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# Optimizing Crop Planning for Smallholder Farmers: A Fuzzy Multi-Objective Linear Programming Approach

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Fuzzy Multi-Objective Linear Programming, Crop Optimization, Smallholder Farmers, LINGO software.

**Abstract**

This studyis to optimize crop production planning for smallholder farmers using a fuzzy multi-objective linear programming model. For this Sadapkpor village of Navsari, Gujarat farmers agricultural data used for decision-making in this region.Thefuzzy logic was used to stochastic the variables, including fluctuating market prices and volatile input costs. The proposed model addresses these uwncertainties, allowing farmers to balance conflicting objectives like maximizing total profit, minimizing production costs, and optimizing financial risk. The model was solve using LINGO software, and the results of the proposed model given the best crop plans that help farmers to optimize cost and utilize land properly compared to the traditional methods.Overall, this framework offers smallholder farmers a practical and data-driven tool for more resilient and profitable crop planning under uncertainty.

## Introduction

In India, agricultural planning is one of the important factors required to enhance as it affects both the economy and people's lives. Especially, our country has natural resources such as fertile soil, various seasons, and climates that allow a wide range of crops to grow. However, small farmers often face challenges to use land effectively and have good profit. Farmers must decide which crops to grow, how to manage resources, and how to optimize the costs and increase the yield. These decisions are difficult for the farmers as it often involves conflicting goals. The cost of such farmers is increased if proper use of fertilizer and water is not used as per the crop needs. In addition, fixed planning method is less effective due to the uncertainties in weather, market prices, and other available inputs. To deal with such uncertainties and risk, a fuzzy multi-objective decision making approaches is developed to balanced such multiple goals under changing conditions.

In 1978, Zimmermann [14, 15] has introduced first time fuzzy mathematical programming, and was modified by Slowinski [12]. Fuzzy goal programming is used widely in agricultural planning to handle fuzziness in data and objectives. Similar study was also carried out by Sinha [11] and Sumpsi et al. [13] for the agricultural planning where objectives and constraints were not clearly defined. Sharma et al. [9] and Pal et al. [7] successfully used fuzzy goal programming tooptimize land and water to get well crop yields. Many other researchers like Igwe and Onyenweaku [2], and Bhatia and Rana [1] used linear programming to optimize crop and resource allocation. In past year Malik et al. [5] have applied fuzzy goal programming to solved the agricultural problems, while Sridevi Polasi and Shalini [8] have compared the crop planning using goal programming and R programming to encourage balanced farming. Such developments have helped to solve complex agricultural problems.

Recent studies in crop planning have increasingly adopted probabilistic and optimization-based frameworks to address uncertainty. Shete [10] has developed an integrated model combining classical probability, Bayesian updating, regression forecasting, and linear programming to optimize crop mix under variable rainfall in semi-arid Maharashtra, maximizing expected profit while respecting land, water, and cost constraints. Similarly, Lavika et al. [4] have applied hybrid nature-inspired optimization algorithms for crop classification using satellite data, achieving over 94% accuracy for Kharif and Rabi seasons in Rajasthan. Jat et al. [3] demonstrated that system optimization practices with zero tillage and legume inclusion improved yields by 26 - 37% and reduced water use by over 1000 ha-mm in the IndoGangetic Plains. Complementing these, Mishra et al. [6] proposed an augmented reality-based mobile decision support system integrating soil macronutrients and climatic variables for real-time crop recommendations. Collectively, these studies highlight a paradigm shift toward data-driven, farmer-centric crop planning that balances economic returns with environmental sustainability.

This study focuses on the Sadakpor village, Navsari. The Navsari district covers an area of about 2,196 square kilometres, in which 1,36,405 hectares are cultivable, with 89,799 hectares under irrigation and 46,606 hectares dependent on rainfall. The average annual rainfall is about 1,864 mm. Other land uses include forest, wasteland, pasture land, non-agricultural areas, and plantations. Farmers in this village grow crops such as rice, chana, juwar, mung, maize, turmeric, cucumber, brinjal, tomato, sugarcane, tapioca, and fruits like banana and mango. As a result, farmers face a difficult choice either take on too much financial risk or miss out on potentially higher profits. Standard linear programming models, despite their usefulness, cannot capture the uncertainty that is part of everyday agriculture. To address this limitation, the present research aims to develop an efficient crop planning model that improves productivity, profitability, and sustainable use of resources in the village Sadakpor.

The research work is to analyse the crop combination to maximize the revenues of the small farmer. The study mainly focuses on creating a multi-objective optimization model that considers productivity, profitability, and sustainability in crop planning. Further, the model is solved using suitable optimization methods and tested using real data from smallholder farming areas. In addition, the research aims to provide useful tools or guidelines that can help small farmers and policymakers make better decisions for sustainable crop production.

## Mathematical Preliminaries

This section presents some important definitions and results that will be needed later.

### FuzzySet:

If U isauniversalsetand $y \in U$ then an fuzzy set $\tilde{A}$ definedonU isgivenby $\tilde{A} = \{(y, \xi(y)) : y \in U\}$, Where $\xi(y)$ is called membership function and $\xi(y)$ can be written as $\xi(y) : U \to [0,1]$ and $y \in U$ denote the elements belonging to the universal set.

### LinearMembershipFunction:

$$\xi(y) = \begin{cases} 1 & \text{if } y > b_1 \\ \dfrac{y - a_1}{b_1 - a_1} & \text{if } a_1 \le y \le b_1 \\ 0 & \text{if } y \le a_1 \end{cases} \tag{1}$$

### Fuzzy Set Operations

Let $\tilde{A}, \tilde{B}$ and $\tilde{C}$ be three fuzzy sets defined on the universal set U then for a given element y of the universal set U, the following set theoretic operations of union, intersection and complement are defined as:

Union. $$\xi_{\tilde{A} \cup \tilde{B}}(y) = \text{Max}\left(\xi_{\tilde{A}}(y), \xi_{\tilde{B}}(y)\right) \tag{2}$$

Intersection. $$\xi_{\tilde{A} \cap \tilde{B}}(y) = \text{Min}\left(\xi_{\tilde{A}}(y), \xi_{\tilde{B}}(y)\right) \tag{3}$$

Complement. $$\xi_{\widetilde{A^C}}(y) = 1 - \xi_{\tilde{A}}(y) \tag{4}$$

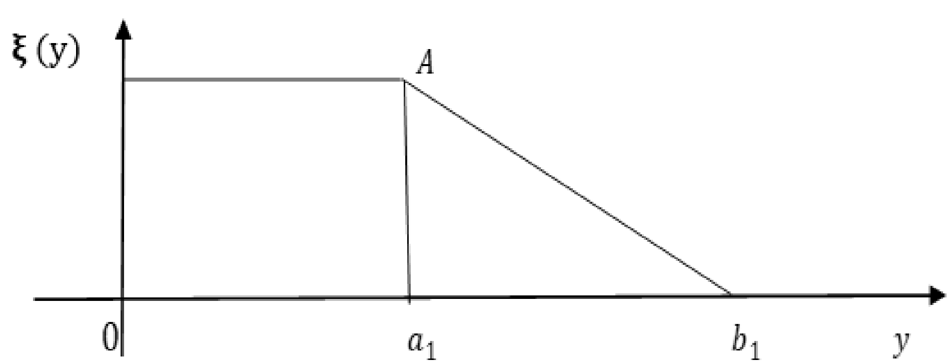


**Figure 1:** Linear Membership Function

**Linear Programming Problem**

Linear programming is an optimization method applicable for solving problems in which the objective function and the constraints equations appear as linear functions of the decision variables. This optimization problem was first recognized in 1930 by economistic Dantzig & Thapa (1963) formulated the general LPP and devised the simplex solution method. Linear programming problem in standard form can be stated as

$$\text{Maximize } \mathrm{G} = \sum_{\mathrm{j}=1}^{\mathrm{t}} \mathrm{c}_{\mathrm{j}} \mathrm{y}_{\mathrm{j}} \tag{5}$$

$$\text{such that} \sum_{j=1}^{t} c_j y_j \le b_i, i = 1, 2, \ldots, r \tag{6}$$

$$y_j \ge 0, j = 1, 2, \ldots, t \tag{7}$$

$$\text{where} U = \{y_1, y_2, \ldots, y_t\}$$

**Multi-Objective Linear Programming Problem:**

In general, a multi objective linear programming problem with $k$ objective functions, $n$ variables and $m$ constraints is as given below:

$$\text{Max}\left\{G_1(y), G_2(y), G_3(y), \ldots, G_k(y)\right\} \tag{8}$$

$$\text{subject to} B_i(y) \le \beta_i \;\; \forall\, i = 1, 2, \ldots, r, \tag{9}$$

$$y_j \ge 0, j = 1, 2, \ldots, t \tag{10}$$

$$\text{where} \beta = \{\beta_1, \beta_2, \ldots, \beta_r\}, U = \{y_1, y_2, \ldots, y_t\}, B = B_{r \times t}$$

**Complete Solution:**

For the above problem (2.5), $y^0$ is said to be the complete solution if there exists $y^0 \in U$ such that $f_m(y^0) \ge f_m(y), m = 1, 2, \ldots, k$ *for all* $y \in U$. However, in general, such complete optimal solutions simultaneously maximize all of the conflicting multi objective functions. Thus, instead of a completely optimal solution, a solution concept called Pareto optimality was introduced in multi objective programming

**Pareto Optimality**

From the above problem (2.5), $y^0 \in U$ is said to be Pareto optimal solution if there does not exist another $y \in U$ such that

$f_m(y^0) \ge f_m(y), \forall\, m = 1, 2, \ldots, k$ and $f_n(y^0) < f_n(y)$ for at least one $n \in 1, 2, \ldots, k$.

**Linear Fractional Programming Problem**

Let there be s objectives out of k objectives so that their ratio maximizes. For simplicity, let us restrict a number of such objectives to two and let these two linear objectives be $f_m(y) > 0$ *and* $f_n(y) > 0$ whose ratio forms a new objective function, giving rise to Linear fractional programming problem as:

$$\text{Maximize} \frac{f_m(y)}{f_n(y)} \tag{11}$$

**Fuzzy Linear Programming Problem:**

A Linear programming problem in which all the parameters are fuzzy numbers is called Fuzzy Linear Programming Problem is considered as:

$$\text{Maximize}\, G = \sum_{j=1}^{t} \widetilde{c_j} y_j \tag{12}$$

$$\text{such that} \sum_{j=1}^{t} \tilde{A}_{ij} y_j \leq \tilde{B}_i, i = 1, 2, \ldots, r \tag{13}$$

$$y_j \geq 0, j = 1, 2, \ldots, t \tag{14}$$

where $\widetilde{A_{ij}}$ , $\widetilde{B_i}$ *and* $\widetilde{c_j}$ *are* fuzzy numbers.

**Fuzzy Multi-Objective Linear Programming (FMOLP) model**

The proposed model deals with crop production planning, where available land is allocated to different crops using a fuzzy multi-objective approach. In this model, land is allocated to crops to get worthy production while controlling investment costs. Also, fuzzy membership is used to represent the degree of satisfaction of the objectives and constraints. Its parameters, decision variables, objectives, and constraints are defined as follows:

$P_i$ = Production per unit area of the i$^{th}$ crop,

$C_i$ = Profit per unit area of the i$^{th}$ crop,

$I_i$ = Investment required per unit area of the i$^{th}$ crop,

$L_i$ = Labour required per unit area of the i$^{th}$ crop,

$L_d$ = Total available cultivable land,
L = Total available labour,
F = Total available fertilizer,

$P_e$ = Minimum required production,

$U_{B_m}$ = Upper bound of the m$^{th}$ objective function. For m = 1, 2, …, r+t,

$L_{B_m}$ = Lower bound of the m$^{th}$ objective function. For m = 1, 2, …, r+t,
α = Minimum degree of membership (DoM) of objectives and constraints,

Decision variables:Land allocated to the i$^{th}$ crop during j$^{th}$ season is $y_{i,j}$, for i = 1,2, …, r and j=1,2, …, t (season).

Maximize Production: The total production obtained from all crops is represent as $D_1(y)$. It is defined as a linear combination of decision variables and production coefficients.

$$D_1(y) = \sum_{i=1}^{r}\sum_{j=1}^{t} P_i y_{i,j} \tag{15}$$

Maximize Profit: The total profit earned from all crops is represent as $D_2(y)$.

$$D_2(y) = \sum_{i=1}^{r}\sum_{j=1}^{t} C_i y_{i,j} \tag{16}$$

Minimize Investment: The total investment required for all crops is represent as $D_3(y)$.

$$D_3(y)=\sum_{i=1}^{r}\sum_{j=1}^{t}I_i y_{i,j} \tag{17}$$

The two economic objectives, profit $D_2(y)$ and investment $D_3(y)$ are combine using fractional programming. The revised multi-objectives are $D_1(y)$ remain unchanged as $G_1(y)$, and the two objectives are converted into a single objective function $G_2(y)$ given as equation (12) and (13) below.

$$G_1(y)=\sum_{i=1}^{r}\sum_{j=1}^{t}P_i y_{i,j} \tag{18}$$

$$G_2(y)=\frac{D_2(y)}{D_3(y)}=\frac{\sum_{i=1}^{r}\sum_{j=1}^{t}C_i y_{i,j}}{\sum_{i=1}^{r}\sum_{j=1}^{t}I_i y_{i,j}} \tag{19}$$

Production Constraint: The maximum production ( $P_i$ ) can obtain from the crop by ensuring that at least it is greater than or equal to the required minimum production level ( $P_e$ ).

$$\sum_{i=1}^{r}\sum_{j=1}^{t}P_i y_{i,j}\geq P_e \tag{20}$$

Land Constraint: The land availability constraint ensures that, in each planning period, the total land allocated to all crops does not exceed the available land.

$$\sum_{i=1}^{r}\sum_{j=1}^{t}y_{i,j}\leq L_d \tag{21}$$

Fertilizer Constraint: The fertilizer availability constraint ensures that, in each planning period, the total amount of fertilizer used by all crops does not exceed the available fertilizer.

$$\sum_{i=1}^{r}\sum_{j=1}^{t}F_i y_{i,j}\leq F \tag{22}$$

Labour Constraint: The labour availability constraint ensures that, in each planning period, the total labour required for cultivating all crops does not exceed the available labour.

$$\sum_{i=1}^{r}\sum_{j=1}^{t}L_i y_{i,j}\leq L \tag{23}$$

Upper Bound ($U_B$): The upper bound of an objective function represents the (maximum acceptable) value of that objective, obtained by optimizing it individually under the given constraints.

$$U_{Bm}^{\xi}=\max\left(G_m\left(y_d\right)\right),\ 1\leq d\leq m \tag{24}$$

Lower Bound ($L_B$): The lower bound of an objective function represents the (minimum acceptable) value of that objective among all individual optimal solutions.

$$L_{Bm}^{\xi} = \min\left(G_m\left(y_d\right)\right), 1 \le d \le m \tag{25}$$

Positive Ideal Solution: The positive ideal solution of all objective functions is found by optimizing each objective separately while keeping the same constraints, and it is used as a reference point to compare the solution as fuzzy multi objective optimization.

Membership Function (MF): The membership function measures the degree of satisfaction of an objective. Its value lies between 0 and 1. A higher value indicates better achievement of the objective.

$$\xi\left(G_m\left(y\right)\right) = \begin{cases} 0 & \text{if } G_m\left(y\right) \le L_{Bm}^{\xi} \\ \dfrac{G_m\left(y\right) - L_{Bm}^{\xi}}{U_{Bm}^{\xi} - L_{Bm}^{\xi}} & \text{if } L_{Bm}^{\xi} \le G_m\left(y\right) \le U_{Bm}^{\xi} \\ 1 & \text{if } G_m\left(y\right) \ge U_{Bm}^{\xi} \end{cases} \tag{26}$$

Transformation of FMOLP into LPP: Using the max-min fuzzy decision method, the FMOLP is transformed into the following Linear Programming Problem (LPP).

$$\max \alpha$$

$$such\,that\;\; \xi(G_m\left(y\right)) = \frac{G_m\left(y\right) - L_{Bm}^{\xi}}{U_{Bm}^{\xi} - L_{Bm}^{\xi}} \ge \alpha, \tag{27}$$

where $0 \le \alpha \le 1$ i.e., $G_m\left(y\right) - \alpha\left(U_{Bm}^{\xi} - L_{Bm}^{\xi}\right) \ge L_{Bm}^{\xi}$ and using equation (20) to (23).

## Numerical Illustrations of Case study for the Proposed FMOLP Model

The goal of this problem is to maximize crop production and profit. A case study was conductedin Sadakpor, Navsari, Gujarat, to show how fuzzy multi-objective approaches can help small farmers to plan their crops better. Farmers in this area grow different crops in three main seasons. In the Kharif season, they grow Cucumber and Rice. In the Rabi season, they grow Chora,

**Table 1:** Data Description for Utilization of Productive Resources, Production Rate, And Profit of Navsari District

| *Seasons* | *Name of Crops* | *Labour (man day/ha)* | *Fertilizer for the crops* | | *Production (Kg/ha)* | *Investment (Rs/ha.)* | *Return (Rs. /ha)* |
|---|---|---|---|---|---|---|---|
| | | | *NPK (Kg/ha)* | *Pesticide (Kg/ha)* | | | |
| Kharif | Cucumber ($y_{1,1}$) | 385 | 90 | 22 | 30000 | 36000 | 2,70,000 |
| | Rice ($y_{2,1}$) | 340 | 200 | 15 | 885 | 9500 | 40,710 |
| Rabi | Chora ($y_{3,2}$) | 283 | 25 | 18 | 6000 | 4250 | 66,000 |
| | Chana ($y_{4,2}$) | 55 | 20 | 15 | 612 | 1400 | 24,480 |
| | Jowar ($y_{5,2}$) | 180 | 30 | 15 | 325 | 2500 | 15,925 |
| | Mung ($y_{6,2}$) | 157 | 20 | 12 | 50 | 1900 | 3,500 |
| | Maize ($y_{7,2}$) | 135 | 90 | 12 | 225 | 4500 | 9,675 |
| | Rice ($y_{8,2}$) | 475 | 40 | 27 | 765 | 16000 | 35,190 |
| | Raw Turmeric ($y_{9,2}$) | 720 | 400 | 35 | 6000 | 140000 | 6,00,000 |
| | Turmeric ($y_{10,2}$) | 650 | 400 | 35 | 12000 | 104000 | 6.00,000 |
| Summer | Brinjal ($y_{11,3}$) | 275 | 320 | 38 | 24000 | 106000 | 3,60,000 |
| | Cucumber ($y_{12,3}$) | 195 | 20 | 20 | 5500 | 25000 | 104,000 |
| | Suran ($y_{13,3}$) | 675 | 800 | 155 | 12000 | 1,50,000 | 5,40,000 |
| | Green Chilli ($y_{14,3}$) | 135 | 240 | 25 | 17000 | 2,40.000 | 7,48,000 |

Chana, Jowar, Mung, Maize, Raw Turmeric, and Turmeric. In the Summer season, they grow Brinjal, Cucumber, Suran, and Green Chilli. In this study, the small farmers of Sadakpor have 3.75 hectares of land available for each season, and 1,350 man-days of labour available for each season given in below table 1. In addition, the farmer has 2,500 kg of fertilizer and 450 kg of pesticide available for crop production. The goal of the model is to find the combination of crops that maximizes profit and production while meeting the minimum requirements for food grains, land, and labour. The farmer needs at least 24,500 kg of Cucumber, 1,652 kg of Rice, 3,573 kg of Chora, 245 kg of Jowar, 35 kg of Mung, 125 kg of Maize, 3,450 kg of Raw Turmeric, 6,780 kg of Turmeric, 22,575 kg of Brinjal, 9,500 kg of Suran and 10400 of green chilli.
The mathematical formulation as a multi-objective linear programming problem is as follows:
Production:

$$\begin{aligned}\text{Maximize, } D_1 &= 30000y_{1.1} + 885y_{2.1} + 6000y_{3.2} + 612y_{4.2} + 325y_{5.2} + 50y_{6.2} \\ &+ 225y_{7.2} + 765y_{8.2} + 6000y_{9.2} + 12000y_{10.2} + 24000y_{11.3} \\ &+ 5500y_{12.3} + 12000y_{13.3} + 17000y_{14.3}\end{aligned} \tag{28}$$

Return

$$\begin{aligned}\text{Maximize, } D_2 &= 270000y_{1.1} + 40710y_{2.1} + 66000y_{3.2} + 24480y_{4.2} + 15925y_{5.2} \\ &+ 3500y_{6.2} + 9675y_{7.2} + 35190y_{8.2} + 600000y_{9.2} + 600000y_{10.2} \\ &+ 360000y_{11.3} + 104000y_{12.3} + 540000y_{13.3} + 748000y_{14.3}\end{aligned} \tag{29}$$

Investment:

$$\begin{aligned}\text{Minimize, } D_3 &= 36000y_{1.1} + 9500y_{2.1} + 4250y_{3.2} + 1400y_{4.2} + 2500y_{5.2} \\ &+ 1900y_{6.2} + 4500y_{7.2} + 16000y_{8.2} + 140000y_{9.2} + 104000y_{10.2} \\ &+ 106000y_{11.3} + 25000y_{12.3} + 150000y_{13.3} + 240000y_{14.3}\end{aligned} \tag{30}$$

Using fractional programming problem. converted two the objective ($D_2$) and ($D_3$) into one objective as $G_2(y)$ and $G_1(y) = D_1(y)$. thus, the above problem is reduced to following fractional programming problem.

$$\begin{aligned}\text{Maximize, } G_1 &= 30000y_{1.1} + 885y_{2.1} + 6000y_{3.2} + 612y_{4.2} + 325y_{5.2} + 50y_{6.2} \\ &+ 225y_{7.2} + 765y_{8.2} + 6000y_{9.2} + 12000y_{10.2} + 24000y_{11.3} \\ &+ 5500y_{12.3} + 12000y_{13.3} + 17000y_{14.3}\end{aligned} \tag{31}$$

$$\begin{aligned}\text{Maximize, } G_2 &= 234000y_{1.1} + 31210y_{2.1} + 61750y_{3.2} + 23080y_{4.2} + 13425y_{5.2} + 1600y_{6.2} \\ &+ 5175y_{7.2} + 19190y_{8.2} + 460000y_{9.2} + 496000y_{10.2} + 254000y_{11.3} \\ &+ 79500y_{12.3} + 390000y_{13.3} + 508000y_{14.3}\end{aligned} \tag{32}$$

Such that
Land Requirement:

$$\left.\begin{aligned} y_{1.1} + y_{2.1} &\le 3.75 \\ y_{3.2} + y_{4.2} + y_{5.2} + y_{6.2} + y_{7.2} + y_{8.2} + y_{9.2} + y_{10.2} &\le 3.75 \\ y_{11.3} + y_{12.3} + y_{13.3} + y_{14.3} &\le 3.75 \end{aligned}\right\} \tag{33}$$

Labour Requirement:

$$\left.\begin{aligned} 385y_{1.1} + 340y_{2.1} &\le 1350 \\ 283y_{3.2} + 55y_{4.2} + 180y_{5.2} + 157y_{6.2} + 135y_{7.2} + 475y_{8.2} + 720y_{9.2} + 650y_{10.2} &\le 1350 \\ 275y_{11.3} + 195y_{12.3} + 675y_{13.3} + 135y_{14.3} &\le 1350 \end{aligned}\right\} \tag{34}$$

Fertilizer Requirement:

$$\begin{aligned}&90y_{1.1} + 200y_{2.1} + 25y_{3.2} + 20y_{4.2} + 30y_{5.2} + 20y_{6.2} + 90y_{7.2} + 40y_{8.2} + 400y_{9.2} \\ &+ 400y_{10.2} + 320y_{11.3} + 20y_{12.3} + 800y_{13.3} + 240y_{14.3} \le 2500\end{aligned} \tag{35}$$

$$\begin{aligned}&22y_{1.1} + 15y_{2.1} + 18y_{3.2} + 15y_{4.2} + 15y_{5.2} + 12y_{6.2} + 12y_{7.2} + 27y_{8.2} + 35y_{9.2} \\ &+ 35y_{10.2} + 38y_{11.3} + 20y_{12.3} + 155y_{13.3} + 25y_{14.3} \le 450\end{aligned} \tag{36}$$

Production Requirements:

$$\left.\begin{array}{l} 885y_{2.1} + 765y_{8.2} \geq 1652 \\ 30000y_{1.1} + 5500y_{12.3} \geq 24500 \\ 6000y_{3.2} \geq 3573 \\ 325y_{5.2} \geq 245 \\ 50y_{6.2} \geq 35 \\ 225y_{7.2} \geq 125 \\ 6000y_{9.2} \geq 3450 \\ 12000y_{10.2} \geq 6780 \\ 24000y_{11.3} \geq 22575 \\ 12000y_{13.3} \geq 9500 \\ 17000y_{14.3} \geq 10400 \\ y_i \geq 0, i = 1,2,\ldots,14 \end{array}\right\} \quad (37)$$

Solving this linear programming problem using Lingo the value obtained for the objective function ($G_1$) is given in the below Table 2.

**Table 2:** Objective function $G_1$ LINGO output for the season wise crop allocation

| *Name of crops* | *Lingo output for $G_1(y)$* | *Name of crops* | *Lingo output for $G_1(y)$* |
|---|---|---|---|
| $y_{1.1}$ | 1.8619 ha. land for Cucumber | $y_{8.2}$ | 0.0000 ha. land for Rice |
| $y_{2.1}$ | 1.8622 ha. land for Rice | $y_{9.2}$ | 0.5750 ha. land for Raw Turmeric |
| $y_{3.2}$ | 0.5955 ha. land for Chora | $y_{10.2}$ | 0.5650 ha. land for Turmeric |
| $y_{4.2}$ | 0.0000 ha. land for Chana | $y_{11.3}$ | 1.9173 ha. land for Brinjal |
| $y_{5.2}$ | 0.7538 ha. land for Jowar | $y_{12.3}$ | 0.4293 ha. Land cucumber |
| $y_{6.2}$ | 0.7000 ha. land for Mung | $y_{13.3}$ | 0.7917 ha. Land for Suran |
| $y_{7.2}$ | 0.5556 ha. land for Maize | $y_{14.3}$ | 0.6118 ha. Land for green chilli |

Therefore, Production: $(G_1\ (y))_1$ = 1,39,992.7 kg andProfit. $(G_2\ (y))_1$ = Rs 22,30,219.852 /-

Solving this linear programming problem using Lingo the value obtained for the objective function ($G_2$) is given in the Table 3.

**Table 3:** Objective function $G_2$ LINGO output for the season wise crop allocation

| *Name of crops* | *Lingo output for $G_2(y)$* | *Name of crops* | *Lingo output for $G_2(y)$* |
|---|---|---|---|
| $y_{1.1}$ | 1.8619 ha. land for Cucumber | $y_{8.2}$ | 0.0000 ha. land for Rice |
| $y_{2.1}$ | 1.8623 ha. land for Rice | $y_{9.2}$ | 0.5750 ha. land for Raw Turmeric |
| $y_{3.2}$ | 0.5955 ha. land for Chora | $y_{10.2}$ | 0.5650 ha. land for Turmeric |
| $y_{4.2}$ | 0.0000 ha. land for Chana | $y_{11.3}$ | 0.9406 ha. land for Brinjal |
| $y_{5.2}$ | 0.7538 ha. land for Jowar | $y_{12.3}$ | 0.0742 ha. Land cucumber |
| $y_{6.2}$ | 0.7000 ha. land for Mung | $y_{13.3}$ | 0.7917 ha. Land for Suran |
| $y_{7.2}$ | 0.5556 ha. land for Maize | $y_{14.3}$ | 1.9436 ha. Land for green chilli |

Therefore, for Production $(G_1\ (y))_2$ = 1,37,254.52 kg and Profit: $(G_2\ (y))_2$ = Rs 26,30,422 /-

Thus, from the above results in a Table 4 to construct the Positive ideal solution of theFMOLP.

**Table 4:** Positive ideal solution

| | *Production ($G_1$)* | *Profit ($G_2$)* |
|---|---|---|
| Production ($G_1$) | 1,39,992.7 kg = $U_{B1}^{\xi}$ | 1,37,254.52 kg = $L_{B1}^{\xi}$ |
| Profit ($G_2$) | Rs 22,30,219.852 = $L_{B2}^{\xi}$ | Rs 26,30,422 = $U_{B2}^{\xi}$ |

Now, to obtain the solution of Fuzzy Multi-Objective Linear Programming, objective functions (31) and (32) are becomes fuzzy constraints as follows:

Max α

Such that use equation (33) to (37)

$$30000y_{1.1} + 885y_{2.1} + 6000y_{3.2} + 612y_{4.2} + 325y_{5.2} + 50y_{6.2} + 225y_{7.2} + 765y_{8.2} + 6000y_{9.2} + 12000y_{10.2} + 24000y_{11.3} + 5500y_{12.3} + 12000y_{13.3} + 17000y_{14.3} - (147934.7 - 137890.85)\alpha \geq 137890.85 \tag{38}$$

$$234000y_{1.1} + 31210y_{2.1} + 61750y_{3.2} + 23080y_{4.2} + 13425y_{5.2} + 1600y_{6.2} + 5175y_{7.2} + 19190y_{8.2} + 460000y_{9.2} + 496000y_{10.2} + 254000y_{11.3} + 79500y_{12.3} + 390000y_{13.3} + 508000y_{14.3} - (2628918 - 2277510.5)\alpha \geq 2277510.5 \tag{39}$$

where, $y_{i,j} \geq 0$ and $\alpha \geq 0$ $\forall$ j = 1, 2, 3 and i = 1, 2, ..., 14.

Solving this linear programming problem using Lingo the value obtained isα= 0.4986787 and other values are shown in the below table 5.

**Table 5:** α output for the season wise crop allocation

| *Name of crop* | *Lingo output for α* | *Name of crop* | *Lingo output for α* |
|---|---|---|---|
| $y_{1.1}$ | 1.862 ha. land for Cucumber | $y_{8.2}$ | 0.0000 ha. land for Rice |
| $y_{2.1}$ | 1.862 ha. land for Rice | $y_{9.2}$ | 0.575 ha. land for Raw Turmeric |
| $y_{3.2}$ | 0.595 ha. land for Chora | $y_{10.2}$ | 0.565 ha. land for Turmeric |
| $y_{4.2}$ | 0.000 ha. land for Chana | $y_{11.3}$ | 1.430 ha. land for Brinjal |
| $y_{5.2}$ | 0.754 ha. land for Jowar | $y_{12.3}$ | 0.252 ha. Land cucumber |
| $y_{6.2}$ | 0.700 ha. land for Mung | $y_{13.3}$ | 0.792 ha. Land for Suran |
| $y_{7.2}$ | 0.556 ha. land for Maize | $y_{14.3}$ | 1.276 ha. Land for green chilli |

Therefor the total maximum production ($D_1$) achieved is 1,38,615.02 kilograms. The maximum return ($D_2$) from this production is Rs. 32,44,784.77. At the same time, the minimum investment ($D_3$) required to achieve these results is Rs. 8,15,146.75.

## Results and Discussion

The FMOLP model was used to improve crop production planning in the Sadakpor, Navsari district of India. The main goals to increase total profit and crop production. The model gave the best results with a total crop production of 138615.02 kg, a total return of Rs. 32,44,784.77, and a total investment of Rs. 8,15,146.75. Land was divided efficiently among different crops and seasons, and all the constraints on land, labour, fertilizer, and capital were fully satisfied.

The FMOLP model works effectively for agricultural planning with multiple goals under uncertain conditions. It includes membership function, which makes it more flexible and realistic when data is unclear or when experts have different opinions. The result helps small farmers to make vise decisions in real world farming, where conditions and resources are limited. Overall, the proposed model is useful for optimizing crops to get more profit and meet the food requirement under uncertainty.

## Conclusion

The proposed fuzzy multi-objective linear programming model proved highly effective for crop allocation across different seasons. By optimizing market prices and prioritizing high-yield crops, the model successfully identifies and removes underperforming crops while focusing resources on productive options such as cucumber, rice, and green chilli. The optimization results, obtained using LINGO software, demonstrate clear practical benefits. Smallholder farmers can now make better crop planning decisions that minimize overall production costs and maximize net profits. Unlike traditional methods that treat all crops equally, this model guides farmers toward data-driven choices based on actual yield potential and seasonal suitability. Overall, the FMOLP framework offers a practical, accessible tool for small-scale farmers in regions like Sadapkhor village, Navsari, Gujarat.

Future research can apply this model to other regions of India to test its generalizability. Additional variables such as rainfall, temperature, and pest risks can be integrated into the fuzzy framework. A mobile-based decision support tool can also be developed to help farmers use the model without technical training.

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