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Irrigated Crop Planning through Optimization Model

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ABSTRACT: The ultimate goal of the irrigated agriculture is obtaining maximum benefit with sustainable and optimal cropping pattern within the available water resources. This can be achieved by assessing the irrigation system performance under existing and alternative scenarios using optimization model. For the purpose (suggesting alternative economically viable *rabi* cropping pattern) a non-linear optimization model is developed with decision variables of the cultivated area in each soil type of the farm and applied to the Banahil Distributary of Hasdeo-Bango Major Irrigation Project, Chhattisgarh, India where single crop (summer rice) is grown during summer season. The objective function of the optimization model is based on crop-water-production function, crop management and irrigation technology used and costs and prices of the products. The data on crops, weather, soils, canal supply and cost of cultivation pertaining to the study area were collected from various government departments, organization and personal contact from the farmers of the command. 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. The optimal cropping pattern not only gives higher net return but also covered 100% of the cultural command area. Sensitivity analysis is carried out to study the effect within the –20 to 20% change in sale price of crop; cost of cultivation (excluding irrigation cost) and cost of canal water on the optimal solution. The sensitivity analysis revealed that the sale price of crop is the most sensitive input parameter followed by the cost of cultivation excluding irrigation cost.

Keywords: India, Irrigated Agriculture, Major Irrigation Project, Non-linear Programming, Optimal Cropping Pattern, Optimization, Sensitivity Analysis, Water Production Function.

INTRODUCTION

Irrigated agriculture has played a crucial role in economic and social development of South-Asia. Irrigation is directly responsible for complete self-sufficiency in food production of India, Pakistan and Sri Lanka (Chambers and Kanwar, 1988). It has also increased employment opportunities and improved the economic conditions of the agricultural labourers (Chitale, 1994). However, most of the major irrigation projects in the developing countries have failed to provide the benefits envisaged at the time of their commissioning. Evaluation reports show that the application efficiencies, cropping intensities and yields have generally not fulfilled planners' expectation due to poor water management and crop planning. Water is the most important factor affecting crop yield and knowledge of water production function is the key for the selection of the most adequate water management plans in irrigated areas. Water production function assume that the crops respond differently to soil-water content and that changes in the latter affect crop yields (Stewart and Hagan, 1973). In addition to the rational water use, there is a need for selecting economically viable cropping patterns for a given area and available resources. Those cropping pattern can be attained through the use of optimization models (Matanga and Marino, 1977; Chavez-Morales *et al.,* 1972). The

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model can be linear or non-linear. Although linear optimization models are used more frequently, they require that both objective function and constraints be linear, conditions that are not always satisfied. Non-linear optimization models do not have the linearity limitation (Hillier and Lieberman, 1980). The development of optimization model with non-linear technique is an useful tool for irrigation system where multiple cropping patterns is practiced and the water supply and irrigation demand become more complex.

PROBLEMS/ISSUES

The Hasdeo Bango Irrigation Project is one of the largest projects in the state of Chhattisgarh, India that provides irrigation facilities to about 2,55,000 ha in 801 villages of 3 districts (Korba, Janjgir, and Raigarh) and also generates 120 MW hydel power. The *kharif* (monsoon) rice (paddy) occupies 100% of the available cultural command area but in the *rabi* (winter) season the occupied area varies according to the availability of water in the reservoir. The present average target of summer rice is about 20% of the Cultural Command Area (CCA), which shows that each irrigator can cultivate summer rice, in the rotation, once in 5 years. Further, the farmers of the command area are completely dependent on the mercy of the State Water Resources Department due to their lack of knowledge about the irrigation water management. Since, the irrigation department presently does not possess any decision support system; the water allocation is frequently subjected to negotiations with the farmers and politicians. Such practices lead to poor performance of the irrigation system because of large deviation between the crop water demand and supply. Therefore, a study was required to develop a suitable optimization model which can suggest economically viable *rabi* cropping pattern for the region within the existing infrastructure. In the light of the aforesaid command area problems, a non-linear optimization model is developed to obtain optimal cropping pattern for maximizing the net seasonal return.

DEVELOPMENT OF OPTIMIZATION MODEL

In irrigation planning, optimization techniques can be used to represent complex relationships of irrigation system and to determine the most beneficial cropping pattern and water allocations. When large irrigated areas with significant crop diversification are considered, this determination can be important, particularly with the spatial and temporal water supply restrictions. During the next few decades, as the inevitable expansion of irrigated lands for increased food production comes into conflict with accelerating economic competition for water and rising environmental concerns, this fundamental precept of irrigation management will probably be abandoned. The new operational rule that replaces it will be based on maximizing total benefits rather than yields (English *et al.*, 2002). This alternative approach, which might be referred to simply as 'optimization', is recognized by economists and a growing number of irrigation professionals as the most rational basis for irrigation management.

To determine the economically optimal crop and irrigation water application pattern, the study considers the irrigation cost to the benefit derived from increased crop productivity and subsequent possible crop production factors. The maximum production can be achieved by only increasing the crop water productivity. The variability of crop water productivity can be ascribed to climate, irrigation water management and soil-nutrient management. Thus, the location specific crop water productivity, as water production functions, is required for deciding the irrigation strategies.

Production Function

The relationship between crop yield and water application is termed as water production function. Keeping all other inputs, like crop variety, seed quality, soil-nutrient, fertilizer and other crop management components constant and at optimum level, the yield of crop can be related to applied water as,

$$Y = f(DW), \text{ and} \qquad \dots (1)$$

$$DW = \frac{I}{A} + ERF \qquad \dots (2)$$

where, Y is the yield of crop, kg/ha; DW is the water applied, cm; I is the amount of irrigation water applied in specified area, ha-cm; A is the cultivated area, ha; and ERF is effective rainfall, cm.

The general relationship between applied water and crop yield per unit area can be shown in two ways, one representing the relationship between consumptive use of water (ET) and yield, the other representing the relationship between applied water and yield (Figure 1). Previous studies show that the ET-yield relationship is linear or at least as a first order approximation (Vaux and Pruitt, 1983). The applied water-yield relationship is more complex. At low levels of applied water (up to about 50% of full irrigation) yields increase more or less linearly with applied water (Vaux and Pruitt, 1983). As more water is applied, the relationship becomes curvilinear due to accelerating losses from surface evaporation, runoff and deep percolation. Beyond the point of maximum yield, the curve turns downward reflecting yield losses from anaerobic root zone conditions, disease and leaching of nutrients from excessive water use (English *et al.,* 2002). The curvilinear (non-linear) relation also varies with the varieties of crops, crop management practices and climate (Kipkorir *et al.,* 2002).

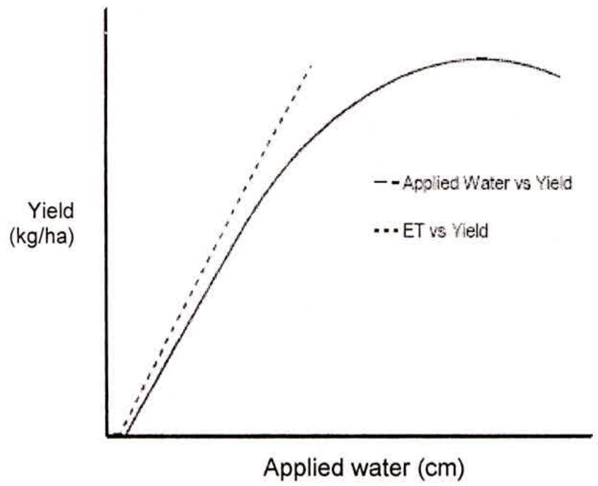

Fig. 1: General relationship between applied water and crop yield

The non-linear relation can be represented as second order polynomial (Hexem and Heady, 1978) equation as,

$$Y = f(DW) = a_0 + a_1 DW + a_2 DW^2 \quad \dots (3)$$

where, a_0, a_1, and, a_2 are the coefficients.

For specific crop i and soil j, the equations can be written as,

$$Y_{ij} = f(DW) = a_{0,ij} + a_{1,ij} DW_{ij} + a_{2,ij} DW_{ij}^2 \quad (4)$$

where, Y_{ij} is the yield of the crop i in soil j, kg/ha and DW_{ij} is the depth of water applied to the crop i in soil j, cm.

Non-linear Programming Model

A non-linear programming model is formulated to maximize the profit subjected to the restriction of water availability and soil type with five common crops that are grown in the command areas of Banahil Distributary considering crop harvest index, cost of cultivation and irrigation water cost. The objective function can be, mathematically, expressed as,

$$\text{Max } Z = (PY - C)A \quad \dots (5)$$

where, Z is the net return, Rs. (Indian currency); P is the sale price of crop, Rs/kg; Y is the yield of the crop, Kg/ha; C is the cost of cultivation, Rs/ha; and A is the cultivated area, ha.

Cost of cultivation can further be sub-divided into several components such as plant production (seed, fertilizer and nutrients), plant protection (pesticides), agronomic management (weeding, thinning and inter-cultural), irrigation and each cultivation operations with involvement of man and machine. However, this optimization study, the cost of cultivation is sub-divided into two categories; cost of irrigation (canal) water, and cost of cultivation excluding irrigation.

For specific crop i and soil j, Eqn. (5) can be written as,

$$\text{Max } Z = \sum_{j=1}^{3}\sum_{i=1}^{5}(P_i Y_{ij} - C_{ij} - C_i^w) A_{ij} \quad \dots (6)$$

where, P_i is the unit value of output (sale price of crop i), Rs/kg; Y_{ij} is the yield of crop i in soil j, Kg/ha; C_{ij} is the cost of cultivation for crop i in soil j excluding irrigation water cost, Rs/ha; C_i^w is the cost of canal water for crop i, Rs/ha; and A_{ij} is the cultivated area of crop i in soil j, ha.

By including water production function Eqn. (6) can be expanded as,

$$\text{Max } Z = \sum_{j=1}^{3}\sum_{i=1}^{5}\left[P_i\left\{f\left(DW_{ij}\right)\right\} - C_{ij}\right]A_{ij} - \sum_{j=1}^{3}\sum_{i=1}^{5} C_i^w A_{ij} \quad \dots (7)$$

Substituting Eqn. (4) in Eqn. (7) yields a non-linear system,

$$\text{Max } Z = \sum_{j=1}^{3}\sum_{i=1}^{5}\left[P_i\left(a_{0,ij} + a_{1,ij} DW_{ij} + a_{2,ij} DW_{ij}^2\right) - C_{ij}\right] A_{ij} - \sum_{j=1}^{3}\sum_{i=1}^{5} C_i^w A_{ij} \quad \dots (8)$$

Constraints

The objective function is subject to the following constraints based on the availability of the sources, soil characteristics, and market considerations as follows:

Land Availability

$$\sum_{i=1}^{5} A_{ij} \leq TA_j \quad \forall j \quad \dots (9)$$

$$\sum_{j=1}^{3} TA_j \leq TC \quad \dots (10)$$

where, TA_j is the total area of soil j, ha; and TC is the total command area, ha.

Water Allocation

$$\sum_{j=1}^{3}\sum_{i=1}^{5}\left(DW_{ij} - GIR_{ij}\right) \geq 0 \qquad \ldots (11)$$

where, GIR_{ij} is the gross irrigation requirement of crop i in soil j, cm.

Water Supply

$$100\sum_{j=1}^{3}\sum_{i=1}^{5} DW_{ij}\, A_{ij} \quad \geq ACW \qquad (12)$$

where, ACW is the minimum available canal water, m^3.

Canal Capacity Constraint

$$100\sum_{j=1}^{3}\sum_{i=1}^{5} DW_{ij}\, A_{ij} \leq 24 \times 3600\,(CC \times DC) \qquad \ldots (13)$$

where, CC is the design capacity of canal, m^3/s and DC is the duration of canal operation, days.

Crop Area Constraint

$$A_{ij} \geq \mu_{ij} TA_{ij} \qquad \forall\, i, j \qquad \ldots (14)$$

where, μ_{ij} is the restriction area constant (fraction).

Water Bound

$$L_{ij} \leq DW_{ij} \leq U_{ij} \qquad \ldots (15)$$

where, L_{ij} is the lower limit, cm; and U_{ij} is the upper limit, cm.

Non-negativity Constraint

$$A_{ij} \geq 0; \qquad \forall\, i, j \qquad \ldots (16)$$

$$DW_{ij} \geq 0; \qquad \forall\, i, j \qquad \ldots (17)$$

MODEL INPUT DATA

The model requires input data which were collected from the study area from the different government organization involved and personal contact with the farmers. The available resources which were considered in the optimization model are given in Table 1. The other data, cost of cultivation and water production functions were estimated based on the collected data.

Table 1: Available Resources for Region under Consideration

Resources	*Availability*	*Units*
Irrigation water	35339840	m^3
Clay soil	539.00	ha
Clay loam soil	6550.43	ha
Sandy clay loam soil	4017.00	ha
Total CCA	11106.43	ha

Cost of Cultivation

The cost of cultivation of different crops grown in different soils of the study area was estimated in consultation with the group of farmers, local officers of Agricultural Department and agricultural water management scientists who are working in the same command area (Table 2). Each aspect (plant production and plant protection) and operations of cultivation are included in the calculation. The costs of inputs are seeds, seed treatment chemicals, fertilizers and pesticides. The cultivation operation cost includes hiring charges of tractor (Indian rupees, Rs. 350/hr) for land preparation, sowing and harvesting, labour charges (Rs. 40/day, local rate) for seed treatments, intercultural operations (i.e. weeding, spraying of insecticides and other pesticides, irrigation, transportation and other miscellaneous works) and canal irrigation charges for different crops (wheat—Rs. 262/ha, sunflower, mustard, gram, safflower—Rs. 247/ha and summer rice—Rs. 494/ha) are considered. The actual fertilizers doses (kg/ha, N: P: K) used for different crops in the study area are 90:44:31, 33:29:15, 45:28:14, 15:38:11, 42:27:13 and 64:38:21 for wheat, sunflower, mustard, gram, safflower and summer rice, respectively. These doses of fertilizers to crops are not similar to the recommendation of the state Agricultural Department. The market price of fertilizers for Nitrogen (N)—Rs. 10.96/kg, Phosphorus (P)—Rs. 21.50/kg and Potash (K)—Rs. 8.33/kg are taken. The output (yield, kg/ha) includes dry biomass (grain) and its by-product (straws) which are taken into consideration for estimation of gross return. Local actual sale prices (Rs/kg) of agricultural produce are taken into consideration. The cost of cultivation of different crops in different soils is estimated using the field data from the study area. The overall cost of cultivation in heavy texture soil (clay) is higher as compared to medium and light-textured (sandy clay loam) soils mainly due to higher expenditure in land preparation. The average cost of cultivation excluding irrigation cost of wheat, sunflower, mustard, gram, safflower and summer rice are 9985, 6720, 8178, 8575, 7974 and 9933 (Rs/ha), respectively.

Table 2: Sale Price, Irrigation Cost, Cost of Cultivation, Average Yield and Sown Area of Different Crops in the Region

Crop	*Sale Price of Crop (Rs/Kg)*	*Irrigation Cost (Rs/ha)*	*Sown Area (fraction)*	*Average Yield of Crop in Different Soils (Kg/ha)*			*Cost of Cultivation Without Irrigation Cost (Rs/ha)*		
				Soil Texture			*Soil Texture*		
				Clay	*Clay Loam*	*Sandy Clay Loam*	*Clay*	*Clay Loam*	*Sandy Clay Loam*
Wheat	7.0	262	0.27	2820	3030	2550	11016	10153	8786
Sunflower	13.0	247	0.04	1850	1950	1700	7543	7012	5605
Mustard	15.0	247	0.14	1200	1250	1100	9183	8320	7033
Gram	16.0	247	0.04	1300	1350	1200	9421	8280	7723
Safflower	14.0	247	0.03	1000	1100	900	8757	8266	6899
Summer rice	5.0	494	1.0	4850	4600	4100	10498	9860	9441

Table 3: Regression Coefficients of Water Production Function of Selected Crops under Different Soils

Crop	*Soil*	*Production Function Coefficients ($Y = a_0 + a_1 x + a_2 x^2$)*			
		a_0	a_1	a_2	R^2
Wheat	Clay	–1218.44	307.54	– 5.07	0.92
	Clay loam	–1964.79	309.27	– 4.18	0.89
	Sandy clay loam	–5934.41	414.96	– 4.76	0.93
Sunflower	Clay	–694.89	222.11	– 4.22	0.97
	Clay loam	–694.89	222.11	– 4.22	0.97
	Sandy clay loam	–694.89	222.11	– 4.22	0.97
Mustard	Clay	–1044.10	284.37	– 8.01	0.96
	Clay loam	–1044.10	284.37	– 8.01	0.96
	Sandy clay loam	–1044.10	284.37	– 8.01	0.96
Gram	Clay	–296.47	242.07	– 7.98	0.94
	Clay loam	–296.47	242.07	– 7.98	0.94
	Sandy clay loam	–296.47	242.07	– 7.98	0.94
Safflower	Clay	–1427.30	334.47	–9.81	0.93
	Clay loam	–1427.30	334.47	–9.81	0.93
	Sandy clay loam	–1427.30	334.47	–9.81	0.93
Summer rice	Clay	–10931.00	254.98	–0.91	0.93
	Clay loam	–20982.00	337.72	–1.04	0.84
	Sandy clay loam	–2958.20	81.69	–0.22	0.89

Water Production Function

The experimental data, "water applied *vs.* yield" of different crops in different soils, were collected from the Annual Progress Reports, Indian Council of Agricultural Research, All India Coordinated Project for Research on Water Management, Indira Gandhi Krishi Vishwavidyalaya, College of Agricultural and Research Station, Bilaspur, Chhattisgarh, India. The water production functions of wheat, sunflower, mustard, gram, safflower and summer rice were developed. The production functions of all the selected crops are well fitted with non-linear second order Hexem and Heady (1978) equation (Table 3 and Figures 2 and 3).

METHODOLOGY

The optimal *rabi* cropping pattern, with the combination of five considered crops, for selected area, was determined with the help of the developed optimization model. The model has many constraints that must be satisfied to the condition of objective function. The total land was sub-divided into a number of sub-areas on the basis of soils and land availability constraint.

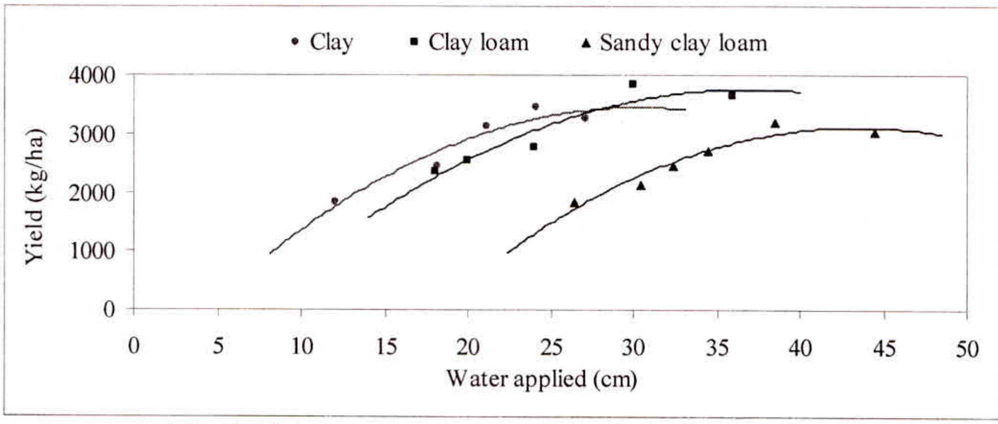

Fig. 2: Water production functions of wheat in different soils

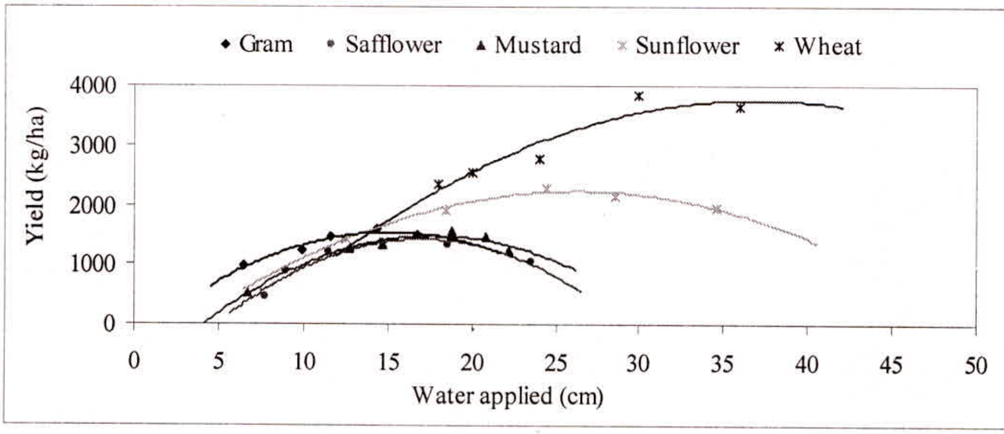

Fig. 3: Water production functions of *rabi* crops in clay loam soil

The applied water depth was always greater than or equal to the gross irrigation requirement of the crops (because water was not in limiting or deficit condition) as water allocation constraint. Seasonal water availability for irrigation was considered the minimum value among all the six years seasonal data as water supply constraint. As canal capacity constraint, there is a limit fixed for the seasonal maximum requirement of irrigation water between the lowest availability of canal water and the canal capacity. During the maximization process, the profitable crops should not dominant over other crops and also to fulfill the basic requirement of the local people, the minimum area for each crop was fixed as per the present cropping pattern (wheat 27%, sunflower 4%, mustard 14%, gram 4% and safflower 3% of cultivated area in *rabi* season) as minimum crop area constraints. To avoid non-negativity, the product of water depth and cropped area was considered as positive value. The optimization model was worked within the water bound of production functions, i.e. gross irrigation requirement as a lower and depth of water for producing the maximum yield as a upper limit. The optimization model was set up by entering the values of variables, which includes water production function, sale price of crop (P_i), cost of cultivation excluding irrigation cost (C_{ij}) and cost of canal water (C_i^w), in the objective function. The depth of water applied and cropping pattern (area) are the decision variables. The model was solved by Lingo 8.0 computer software. Local sensitivity analysis method was adopted in which only one parameter varied at a time to see its effect on the outputs. The selected inputs parameters are sale prices of the crop (P_i), costs of cultivation excluding irrigation cost (C_{ij}) and cost of irrigation (C_i^w) and varied for –20, –10, –5, 5, 10 and 20% from its optimal solution values.

RESULTS AND DISCUSSIONS

Optimal Cropping Pattern

The optimization model was run to obtain the optimal cropping pattern of the five selected crops in the command area of the Banahil Distributary (11106.43 ha) considering the minimum available irrigation water (35339842 m^3) during the study period (1995–2000). The model gave the optimal solution (Table 4)

Table 4: Optimal Cropping Pattern and its Gross Irrigation Requirement for Different Soil Types

Crop	*Soil Type*	*Crop Area (ha)*	*Coverage of Total Command Area (%)*	*Gross Irrigation Requirements (cm)*
Wheat	Clay loam	6027.70	54.27	36.97
Sunflower	Sandy clay loam	2746.38	24.73	32.40
Mustard		1554.90	14.00	34.78
	Clay	539.00		14.25
	Sandy clay loam	1015.90		20.53
Gram	Sandy clay loam	444.26	4.00	15.16
Safflower		333.19	3.00	36.53
	Clay loam	78.47		17.05
	Sandy clay loam	254.72		19.48

comprising of total net profit of Rs. 18,49,50,800, which is about Rs.16,653 per ha. The optimal area of wheat, sunflower, mustard, gram and safflower was found to be 6227.70 ha, 2746.38 ha, 1554.90 ha, 444.26 ha and 333.19 ha, respectively (Figure 4). The wheat was the most profitable crop, followed by sunflower and was allocated about 54.27% and 24.73% area of the total command, respectively. The model allocated the minimum area for the remaining three crops, i.e., mustard (14%), gram (4%) and safflower (3%) as specified in the respective constraints. In the optimal solution, wheat occupied only clay loam whereas sunflower occupied sandy clay loam soil. Similarly, the mustard crop preferred clay (539.0 ha) and sandy clay loam soils (1015.90 ha) whereas safflower preferred clay loam (78.47 ha) and sandy clay loam soils (254.72 ha). The gram is preferred in only clay loam soil (444.26 ha).

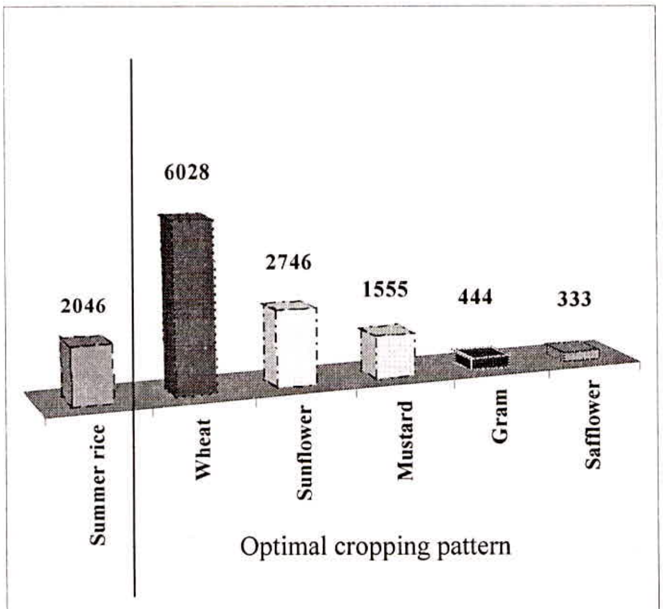

Fig. 4: Optimal cropping area

Comparison of Optimal *Rabi* Cropping Pattern with the Summer Rice

The total net return from the summer rice with the average sown area (2046 ha) is about Rs. 2,90,18,418, which is about Rs. 14,183 per ha. The net return per unit area obtained from optimal solution was higher than that obtained using summer rice because it takes into account 100% of the command area under cultivation. This shows that the income from the command area can be raised more than five times (5.37) of summer rice with the optimal cropping pattern.

Sensitivity Analysis

Sensitivity analysis was conducted by varying the values of input parameters to see their impact on the optimal solution. The input parameters varied from—20 to 20% of their respective value obtained in the optimal solution.

Effect of Sale Price of Crop (P_i)

The variations in sale price of crops (P_i) resulted in a linear trend with the net return (Z), i.e., –20, –10, –5, 5, 10 and 20% change in the original values of P_i (Rs. 16653/ha) changed Z by –30.47, –15.26, –7.64, 7.64, 15.28 and 30.58%, respectively (Figure 5). The change in P_i resulted in change in wheat and sunflower cropped areas, whereas other three crops remained unchanged (Figure 6). The area under wheat decreased with the decreasing P_i and did not change after 5% increase in P_i. The change in P_i by –20, –10, –5, and 5 to 20% resulted in –8.49%, –3.87%, –1.78% and 1.29 % change in wheat crop area, respectively. However, the area under sunflower increased with the decrease in crop selling price and *vice-versa* in P_i. It remains constant for more than 5% change in P_i. The rate of change in cropped area for sunflower was higher than for wheat. The change in P_i by –20, –10, –5, and 5 to 20% resulted in 8.64, 8.47, 3.88 and remained constant at –2.86% change in sunflower area, respectively.

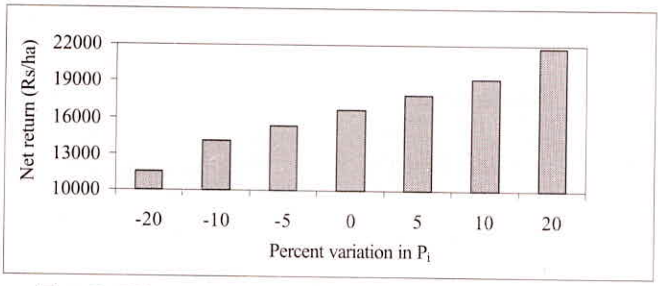

Fig. 5: Effect of percent variation in the sale price of crops on net return

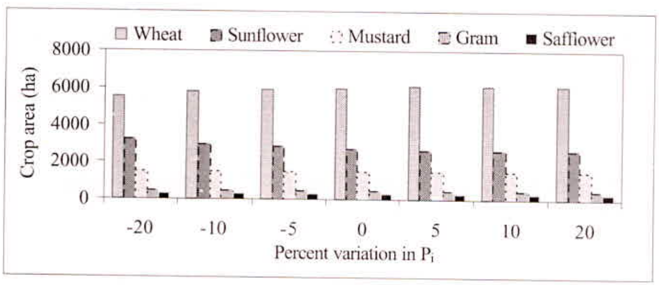

Fig. 6: Effect of percent variation in sale price of crops on crop area

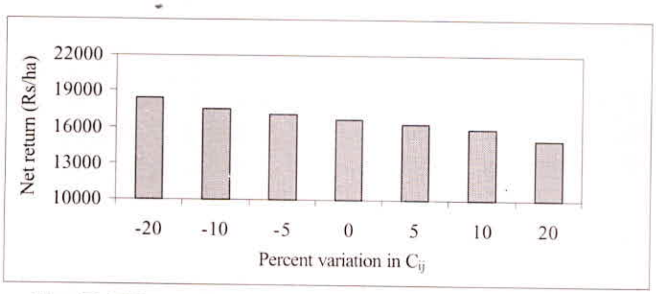

Fig. 7: Effect of percent variation in cost of cultivation (without irrigation cost) on net return

Effect of Cost of Cultivation Excluding Irrigation Cost (C_{ij})

The variations in the cost of cultivation excluding the irrigation cost (C_{ij}) resulted in linear and reverse trend with the lower rate of net return (Z), i.e., –20, –10, –5, 5, 10 and 20% change in the original values of Z (Rs. 16653/ha) resulted in changes in the optimal solution Z by 10.27, 5.13, 2.56, –2.56, –5.11 and –10.18%, respectively (Figure 7). The change in C_{ij} resulted in change in wheat and sunflower cropped areas, whereas the cropped area for the other three crops remained unchanged. The area under wheat decreased with the increasing C_{ij} and did not change after –5% changes in C_{ij}. The reverse trend was observed in case of sunflower but it also did not change after –5% changes in C_{ij}. The variation of 20, 10, 5 and –5 to –20% in C_{ij} resulted in –6.59%, –3.43%, –1.69% and 1.29% change in wheat crop area and 14.44%, 7.51%, 3.69% and –2.86`%, change in sunflower area, respectively (Figure 8).

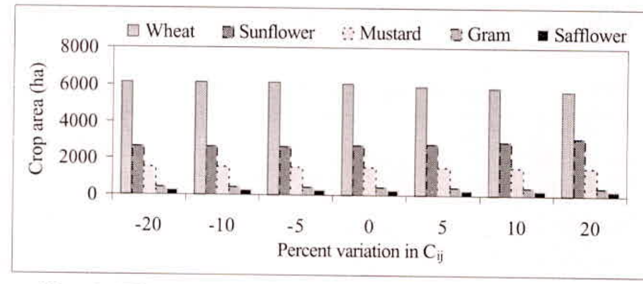

Fig. 8: Effect of percent variation in cost of cultivation (without irrigation cost) on crop area

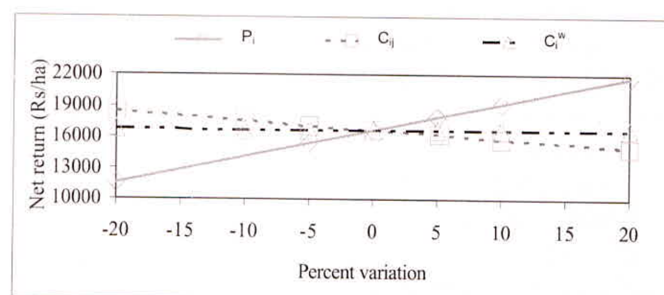

Fig. 9: Effect of input parameters on net return

SUMMARY AND CONCLUSIONS

The developed non-linear optimization model was used for selected five common crops, 100% of CCA under cultivation and minimum available irrigation water (35.334 Mm^3). The model gave the optimal solution comprising of total net seasonal profit of Rs. 18,49,50,800 which is about Rs. 16,653/ha. The optimal area of wheat, sunflower, mustard, gram and safflower was found to be 6227.70, 2746.38, 1554.90, 444.26 and 333.19 ha, respectively. The wheat was the most profitable crop followed by sunflower and was allocated about 54.27 and 24.73% area of the CCA, respectively. The model allocated the minimum area for the remaining three crops. Wheat occupied only clay loam whereas sunflower occupied sandy clay loam soil. Similarly, the mustard crop preferred clay and sandy clay loam soils, whereas safflower preferred clay loam and sandy clay loam soils. The gram preferred only clay loam soil. The net seasonal return of summer rice, Rs. 2,90,18,418 (about Rs. 14,183/ha), from average served area (2046 ha) was compared with the optimal cropping pattern. It was found that the Z value of optimal cropping pattern was higher than the summer rice because it takes 100% of CCA into account. The over all return from the command area can be raised more than five times (5.37) as compared to that of summer rice with the optimal cropping pattern and the minimum canal water availability. During the sensitivity analysis, the variations –20 to 20% change in sale price of crop; cost of cultivation (excluding irrigation cost) and cost of canal water were considered. The variation in sale price of crop resulted in linear trend with the higher rate of Z (–30.47 to 30.58%). The crop area of wheat and sunflower were changed whereas the cropped area for the other three crops (mustard, gram and sunflower) remained unchanged. The variations, –20 to 20% in the original value of cost of cultivation including irrigation cost resulted in linear and reverse trend with the lower rate in changing of net return (10.27 to –10.18%). The change in wheat and sunflower cropped areas were also noticed whereas cropped area for other three crops remained unchanged. The effect of change in all selected inputs parameters (P_i, C_{ij} and C_{iw}) on Z of the optimal solution revealed that the P_i is the most sensitive input parameter followed by C_{ij}. The C_i^w is found to be the least sensitive parameter since it did not change net return.

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