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A PROFIT OPTIMIZATION MODEL FOR AGRICULTURAL PRODUCTION

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Abstract: In this paper, we proposed a mathematical model for optimization of profit in agricultural production considering ecological, financial and irrigation constraint. The study aims to describe the profitability of the current crop production systems in the Ranchi district, calculate the annual production and profit that could result from optimal land use using linear programming and analyze how using linear programming, irrigation constraints might have a beneficial impact on irrigation efficiency and as a result, sustainable use of environmental and natural resources. We selected 6 crops (arhar, gram, maize, rapeseed and mustard, rice and wheat) for the purpose of study and collected data regarding agricultural practices such as land size, cost of production, productivity of crops per hectare, crop irrigated area etc. The study suggests that linear programming model might be applied to improve agricultural production's profitability.

Keywords: linear programming, irrigation, sustainable development, food crop, land use.

1. INTRODUCTION

Linear programming is a widely used optimization method for decision making in various sectors, such as public transportation, private and state industrial activities, and other resource allocation problems, including agricultural land use [1-5]. We use a land allocation approach based on linear programming to increase productivity and produce a profitable outcome for six crops that are commonly grown in the region. The purpose of this study is to investigate the possibility of linear programming-based land use modeling as a decision-making tool to improve crop production efficiency, which would in turn improve resource use efficiency and maybe boost profitability. To be more precise, this study aims to:

(1) Describe the profitability of the current crop production systems in Ranchi district;

(2) Using linear programming, calculate the annual production and profit that could result from optimal land use; and

(3) Analyze how using a linear programming irrigation constraint might have a positive impact on irrigation efficiency and, consequently, sustainable use of environmental and natural resources.

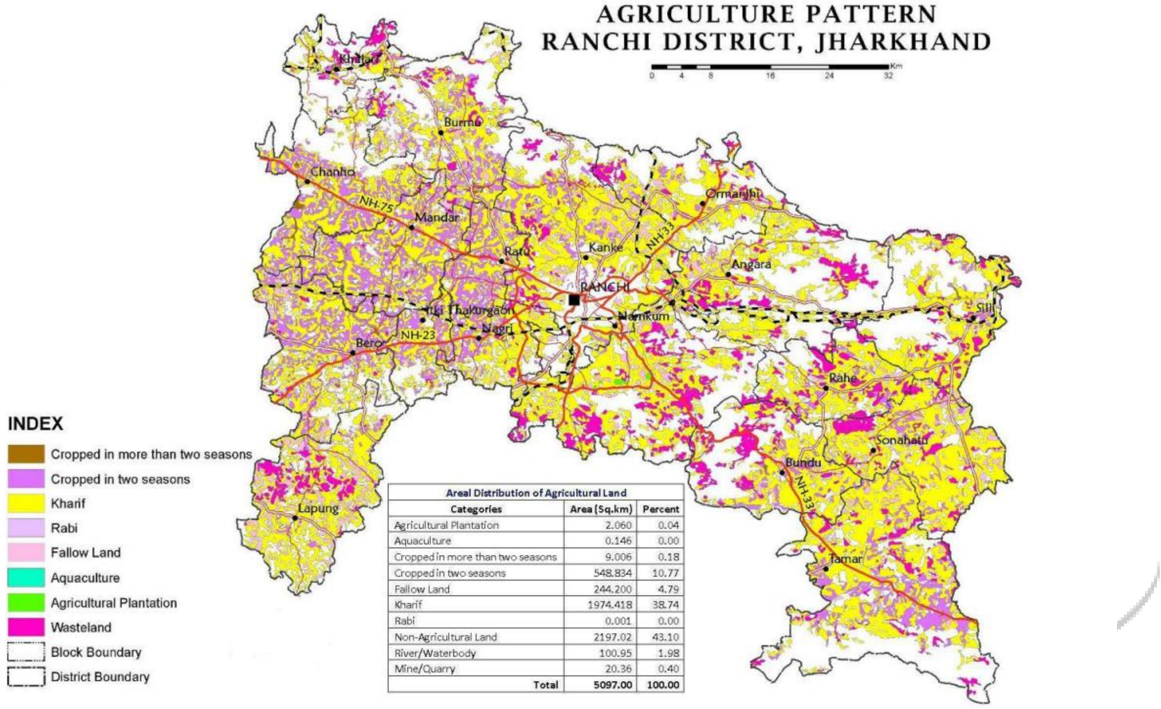
The population growth and shortage of food will consequently boost the demand for agricultural productions. Meanwhile, people's diet has been changing as well, mainly reflected in demanding for high-value animal protein. Furthermore, with the development of urbanization, infrastructures and buildings would take place of farmlands [6]. The smart irrigation decision support system (SIDSS) was proposed in a study [7]. Traditionally, irrigation activities are planned by an agronomist according to resources like collected meteorological data, crop characteristics, and soil measurements. The objective of the proposed SIDSS is to generate irrigation plans in a more efficient and accurate way with the same resources. With the help of SIDSS, irrigation activities can achieve better performances with the minimum water usages.

For the purpose of ensuring the best possible use of water, optimal agricultural patterns and linear programming (LP) were utilized to make decisions on irrigation water use alternatives. Due to the scarcity of water and land, irrigation management optimization has become a key and important issue for the agriculture sector. It is challenging to increase the cultivated area, resulting in a decrease in per capita land due to water constraints. This can be seen in the increasing food gap, and agriculture is going to face significant difficulties in the years to come. It is important to use new technological methods in agriculture and irrigation management since the two primary challenges for better agricultural production are the availability of more land for cultivation and sufficient irrigation water.

2. MATERIAL AND METHODS

2.1 DESCRIPTION OF THE STUDY AREA

Ranchi district is one of the twenty-four districts of Jharkhand state in eastern India. Ranchi district lies in the southern part of Jharkhand state. The district has total area of 5097 sq.km, and is located between 22°52'- 23° 45' North latitude to 84° 45'- 85° 50' East longitude. The density of population is 572 person per sq. Km. The total population of the Ranchi district as per the 2011 census is 29, 14, 253 persons. Total urban population is 12, 57, 335 and the rural population is 16, 56,918. Percentage of urban population is 56% and rural population is 44%. Ranchi is located in the southern part of the Chotanagpur plateau. The area receives a good amount of amount rainfall. It is characterized by Pre-monsoon, monsoon and post-monsoon. Population density of the district is 572 persons per square kilometre [8].



Categories	Area (Sq.km)	Percent
Agricultural Plantation	2.060	0.04
Aquaculture	0.146	0.00
Cropped in more than two seasons	9.006	0.18
Cropped in two seasons	548.834	10.77
Fallow Land	244.200	4.79
Kharif	1974.418	38.74
Rabi	0.001	0.00
Non-Agricultural Land	2197.02	43.10
River/Waterbody	100.95	1.98
Mine/Quarry	20.36	0.40
Total	5097.00	100.00

Source: Jharkhand space application centre.

Out of total geographical area of 5,09,700 hectares, forest area is 20.97%, land put to non-agricultural use is 5.6%, Barren land is 4.2%, current fallow is 16.35%, Land other than current fallow is 8.7%, Net area sown is 33.64%, cultivable waste land is 3.4% and area sown more than once is 2.21%. 89 % of Kharif crops are unirrigated and 4 % of Kharif crops are irrigated. 3 % of Rabi crops are irrigated and 2 % of Rabi crops are unirrigated. Only 2 % of summer crops are irrigated [9].

2.2 NATURE AND TYPE OF DATA

Data regarding crop production practices, such as land size, cost of production, productivity of crops per hectare, crop irrigated area were collected from websites of Government of India. Reports from Ministry of agriculture and farmers' welfare, irrigation census and other offices were also used.

2.3 MODEL DESCRIPTION

A linear program (LP) with the objective of model is to maximize productivity and profit, subject to constraints, including ecological constraints (total land available cannot be exceeded), crop budget constraints, and constraints on the amount of irrigation water and irrigation technology that can be used.

2.3.1 PROFIT MAXIMIZING OBJECTIVE

Since the main aim of the study was profit maximization and minimize the quantity of water with efficient use of water with technological advancements. The LP problem was to determine the area of land L_i, i = 1, 2, 3,... n which should be allocated for each crop selected to plant in the particular cropping season in order to maximize profit, given n crop choices practiced in the study area with productivity per unit of land q_i, i = 1, 2, 3,... n and total land size L subject to a given set of ecological, financial, limits of available irrigation water and an additional constraint for various irrigation methods.

Given the price $P_i, i = 1,2,3 \ldots n$ per kg of each crop and the $C_i, i = 1,2,3 \ldots n$ is the cost of production per unit land $L_i, i = 1,2,3 \ldots n$. The Profit from using L_i unit of i-th land considering its price P_i and q_i production per unit land is given by

$$\varphi = \sum_{i=1}^{n}(P_iL_iq_i - C_iL_i) \quad (1)$$

2.3.2 CONSTRAINTS

The Linear Programming model was estimated for the combined sample subject to the ecological constraint[10-13] that land allocated not exceed the total land suitable for selected crops in the region and with the financial constraint [14-16] that total expenditure not exceed the sum of total crop budget. Finally, we imposed additional constraints for available irrigation water and another for various irrigation methods available in the area.

Ecological Constraints

The total amount of land that is available for the production of the chosen crops (and is appropriate for cultivation during the specific cropping season) was calculated using the sum of the land allotted for crop production. Although the model may potentially include several kinds of additional natural restrictions, such as temperature, soil quality, resource availability, and geographic obstacles, we selected to keep things by just including the total area of the land. The sum of the land allocated among selected crops $L_i, i = 1,2,3\ldots n$ could not exceed the total land size L that is available for crop production.

$$\sum_{i=1}^{n} L_i \leq L \text{ (Aggregate Land)} \quad (2)$$

Aggregate Crop Budget Constraint

Studies indicate that financial access is one of the major constraining factors limiting the performance of smallholder agriculture in low-income countries [17]. The total cost per hectare for crop production could not exceed the annual aggregated crop budget(Y).

$$\sum_{i=1}^{n} C_iL_i \leq Y \text{ (Aggregate Crop Budget)} \quad (3)$$

Additional Constraints for Irrigation Method

The advantages and drawbacks of various strategies must be understood in order to choose an irrigation plan that is practicable. According to the local circumstances, farmers must be able to choose the optimal method to employ. However, because every method has advantages and disadvantages, it might be challenging to choose the optimum course of action. The variety of plants, the available techniques, past knowledge, the number of workers that are available, and the cost factor all have a role in the decision of whether to use surface, sprinkler, or drip irrigation.

Limits of available Irrigation Water

The amount of irrigation water allocated to the i-th crop should not exceed the total irrigation water. We are restricting the total allocation of irrigation water to not exceed the available water supply.

$$\sum_{i=1}^{n} i_iL_i \leq I, i_i \in I, i_i \geq 0 \quad (4)$$

(This condition applies when the rainfall is insufficient).

Irrigation Method

The sum of the products of each land size L_i and the efficiency of its irrigation method m_i should not exceed the total available irrigation method in that area which ensures that we are using irrigation methods efficiently across all the different lands while staying within the total land area.

$$\sum_{i=1}^{n} L_im_i \leq ML \quad (5)$$

Finally, the problem was reduced to the following linear program:

$$\text{Max. } \varphi = \sum_{i=1}^{n}(P_iL_iq_i - C_iL_i)$$

Subject to

$$\sum_{i=1}^{n} L_i \leq L \text{ (Aggregate Land)}$$

$$\sum_{i=1}^{n} C_iL_i \leq Y \text{ (Aggregate Crop Budget)}$$

$$\sum_{i=1}^{n} i_iL_i \leq I, i_i \in I, i_i \geq 0\text{(Availability of irrigation of water)}$$

$$\sum_{i=1}^{n} L_im_i \leq M\, L\text{(Irrigation method)}$$
$$and\ P_i, L_i, q_i, C_i, i_i, m_i \geq 0$$

Table 1: Details of some of the crops grown in the study area

Crop	Arhar	Gram	Maize	Rapeseed & Mustard	Rice	Wheat
Price (Rs. /Kg.)	88.27	66.93	9	8	25	24
Area (ha)	4814.67	4212.78	5579.11	5074.67	125832	6894.33
Cost of Production (Rs./Kg)	13.80	12.63	5.92	15.40	15	17.5
Yield(Kg./ha)	1020	1070	2570	800	2070	1820

Source: DAC & FW, Directorate of Economics & Statistics

Table 2: Crop irrigated area (in ha.) in Ranchi

Year	2015-16	2016-17	2017-18	2018-19	2019-20	2020-21	2021-22
Maize	146	151	212	159	1130	219	152
Rapeseed & mustard	110	10907	53	221	195	191	176
Rice	658	4627	3345	2843	1789	1346	1495
Wheat	2107	11845	1818	11622	11641	11223	10180

Source: aps.dac.gov.in/LUS/Public/Reports.aspx

Table 3: Source wise Net Irrigated area (ha.)

	2015-16	2016-17	2017-18	2018-19	2019-20	2020-21	2021-22
Canal	-	-	-	-	-	-	-
Tank	1496	10362	5247	7862	8168	7385	8024
well	9929	14785	8859	12915	11694	9676	6984
Other	2509	8753	2692	5010	4685	5083	6183
Total	13934	33900	16798	25787	24547	22144	21191

Source: aps.dac.gov.in/LUS/Public/Reports.aspx

Crop water needed

If in a particular area, a normal grass crop requires 5.5 mm of water per day, then maize will require 10% more water in the same area thus maize would require 6.1mm of water per day. The major climatic factors on crop water needs include temperature, humidity, wind speed, and sunshine. We used the Blaney-Criddle Method [18] to determine crop evapotranspiration (ET_0) by taking grass as a reference crop.

$$ET_0 = p(0.46\, T_{mean} + 8)$$

Table 4: Estimation of Mean Temperature

Month	T_{max}	T_{min}	T_{mean}	p	ET_0(mm/day)
Jan	24	8	16	0.24	3.69
Feb	29	12	20.5	0.26	4.53
March	34	17	25.5	0.27	5.32
April	39	22	25.5	0.29	5.72
May	40	24	32	0.30	6.82
June	36	25	30.5	0.31	6.83
July	31	24	27.5	0.31	6.42
August	29	23	26	0.29	5.79
September	29	22	25.5	0.28	5.52
October	28	19	23.5	0.26	4.89
November	26	13	19.5	0.25	4.24
December	24	9	16.5	0.24	3.74

The average temperature from 2010 to 2020 has been calculated. T_{mean} stands for mean daily temperature in degrees Celsius, and p for mean daily percentage of sunlight in a year. Using the p-table for different latitudes, p was determined using Ranchi's latitude of 25 degrees north.

The crop factor K_c, determines the connection between the grass crop and the crop that is actually cultivated. It is mainly affected by the type of crop, the crop's growth stage, and the environment. In order to calculate the crop factor, it is important to know the durations of each crop's distinct growth phases as well as the length of the whole growing season.

$$ET_0 \times K_c = ET_{crop}$$

Table 5: Total growing period of Maize and Wheat

Crop	Total days	Initial stage	Crop development stage	Mid-season stage	Late season stage
Maize(sweet)	80	20	25	25	10
	110	20	30	50	10
wheat	120	15	25	50	30
	150	15	30	65	40

Since maize (sweet) is cultivated all year round. Considering March 1 as the date for planting.

Table 6: Day-wise growing period of Maize

Planting day		**1 March**
Initial phase	20 days	1 March-20 March
Crop dev. phase	25 days	21 march-15 April
Mid-season phase	25 days	16 April-10 May
Late season phase	10 days	11 May- 20 May
The Last day of harvest		20 May

Climate has an impact on the length of the entire growing season and the different growth phases. For the months of March, April, and May, the research area's relative humidity is considered to be 30%, 29%, and 37%, respectively, and wind-speed 10.9mph, 10.3mph and, 10.6mph respectively.

Table 7: Crop water need of Maize

Month	March	April	May
$\boldsymbol{ET_0}$	5.32	5.72	6.82
$\boldsymbol{K_C}$	0.53	1.01	0.72
$\boldsymbol{ET_{crop}}$ (mm/day)	2.82	5.78	4.910
$\boldsymbol{ET_{crop}}$ (mm/month)	84.6	173.4	147.8

The crop water needed for the whole growing season of maize is 405.3 mm. Also from Table 2, it is clear that the crop irrigated area for maize is 146, 151, 212,159, 1130,219,152 from 2015-2022.

The exception is paddy rice, which grows with "its feet in the water". Water is required not just for irrigation or rainfall to meet the crop's water needs, but also for soil saturation prior to planting, percolation and seepage losses, and the creation of a water layer. Farmers during the irrigation process may face the following conditions:

Case 1: If rainfall provides all the water required for the crop to develop to its full potential; therefore, irrigation is not necessary and the Irrigation water need is equal to zero.

$IWN = 0$

Case 2: If there is no rain at all throughout the growing season, irrigation is required to provide all water.

$IWN = ET_{crop}$

Case 3: If irrigation provides the remaining part of the crop's water needs and rainfall provides the rest.

$IWN = ET_{crop} - P_e$

Where, P_e is the part of the rainfall that is effectively used by the crop.

The total growing period of rice is 130 days. The value of crop factor is 1.10, 1.20, and 1 for the initial 60 days, mid-season (40 days), and last 30 days respectively.

Saturation requirement= 200 mm (July)

Percolation and seepage=6mm/day= 180mm/month

Establishment of water layer=100 mm (August)

Table 8: Estimation of water for Rice

	July	August	September	October	November	December
ET_0(mm/day)	6.42	5.79	5.52	4.89	4.24	3.74
K_c(/month)	-	1.10	1.10	1.20	1.07	1
ET_{crop}(mm/day)	-	4.6	5.0	5.3	5.4	5.3
ET_{crop}(mm/month)	-	138	150	159	162	53
Saturation	200	-	-	-	-	-
Percolation(mm/month)	-	180	180	180	180	60
Water Layer(mm)	-	100	-	-	-	-

Since the area of study receives less than 75mm of rainfall every month. So we obtained the effective rainfall by the formula

$P_e = 0.6P - 10$(mm/month), $P_e \geq 0$, and $IWN = ET_{crop} + SAT + PERC + WL - P_e$

Table 9: Estimation of irrigation water need for Rice

Month	Jan	Feb	Mar	April	May	June	July	Aug	Sep.	Oct	Nov	Dec
P	12.4	9.2	7.6	7.3	24.7	13.8	18.4	17.9	17.6	16.4	8.0	15.1
P_e	0	0	0	0	4.82	0	1.04	0.74	0.56	0	0	0
IWN (mm/month)	-	-	-	-	-	-	63	417.26	329.44	339	342	113
IWN (mm/day)	-	-	-	-	-	-	2.1	13.91	10.98	11.3	11.4	11.3

The irrigation water needed for the whole growing season of Rice is 1603.7mm.

Adopting new technologies to increase irrigation efficiency is a tool rather than an end. Improved environmental conditions, higher agriculture yields and better-quality crops, less labor-intensive irrigation, and possibly more water available for irrigation or other uses.

Irrigation efficiency is given by

$$E_I = \frac{A - E - R - P}{A}$$

Where,

E_I = Irrigation Efficiency

A = Amount of water applied to field.

E = Amount of water evaporated during application

R = Amount of water which runs off the field.

P = Amount of water deep percolated below root zone.

The values of the variables A, E, R, and P for maize irrigation are 800, 100, 50, and 150 (in liters), however, these values can vary depending upon factors like irrigation method, climate, soil type, etc. The irrigation efficiency for maize will be 62.5% which indicates that 62.5% of the water applied to maize field is effectively used for irrigation, while the remaining 37.5% is lost through evaporation, runoff, and deep percolation.

3. RESULT

To resolve the optimization problem, the linear programming tool LINGO 20.0 software is used. The obtained result indicates that the total profit using the proposed model is Rs. 652330.4. with values of the variable 7.246377, 0, 0, 0, 0,0 and value of reduced cost is 0, 10786.86, 15493.88, 94074.29, 46114.57, 70495.33 which means L_2, L_3, L_4, L_5, L_6 can be increased before it becomes economically advantageous to bring these variables into the optimal solution. Also, the value of reduced cost is positive suggesting that increasing the value of these variables by a small amount could lead to an improvement in the overall objective function value of the problem which indicates that profit could be increased by increasing the coefficients of objective function. The sensitivity of the coefficient of $L_1$is found by examining the reduced cost of L_1. The reduced cost of a variable measures how much the objective function value would increase or decrease if the coefficient of that variable were to change by one unit while keeping all other parameters constant. In Lingo output, the reduced cost for L_1 is 0. The existing solution is therefore not sensitive to variations in the coefficient of L_1, according to this. The present optimal solution will not change whether the coefficient of L_1 is increased or lowered by one unit. The optimum solution is insensitive to changes in the coefficient of L_1, as shown by the zero coefficient of L_1 sensitivity. L_2, L_3, L_4, L_5 and, L_6, whose values have non-zero reduced costs, are sensitive to changes in the coefficients of those variables. The value of the objective function would increase by about 10,786,86,15,493.88, 94,074,29,46,114.57,70,495.33 units, respectively, for each unit increase in the coefficient . L_2, L_3, L_4, L_5 and, L_6.

CONCLUSION AND FUTURE WORK

It is an area where the farmer needs guidance about agricultural operations such as scheduling equipment for agricultural use, economic, and social, and optimizing the planting pattern, and agricultural land, etc. to maximize income. For optimum agricultural production, the proper use of land, crop, soil, and water resources is necessary. Unfortunately, due to illiteracy, farmers have faced challenges in making the right decision regarding what to grow, which season, and within available resources. The present technique of micro irrigation (MI), which comprises drip and sprinkler irrigation, offers a very substantial benefit in this context. Improving efficiency is of utmost importance. The model may be improved such that it has additional capabilities and is integrated with modern technology, such as the Internet of Things, Artificial Intelligence, Remote sensing, Cloud computing, etc. to track and plan cropping patterns which will improve agricultural efficiency.

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