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Optimization modelling for *kharif* and *rabi* crop planning of command area of Ghonga Jalashay of Bilaspur, Chhattisgarh

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Abstract
The current study is based on a non-linear optimization modelling for *kharif* and *rabi* crops grown in command area of Ghonga Jalashay of Bilaspur, Chhattisgarh to maximize the net return. A non-linear optimization model was developed by using lingo 19.0 optimization software. Various inputs like cost of cultivation for different crops in different soils, irrigation crops, and sale price of the crops were used to get optimal solution.
The results showed that net return of Rs. 59,52,64,300 from the single *kharif* rice sown in 7311 hectare. The net seasonal return of summer rice Rs 3,80,84,680. The optimal solution was enumerated for five selected *rabi* crops *viz.* sunflower, wheat, mustard, safflower and gram based on minimum available irrigation water .The model gave the optimal solution comprising of total net return of Rs. 19,38,47,900. The optimal area occupied by sunflower, wheat, mustard, safflower and gram was found to be 2151.81, 1537, 819, 204.98 and 409.86 ha respectively. When we compare area covered and net return of summer rice with area covered and net return with projected rabi crops, the area increased to eight time and net return increased to six time higher in rabi crops.

Keywords: Non-linear, optimization, crop planning, crop pattern

Introduction
In traditional agriculture, crop planning decisions were mainly based on the farmer's judgment and experience. However, advancement in agriculture and increasing pressure on land and other resources, coupled with increased specialization and the adoption of capital-intensive production systems farmers wanted to take higher return from thir land. The development of more formal planning methods based on the construction and analysis of a mathematical model plays important role in crop planning. Since its inception, mathematical programming models have been applied directly or indirectly in agricultural sector and have contributed significantly in the analysis of policy issues such as resource allocations, decisions based on investment, comparative benifits, risk analysis and higher net returns etc
Optimal cropping pattern for getting higher monitory return is one of the essential tasks which require an irrigation command with the available water resources. This task can be achieved by using optimization model, which plays a crucial role in planning and management of water resource system.
Irrigation is the artificial application of water to soil for the purpose of crop production. Land and water are basic input for agriculture but both the resources are limited. To irrigate more area and achieve maximum benefits from the area, it is necessary to use land and water efficiently and optimally. Thus the farmers require better and precise program of optimal cropping pattern suited for the region which will maximize economic returns.
Pandey *et al.*, (2009) [5] developed a non-linear optimization model for farm with soil type and applied to the Banahil Distributary of Hasdeo-Bango Major Irrigation Project, Chhattisgarh. The model gives the optimal distribution of areas and crops. The wheat crop is the most profitable crop, followed by sunflower. The total net return from the optimal cropping pattern is found to be 5.37 times more than the summer rice. Ramesh *et al*., (2022) [6] formulated a linear programming model for optimal cropping pattern for surface irrigation in a Bhadra command area. The objective of the model was to suggest the cropping pattern for varied water availability in the canal. Nazarifar *et al*., (2017) [2] developed a nonlinear programming model for determination of an optimal cropping pattern in deficit irrigation conditions.

A non-linear model with the objective function of economical water productivity index (Net profit to water consumption ratio) was combined with a crop growth model and it was evaluated using the data of Shahid Chamran irrigation network. Neamatollahi *et al*., (2017) [4] used fuzzy system for achieving the best cropping pattern in Agriculture. It was four main objectives maximization of net income of farmers, minimizing the amount of water used in agriculture, minimizing the use of chemical fertilizers and chemical pesticides. Mahsafar *et al*., (2017) given a non-linear optimization model for optimal cropping patterns under water deficits. The objective function of non-linear model was to maximize total net benefit return from all crops in the Qazvin plain. The model was solved using Lingo solver package for conditions existing in region. Garg *et al.*, (2014) applied a non-linear optimization model for deficit irrigation. The objective was to maximize the net financial return within the available resource constraints. Singh (2014a) [8] formulated and used the linear programming model for the maximization of net annual farm income from an area located in the Rohtak district of Haryana, India. Singh (2012b) [8] developed a linear programming model for the optimal land and water resources allocation in order to maximize net annual returns from an irrigated area located in Haryana state of India. Dhole *et al.*, (2011) [1] used a linear programming model for maximization production, net benefit and labor employment in command area Som-Kagdar irrigation project Udaipur, Rajasthan. Sahoo *et al*., (2006) [7] developed a linear programming and fuzzy optimization models for planning and management of available land-water-crop system of Mahanadi-Kathajodi delta in eastern India. The models was applied to optimize the economic return, production and labour utilization, and to search the related cropping patterns and intensities with specified land, water, fertilizer and labour availability, and water use pattern constraints.

Objectives

1. To develop an optimization model to determine the optimal cropping pattern for the command area of Ghonga Jalashay.

Materials and Methods

Description of study area

The dam site of the Ghonga is located on the Bilaspur-Achanakmar road, near Kori village, at a distance of 5 km from Kota Nagar. Whose latitude is 22° 80’ 0” and longitude 81° 58’ 0”. This project comes under Kota and Takhatpur development block in Bilaspur district of Chhattisgarh State, India. The surrounding boundaries of the dam is covered by hill and forest areas and also it is connected by four small rivers Katori, Ghonga, Bagaiha and Suknaiya .The maximum Bund Level (MBL) is 321.80m. and the Maximum Water Level (M.W.L) is 320.20m. Currently, 7331 hectare area are irrigated by right bank canal system in 48 villages, while 1012 hectare area are irrigated by left bank canal system in 6 villages, totalling 8343 hectare area irrigated from Ghonga project.

Methodology

The analysis compares the cost of irrigation against the benefit of enhanced crop productivity, as well as other possible crop production aspects, to establish the economically best crop combination and irrigation water application pattern. Only by the boosting agricultural water productivity can one reach maximum output. Climate, irrigation water management and soil-nutrient management all have a role in crop water production variability. As a result, selecting irrigation techniques requires specific crop water productivity, as well as water production functions for an established location.

Assumptions

Model has been developed under the following assumptions.

- For a given soil in the unit command area is homogeneous (uniform).
- Various inputs other than water are at the optimum level.
- Each unit of land under consideration receives the same management practice for a particular crop.
- Seeds, fertilizers, and plant protection measures (insecticides and pesticides), among other inputs, are considered to be accessible at optimal levels.
- All the activities levels are within the finite limit and non-negative in nature.

Production function

The production function is a mathematical relationship describing the way in which the quantity of a particular product depends upon the quantities of particular input used.
At the optimal level

Yield of a crop associated with applied water given by

$$Y = f(W) \quad (3.1)$$

and

$$W = \frac{I}{A} + ERF \quad (3.2)$$

Where,
W = Water applied (cm),
I = Amount of irrigation water applied in specified area of command (ha-cm),
A = Cultivated area under command (ha),
ERF= Effective rainfall during season (cm)
The non-linear equation can be represented as second order polynomial (Hexem and Heady, 1978) [3] as:

$$Y = f(W) = a_0 + a_1 W^1 + a_2 W^2 \quad (3.3)$$

Where,
a_0, a_1, and a_2 are the coefficients.
For a specific crop i and soil j, the equations can be written as

$$Y_{ij} = f(W) = a_{0,ij} + a_{1,ij} W_{ij} + a_{2,ij} W_{ij}^2 \quad (3.4)$$

Where,
Y_{ij} = yield of the crop i in soil j (q ha^{-1}) and
W_{ij}= depth of water applied to the crop i in soil j (cm).

Non-linear programming model

With six major crops (wheat, sunflower, sfflower, mustard and gram) farmed in the command area of Ghonga Jalashay, a non-linear model has been developed to optimize net profit under constraints of water availability and soil type, cultivation costs, and cost of irrigation water.
The objective function can be, expressed mathematically, as

$$\text{Max } Z = (PY-C)\,A \quad (3.5)$$

Where,
Z = Net return, Rs. (Indian currency) ,
A = Cultivated area of command (ha)
P = Sale price of crop (Rs/kg),
Y = Yield of the crop (q ha^{-1}),
C = Cost of cultivation (Rs/ha) and

Plant production (seed, fertilizer, and nutrients), plant protection (insecticide and pesticide), agronomic management (weeding, thinning, and intercultural), irrigation and any cultivation activity involving man and machine can all be subdivided under the cost of cultivation. However, the cost of cultivation is separated into two groups in this optimization study:

- Cost of irrigation water in command area and
- Cost of cultivation including irrigation in command area

For specific crop i and soil j, Eq. (3.5) can be written as

$$\text{Max } Z = \sum_{i=1}^{6}\sum_{j=1}^{3}(P_i Y_{ij} - C_{ij} - C_i^{w})A_{ij} \quad (3.6)$$

Where,
P_i= sale price of crop i (Rs/kg),
Y_{ij}= Yield of crop i in soil j (q/ha)
C_{ij}= Cost of cultivation for crop i in soil j excluding irrigation water cost (Rs/ha)
C_i^{w} = Cost of canal water for crop i (Rs/ha) in command area and
A_{ij}= Cultivated area of crop i in soil j (ha) in command area

The Production function By using the water, Eq. (3.6) can be written as

$$\text{Max } Z = \sum_{i=1}^{6}\sum_{j=1}^{3}\left[P_i\{f(W_{ij})\} - C_{ij}\right]A_{ij} - \sum_{i=1}^{6}\sum_{j=1}^{3}C_i^{w})A_{ij} \quad (3.7)$$

Substituting Eq. (3.4) in Eq. (3.6) it yields a non-linear equation

$$\text{Max } Z = \sum_{i=1}^{6}\sum_{j=1}^{3}\left[P_i\{f(a_{0,ij} + a_{1,ij}W_{ij} + a_{2,ij}W_{ij}^2)\} - C_{ij}\right]A_{ij} - \sum_{i=1}^{6}\sum_{j=1}^{3}C_i^{w})A_{ij} \quad (3.8)$$

Constraints
The objective functions with subject to the following constraints based on the availability of the resources, soil characteristics, and market considerations as follows:

Land availability
The summation of the area could be allocated for different crops should be less than or equal to the total available area. It can be given as

$$\sum_{j=1}^{3} A_{ij} \le TA_j \ \forall j \quad (3.9)$$

$$\sum_{j=1}^{3} TA_j \le TC \quad (3.10)$$

Where,
TA_j=Total area of soil j (ha) in command area and
TC = Total command area (ha)

Water allocation
The need of net irrigation water should always be greater than or equal to the depth of irrigation water applied. It can be expressed as

$$\sum_{i=1}^{6}\sum_{j=1}^{3}(w_{ij} - GIR_{ij}) \ge 0 \quad (3.11)$$

Where,
GIR_{ij} is the gross irrigation requirement of crop i in soil j (cm) in command area

Water supply
Crop i in soil j should have a cumulative water demand in command area that is less than or equal to the minimum available water supply. It can be expressed as

$$100\sum_{i=1}^{6}\sum_{j=1}^{3} W_{ij}A_{ij} \ge ACW \quad (3.12)$$

Where,
ACW = the minimum available canal water in command area (m^3)

Canal capacity constraint
Crop i in soil j in command area should have a cumulative water demand that is less than or equal to the canal capacity. It can be expressed as

$$100\sum_{i=1}^{6}\sum_{j=1}^{3} W_{ij}A_{ij} \le 24x3600(CCxDC) \quad (3.13)$$

Where,
CC = the design capacity of canal (m^3/s) in command area and
DC = the duration of canal operation (days) in command area

Crop area constraint
To consider the societal barrier and to avoid high-value crops from getting the maximum benefit search, minimum area percentages for each crop must be considered, based on the research area's current cropping practice.

$$A_{ij} \ge \mu_{ij} TA_{ij} \ \forall i, j \quad (3.14)$$

Where,
μ_{ij}= restriction area constant (fraction)

Water bound
The decision variable (W) is subjected to work within the lower and upper limit of water bound

$$L_{ij} \le W_{ij} \le U_{ij} \quad (3.15)$$

Where,
L_{ij}= lower limit (cm) of water and
U_{ij}= upper limit (cm) of water

Non-negativity constraint
The area and water applied depth values in command area are always positive.

$$A_{ij} \ge 0; \forall i,j \quad (3.16)$$

$$W_{ij} \ge 0 ; \forall_{i,j} \quad (3.17)$$

Result and Discussion
Optimal cropping pattern for *kharif* rice
The optimal cropping pattern for *kharif* rice was enumerated by the optimization software, results showed net return of

Rs.59,52,64,300 from the single *kharif* rice sown in 7311 ha by using 77.00 cm average water consumption in different soils and saved up to 40% excess water in *kharif* season, which can be utilized for succeeding *rabi* crops.

Table 1: optimal cropping pattern for *kharif* rice

Crops	Type of soil	Crop area (ha)	Coverage of total command area (%)	Gross irrigation requirements (cm)
Kharif rice	Clay	438.66	6	77.00
	Clay loam	4240.38	58	77.26
	Sandy clay loam	2631.96	36	77.26
	Total	7311	100	231.52

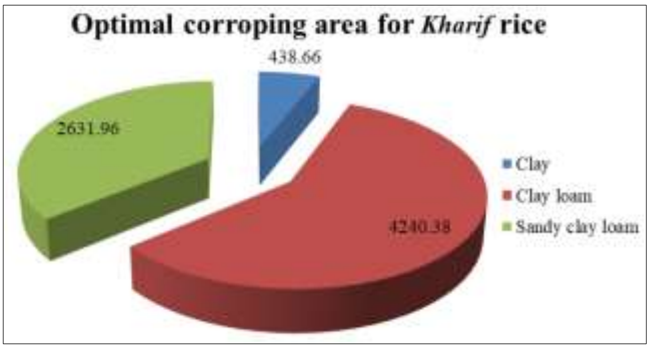

Fig 1: Optimal cropping pattern for *Kharif* rice

Optimal cropping pattern for summer rice

The optimal cropping pattern for summer rice was enumerated by the optimization software. The results showed that net return with an application of 135 cm/ha, summer rice gave net return of Rs.3,80,84,680 with an average sown area 616 hectare in clay and clay loam soil.

Table 2: Optimal cropping patterns for summer rice

Crops	Type of soil	Crop area (ha)	Coverage of total command area (%)	Gross irrigation requirements (cm)
Summer rice	Clay	307.00	49.84	128.00
	Clay loam	309.00	50.16	142.00
	Total	616	100	270

Optimal cropping pattern for *rabi* crops

The optimization model was run to get the optimal cropping pattern of the five selected *rabi* crops in the study area bearing to mind of the minimum available irrigation water (8323520.02 m^3). The model gave optimal solution for total net return Rs.19,38,47,900. The optimal area of wheat, sunflower, mustard, gram and safflower have found to be 1537.02 ha, 2151.81 ha, 819.73 ha, 409.86 ha and 204.93 ha respectively in clay loam and sandy clay loam soil in command area. The most profitable crop was sunflower covered 42% area followed by wheat (30%).

Table 3: Optimal cropping patterns for gross irrigation (8323520.03 m^3) requirement for different soil types

Crops	Type of soil	Crop area (ha)	Coverage of total command area (%)	Gross irrigation Requirements (cm)
Sunflower	Clay	-	-	-
	Clay loam	1537.01	-	18.15
	Sandy clay loam	614.80	-	18.15
	Total	2151.82	42	36.30
Wheat	Clay	307.40	-	17.52
	Clay loam	1229.61	-	17.52
	Sandy clay loam	-	-	-
	Total	1537.01	30	35.04
Mustard	Clay	-	-	-
	Clay loam	-	-	-
	Sandy clay loam	819.73	-	12.63
	Total	819.73	16	12.63
Gram	Clay	-	-	-
	Clay loam	-	-	-
	Sandy clay loam	409.86	-	10.19
	Total	409.86	8	10.19
Safflower	Clay	-	-	-
	Clay loam	204.93	-	13.17
	Sandy clay loam	-	-	-
	Total	204.93	4	13.17

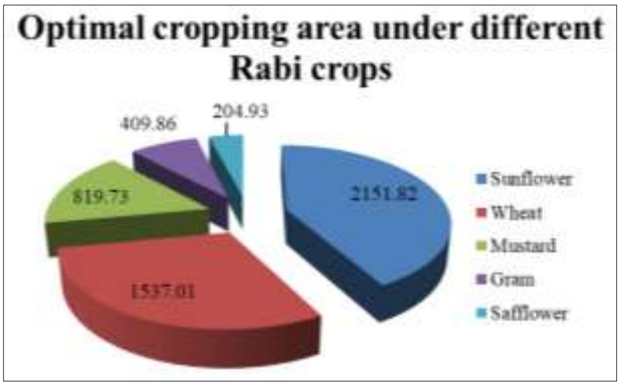

Fig 2: Optimal cropping pattern for *Rabi* crops

Comparison of optimal rabi cropping pattern with the summer rice

Total net return of *rabi* crops was higher than summer rice. If we compare total net return of *rabi* crops with summer rice the net return of *rabi* crops was higher than the total net return of summer rice. The area coverage of total *rabi* crops 5123 ha (19,38,47,900) was also more than area under summer rice with same water utilization.

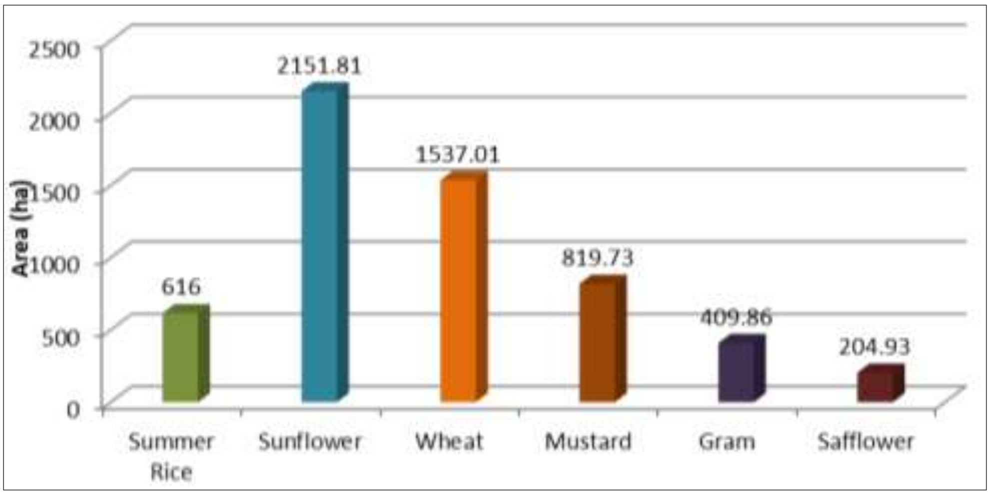

Fig 3: Comparison of optimal *rabi* cropping pattern with the summer rice

Conclusion

The optimal cropping pattern for *kharif* crop was enumerated by the LINGO 19.0 software. The results showed that net return of Rs.59,52,64,300 from the single *kharif* rice sown in 7311 hectare by 77.00 cm average water consumption in different soils and saved up to 40% excess water in *kharif* season, which may be utilized for succeeding *rabi* crops and summer rice.

The optimal solution was enumerated for five selected *rabi* crops *viz*. sunflower, wheat, mustard, safflower and gram based on minimum available irrigation water (8323520.02m^3) in the reservoir after *kharif* crop. The model gave the optimal solution comprising of total net return of Rs 19,38,47,900. The optimal area occupied by sunflower, wheat, mustard, safflower and gram was found to be 2151.81, 1537, 819, 204.98 and 409.86 ha respectively.

In the optimal solution, sunflower preferred clay loam and sandy clay loam soils (total area 2151.81 ha), wheat preferred clay loam and clay soil (total area 1537 ha) whereas, the mustard crop occupied sandy clay loam soil (total area 819 ha), gram preferred only sandy clay loam soil (total area 409.86 ha) and safflower preferred clay loam soil (204.98 ha) respectively.

The sunflower was the most profitable crop in optimal solution followed by wheat. The area allocation was about sunflower (42%) and wheat (30%) of total *rabi* crops followed by other *rabi* crops of the CCA, respectively.

In the optimal solution net return of summer rice was found to be Rs 3,80,84,680 in the area of 616 ha., The optimal cropping pattern of rabi crop in the model gave the optimal solution comprising of total net return of Rs 19,38,47,900 in 5123ha. When we compare area covered and net return of summer rice with area covered and net return with projected rabi crops, the area increased to eight time and net return increased to six time higher in rabi crops

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