} + 29,600* A_{13}) - 11,152(S_w) - 15,921(G_w)\) (where, \(i = 1,2,3,6,7,9,10,11,12\)) |
| GP       | \(148.50* A_1 + 444.00* A_2 + 260.00* A_3 + 691.20* A_4 + 156.10* A_5 + 192.00* A_6 + 400.00* A_7 + 363.00* A_8 + 205.20* A_9 + 304.50* A_{10} + 295.50* A_{11} + 441.00* A_{12} + 480.00* A_{13}\) |
| 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, \(A_1, A_2, A_3, \ldots, A_3\) are assigned to areas (in ha) for different crops respectively. The crops like Paddy (\(A_1\)), Maize (\(A_2\)), Soyabeans (\(A_4\)), Red Gram (\(A_5\)), Black Gram (\(A_7\)), and Kharif seasonal Vegetables (\(A_8\)) are called Kharif crops. Likewise, the crops like Wheat (\(A_3\)), Gram (\(A_6\)), 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 |  | Water availability constraints for different months for GPM |  |
|-------|-------|----------------------------------------------------------|---|----------------------------------------------------------|---|
|       |       | SW            | GW            | SW            | GW            |
| 1     | January | \(S_w \leq 9,776.16\) | \(G_w \leq 2,131\) | \(S_w + d_{3a}^2 = 9,776.16\) | \(G_w + d_{6a}^2 = 2,131\) |
| 2     | February | \(S_{w2} \leq 6,514.40\) | \(G_{w2} \leq 2,131\) | \(S_{w2} + d_{3b}^2 = 6,514.40\) | \(G_{w2} + d_{6b}^2 = 2,131\) |
| 3     | March   | \(S_{w3} \leq 5,841.80\) | \(G_{w3} \leq 2,131\) | \(S_{w3} + d_{3c}^2 = 5,841.80\) | \(G_{w3} + d_{6c}^2 = 2,131\) |
| 4     | June    | \(S_{w4} \leq 3,634.80\) | \(G_{w4} \leq 2,131\) | \(S_{w4} + d_{3d}^2 = 3,634.80\) | \(G_{w4} + d_{6d}^2 = 2,131\) |
| 5     | July    | \(S_{w5} \leq 7,564.10\) | \(G_{w5} \leq 2,131\) | \(S_{w5} + d_{3e}^2 = 7,564.10\) | \(G_{w5} + d_{6e}^2 = 2,131\) |
| 6     | September | \(S_{w6} \leq 9,460.80\) | \(G_{w6} \leq 2,131\) | \(S_{w6} + d_{3f}^2 = 9,460.80\) | \(G_{w6} + d_{6f}^2 = 2,131\) |
| 7     | October | \(S_{w7} \leq 9,776.16\) | \(G_{w7} \leq 2,131\) | \(S_{w7} + d_{3g}^2 = 9,776.16\) | \(G_{w7} + d_{6g}^2 = 2,131\) |
| 8     | November | \(S_{w8} \leq 9,460.80\) | \(G_{w8} \leq 2,131\) | \(S_{w8} + d_{3h}^2 = 9,460.80\) | \(G_{w8} + d_{6h}^2 = 2,131\) |
| 9     | December | \(S_{w9} \leq 9,776.16\) | \(G_{w9} \leq 2,131\) | \(S_{w9} + d_{3i}^2 = 9,776.16\) | \(G_{w9} + d_{6i}^2 = 2,131\) |

(where \(d_{3a}, d_{3b}, d_{3c}, d_{3d}, d_{3e}, d_{3f}, d_{3g}, d_{3h}, d_{3i}, d_{6a}, d_{6b}, d_{6c}, d_{6d}, d_{6e}, d_{6f}, d_{6g}, d_{6h}, d_{6i}\) 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 channel 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 channel 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 4**

| S. No. | Type of crops | Cultivation period | Land availability constraints for Kharif and Rabi crops for different seasons for LPM and GPM |
|--------|---------------|--------------------|------------------------------------------------------------------------------------------|
| 1      | Kharif        | Jun - Oct          | \(A_1 + A_2 + A_3 + A_6 \leq 45,000\) \(+ A_8 - d_{7a} = 45,000\) \(A_1 + A_2 + A_3 + A_6 \leq 45,000\) |
| 2      | Kharif and Rabi| Oct                | \(A_1 + A_2 + A_3 + A_6 \leq 45,000\) \(+ A_7 + A_8 + d_{7b} = 45,000\)               |
| 3      | Rabi          | Mar                | \(A_1 + A_2 + A_3 \leq 45,000\) \(+ A_7 + A_8 + d_{7c} \leq 45,000\)                 |
| 4      | Rabi          | Jan and Feb        | \(A_1 + A_2 + A_3 + A_6 \leq 45,000\) \(+ A_7 + A_8 + d_{7d} \leq 45,000\)          |
| 5      | Rabi          | Nov and Dec        | \(A_1 + A_2 + A_3 + A_6 \leq 45,000\) \(+ A_7 + A_8 + d_{7e} \leq 45,000\)          |
| 6      | Rabi          | Nov - Mar          | \(A_1 + A_2 + A_3 + A_6 \leq 45,000\) \(+ A_7 + A_8 + d_{7f} \leq 45,000\)          |

(\(d_{7a}, d_{7b}, d_{7c}, d_{7d}, d_{7e}, d_{7f}\) are negative deviational variables)

---

**TABLE 5**

| S. No. | Crop               | Minimum area constraints for Kharif and Rabi crops for LPM and GPM |
|--------|--------------------|--------------------------------------------------------------------|
| 1      | Paddy              | \(A_1 \geq 6,080\) \(A_1 - d_{50} = 6,080\)                      |
| 2      | Maize              | \(A_2 \geq 760\) \(A_2 - d_{50} = 760\)                          |
| 3      | Jowar              | \(A_3 \geq 608\) \(A_3 - d_{50} = 608\)                          |
| 4      | Soyabean           | \(A_4 \geq 1,520\) \(A_4 - d_{50} = 1,520\)                     |
| 5      | Red Gram           | \(A_5 \geq 1,738\) \(A_5 - d_{50} = 1,738\)                     |
| 6      | Black Gram         | \(A_6 \geq 1,520\) \(A_6 - d_{50} = 1,520\)                     |
| 7      | Vegetables (K)     | \(A_7 \geq 1,520\) \(A_7 - d_{50} = 1,520\)                     |
| 8      | Wheat (T&H)        | \(A_8 \geq 8,107\) \(A_8 - d_{50} = 8,107\)                     |
| 9      | Gram               | \(A_9 \geq 1,014\) \(A_9 - d_{50} = 1,014\)                     |
| 10     | Linseed            | \(A_{10} \geq 2,606\) \(A_{10} - d_{50} = 2,606\)               |
| 11     | Peas               | \(A_{11} \geq 608\) \(A_{11} - d_{50} = 608\)                   |
| 12     | Groundnut          | \(A_{12} \geq 912\) \(A_{12} - d_{50} = 912\)                   |
| 13     | Vegetables (R)     | \(A_{13} \geq 1,267\) \(A_{13} - d_{50} = 1,267\)               |

(\(d_{50}, d_{50a}, d_{50b}, d_{50c}, d_{50d}, d_{50e}, d_{50f}\) are positive deviational variables)
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 (Doorenbos 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 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 (10^3 Rs) | Total protein (10^3 kg) | Total calorie (10^3 cal.) |
|--------|------------------|--------------------------|-----------------------------------------|---------------------|-------------------------|--------------------------|
| 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                    |
## 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 |          | Available water (ha m.) for utilization for different months for cropping pattern of GP |          |
|--------|------------|----------------------------------------------------------------------------------------|----------|-----------------------------------------------------------------------------------|----------|
|        |            | SW GW                                                                                  | SW GW    | 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 0.00 |
| 4      | June       | 636.50 0.00                                                                            | 636.50 0.00 |
| 5      | July       | 1,909.12 0.00                                                                          | 1,809.12 0.00 |
| 6      | September  | 2,558.82 0.00                                                                          | 2,358.82 0.00 |
| 7      | October    | 3,075.34 0.00                                                                          | 3,075.34 0.00 |
| 8      | November   | 3,154.30 0.00                                                                          | 3,054.30 0.00 |
| 9      | December   | 6,505.20 0.00                                                                          | 6,405.20 0.00 |
|        | 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 | Proposed cropping pattern of GP |
|--------|-----------|---------------------------|---------------------------|-------------------------------|-------------------------------|
|        |           |                           | Area SW                   | 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              | 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             | 1,520 233.64 |
| 8      | Wheat (T) | 1,013 15,000              | 1,014 477.59              | 1,014 497.59 |
|        | Wheat (H) | 7,094 3,920               | 7,094 924.26              | 7,094 875.31 |
| 9      | Gram      | 1,014 25,000              | 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 |

| 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

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 m. 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, 1,675 ha, 32,408 ha and 934 ha 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 different crops under existing, LP and GP cropping pattern available SW for utilization and area allocated for irrigation project.

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.

References

Agrawal, M. C. and Agrawal, R. P., 1985, “Crop Planning Model Under Limited Irrigation Water Availability in Hisar District”, Haryana Agricultural University, Hisar.

Anderson, A. M. and Farle, M. D., 1983, “Diet Planning in the Third World by Linear and Goal Programming”, Journal of Operational Research Society, 20, 69-76.

Barna Irrigation Project Report, 1984, “Water Resources Department (Operation& Maintenance Division)”, Bhopal, Madhya Pradesh.

Charnes, A. and Cooper, W. W., 1967, “Management Models and the Industrial Applications of Linear Programming”, 1 & 2, John Wiley, New York.

Doorcabolos, J. and Pruitt, W. O., 1977, “Guidelines for Predicting Crop Water Requirements”, FAO Irrigation and Drainage Paper 24, Food and Agriculture Organization of the United Nations, Rome.

Dorfon, Robert Samuelson, Paul, A. and Robert, M. Salow, 1958, “Linear Programming & Economic Analysis”, Mc-Graw-Hill Book Company Inc., New York.

Ghei, A. N. and Ghei, P., 1973, “Text Book of Food and Nutrition”, M/s Sagar Publication, New Delhi.

Ignizio, James P., 1983, “A Note on Computational Methods in Lexicographic Linear and Goal Programming”, Journal of Operational Research Society, 20, 213-218.

Jain, S. K., Soni, B. and Seethapathi, P. V., 1998, “An Optimization Technique for Water Resources Management”, Journal of Civil Engineering Division, The Institute of Engineers (India), 69, 16-19.

Loucks, D. P., Stedinger, J. R. and Haith, D. A., 1981, “Water Resources Systems Planning and Analysis”, M/s Prentice Hall, Englewood Cliffs, New Jersey.

Maji, C. C. and Earl, O. Heady, 1978, “Inter Temporal Allocation of Irrigation Water in Mayurakshi Command area, An Application of Chance – Constrained Linear Programming”, Water Technology Centre, IARI, New Delhi.

Romero, Carlos and Tahir, Rehman, 1984, “A Note on Diet Planning in the Third World by Linear and Goal Programming”, Journal of Operations Research Society, 21, 109-205.

Soni, B. , 1985, “A Goal Programming Approach for Water Resources Management – A Case Study”, National Institute of Hydrology, Roorkee.

Srinivas, Raju K. and Nagesh Kumar, D., 2000, “Irrigation Planning of Sri Ram Sagar Project Using Multi-Objective Fuzzy Linear Programming”, Journal of Indian Society for Hydraulics, 6, 1, 55-63.

Valunjkar, S. S., 2002, “Optimization of Available Water Resources for Irrigation Use through Fuzzy Logic System, Case Study: Pench Irrigation Project (Maharashtra)”, Proceedings of the National Conference on Hydraulics and Water Resources and Ocean Engineering (HYDRO 2002), 358-362.
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
\( C_j \) = Unit contribution rate or cost coefficient
\( C_G \) = Cost of unit volume (ha m) of ground water
\( C_{ij} \) = 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
\( d_i, d_i^+ \) = 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
\( g_i \) = 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
\( T_{(min)} \) = Minimum area (ha) allocated to \( i^{th} \) crop
\( T_A \) = Total available cultivable command area (ha)
\( X \) = \((n*1)\) Column vector of real variables
\( X_i \) = 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