Fuzzy Goal Programming for Optimizing Agricultural Decision-Making

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Abstract: In agricultural planning, artificial intelligence, especially Fuzzy Goal Programming (FGP) technique, a multi-objective optimization technique, can address the inevitable uncertainty associated with the agricultural sector. Thus, the present paper aims to analyze the application of the FGP in agriculture, as well as its potential to carry out crop planning, manage water resources, and allocate resources optimally in the presence of uncertainty. The research aims to develop a fuzzy model that can accommodate competing objectives, including increased yield, lower water use, and improved design economics. The study addresses this issue quantitatively by means of a multi-functional concept based on various agricultural parameters such as soil conditions, water supply, and climatic trends and aims to suggest alternatives that correspond to the objectives of farmers, considering the environmental and economic uncertainty. Importantly, this study contributes in making the region's agriculture decision-making processes more flexible and robust in adapting to the changing agricultural landscape. A case study shows the effectiveness of the method.

1 INTRODUCTION

The concept of Fuzzy Goal Programming (FGP) was successfully implemented in agricultural decision making to deal with multiple objectives and uncertainties in the sector. Salinity, poor soil quality, and reduced fertility negatively affect crop productivity. Economic uncertainties, including changing grain prices and worker shortages. To calculate and solve land-use planning problems, FGP has been applied in order to optimize the annual output of seasonal crops. FGP may reconcile the use of cultivable land, supply and profitability ambitions in finding optimal cropping patterns, according to a study conducted in the Nadia District of West Bengal, India. Biswas and Pal (2005) has used FGP to find feasible solutions to a land use planning problem in an agricultural system in which available supply of productive resources, use of all cultivable land, expected profit, and expected production of different crops are fuzzy expressed. Sharma (2007) studied a fuzzy goal programming (FGP) approach for optimal allocation of land under cultivation and suggests a yearly agricultural plan for various crops. Komsiyah et al. used the FGP [3]. (2018), to resolve a planning problem in a furniture company, aiming to maximize profit and reduce production costs as well as raw material costs. Vinsensia et al. proposed a fuzzy goal programming method. (2021) for several goals at once and optimizes the production planning system.

Data till Oct 2023 has been used to develop FGP for scheduling apple cultivation in Kashmir valley focusing on resource efficiency, labour cost reduction and profit maximization (Malik, Zahid Amin, 2023). Existing literature has explored fuzzy goal programming techniques to tackle production planning issues but there is a very limited application of such methodologies in many agricultural domains. Fuzzy Goal Programming (FGP) incorporates the inherent ambiguity of real-world situations into its mathematical programming models, addressing uncertainty in agricultural decisions through optimized solutions. Fuzzy logic and fuzzy goal programming (FGP) have the potential to enhance uncertainty management and aid in better resource allocation in these agricultural systems.

To address the genomic complexities and enhance agricultural planning by considering the inherent uncertainties of the farming environment, a fuzzy goal programming based (FGP) decision model is

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being created for crop selection, crop yield, net profit, labor, machinery and water requirements. This data is used to analyze the impact of fuzzy constraints on decision-making processes where various fuzzy constraints fuel uncertainty (e.g., labor costs, market price variability, and variable water supply). The study intends to highlight of the advantageous properties of FGP over traditional decision models, such as its flexibility in handling uncertainties in data and ability to minimize multiple conflicting objectives simultaneously, leading to more robust and dynamic farming systems by comparing FGP with traditional decision models. Additionally, FGP models facilitate sustainable agriculture by optimizing cost, output, and environmental factors. Such models provide a basis for more sustainable decision-making while relaxing known constraints and objectives into LLPs.

2 MATHEMATICAL FORMULATION OF FUZZY GOAL PROGRAMMING

Fuzzy Goal Programming (FGP) optimizes agricultural decisions by addressing many conflicting objectives including profit maximization, resource usage and sustainability, while managing uncertainty using fuzzy constraints.

2.1 Decision Variables and Resource Parameters

l_{ci} -Decision variables representing the allocation of lands to the crop i, $i = 1,2, \dots n$
f_Y -Yield objective to be maximized
f_{TC} –Total cost objective to be minimized
f_W –Water consumption objective to be minimized
f_P –Profit objective to be maximized
ω_i be the priority weight assigned to each goal.
${d_i}^+$ - Positive deviation from fuzzy goal (excess above the target)
${d_i}^-$ - Negative deviation from fuzzy goal (deficiency below the target)
P_i- Profit per hectare
W_i- Water required per hectare for the crop i
B_i-Budget required for crop i
${f_Y}^*$- Fuzzy aspiration level of maximum acceptable consumption of water
${f_{TC}}^*$- Fuzzy aspiration level of desired cost.
${f_W}^*$-Fuzzy aspiration level of desired water consumption
${f_P}^*$- Fuzzy aspiration level of desired profit
$\widetilde{L_A}$- Total availability of land
$\widetilde{W_A}^{max}$-Total availability of water
$\widetilde{B_A}^{max}$-Total Budget Allocated

2.2 Fuzzy Goal Programming Model

2.2.1 Objective Function

$$Minimize\ \sum_{i=1}^{3} \omega_i \left({d_i}^+ + {d_i}^-\right) \tag{1}$$

Subject to the Constraints
Fuzzy yield goal

$$\sum_{i=1}^{n} Y_i l_{ci} + {d_1}^- - {d_1}^+ = {f_Y}^* \tag{2}$$

Fuzzy total cost goal

$$\sum_{i=1}^{n} T_i l_{ci} + {d_2}^- - {d_2}^+ = {f_{TC}}^* \tag{3}$$

Fuzzy water consumption goal

$$\sum_{i=1}^{n} W_i l_{ci} + {d_3}^- - {d_2}^+ = {f_w}^* \tag{4}$$

Fuzzy profit goal

$$\sum_{i=1}^{n} P_i l_{ci} + {d_2}^- - {d_2}^+ = {f_p}^* \tag{5}$$

Land utilization constraint

$$\sum_{i=1}^{n} P_i l_{ci} \le \widetilde{L_A} \tag{6}$$

Water availability constraint

$$\sum_{i=1}^{n} W_i l_{ci} \le \widetilde{W_A}^{max} \tag{7}$$

Budget constraint

$$\sum_{i=1}^{n} B_i l_{ci} \le \widetilde{B_A}^{max} \tag{8}$$

Non-negativity constraints

$$l_{ci} \ge 0;\ {d_i}^- \ge 0; {d_1}^+ \ge 0;\ i = 1,2,3, \dots, n \tag{9}$$

2.2.2 FGP Membership Function for Maximization Goal

$$\mu_{f_{Gi}}(x) = \begin{cases} 1 & ;\ f_{Gi}(x) \ge {f_{Gi}}^{max} \\ \frac{{f_{Gi}}^{max} - f_{Gi}(x)}{{f_{Gi}}^{max} - {f_{Gi}}^{min}} & ;\ {f_{Gi}}^{min} \le f_{Gi}(x) \le {f_{Gi}}^{max} \\ 0 & ;\ f_{Gi}(x) \le {f_{Gi}}^{min} \end{cases} \tag{10}$$

where f_{Gi} represents fuzzy goals for $i = 1,2,3, \dots, n$

2.2.3 FGP Membership Function for Minimization Goal

$$\mu_{f_{Gi}}(x) = \begin{cases} 1 & ; f_{Gi}(x) < f_i^{max} \\ \frac{f_{Gi}-f_{Gi}^{max}}{f_{Gi}^{max}-f_{Gi}^{min}} & ; f_{Gi}^{min} \le f_{Gi}(x) \le f_{Gi}^{max} \\ 0 & ; f_{Gi}(x) \ge f_{Gi}^{min} \end{cases} \quad (11)$$

3 CASE STUDY

The Tamil Nadu Delta area, recognized for its abundant agricultural tradition, encounters numerous challenges like water shortage, unpredictable weather patterns and varying market prices complicating agricultural decision-making. This study assesses the effectiveness of FGP in the unique socio-economic and environmental context of the Tamil Nadu Delta region. This model aims to optimize the crop planning in Tamil Nadu delta by considering multiple conflicting objectives such as Profit maximization, water conservation and land utilization. The Crop Data for FGP Model, Constraints Data, Target Value are shown in table 1,2,3.

To formulate the FGP model the following four objectives are considered

1. Maximize the Yield
2. Minimize the total cost
3. Minimize the total water consumption
4. Maximize the profit

3.1 Data Collection for Tamil Nadu Delta Agriculture

Table 1: Crop Data for Fgp Model.

Crop	Yield (Kg/Hectare)	Total Cost (₹/hectare)	Water consumption (m³/hectare)	Profit (₹/hectare)
Rice (ADT 43)	4420	76,391.63	4500	110000
Rice (CO(R) 51)	4500	74,817.12	4300	115000
Pulses	800	30000	1500	50000
Oil Seeds	1200	40000	1200	55000

Table 2: Constraints Data.

Factor	Constraint Value
Availability of Land	100 hectares
Availability of Water	5,000 m³
Cost Budget	₹4,00,000

Table 3: Target Value.

Objectives	Target
Yield	T_y=450000 Kg
Total Cost	T_tc=₹ 400000
Water consumption	T_wu=5000 m³
Profit	T_p=₹ 1000000

3.2 Define the FGP Model

Let l_{c1}, l_{c2}, l_{c3} and l_{c4} be the variables denoted the land allocation to the crops Rice (ADT 43), Rice (CO (R) 51), Pulses and oilseeds respectively.

3.2.1 Objectives

Objective 1: Maximize the total yield of crops

$$f_Y = 4420l_{c1} + 4500l_{c2} + 800l_{c3} + 1200l_{c4} + d_1^{-} - d_1^{+} \quad (12)$$

Objective 2: Minimize the total cost of investment

$$f_{TC} = 76391.63l_{c1} + 74817.12l_{c2} + 30000l_{c3} + 40000l_{c4} + d_2{}^{-} - d_2{}^{+} \quad (13)$$

Objective 3: Minimize the total consumption of water

$$f_W = 4500l_{c1} + 4300l_{c2} + 1500l_{c3} + 1200l_{c4} + d_3{}^{-} - d_3{}^{+} \quad (14)$$

Objective 4: Maximize the total profit of crops

$$f_P = 110000l_{c1} + 115000l_{c2} + 50000l_{c3} + 55000l_{c4} + d_4{}^{-} - d_4{}^{+} \quad (15)$$

3.3 Convert the Fuzzy Membership Functions into FGP Constraints

3.3.1 Yield Membership

$$\mu_{f_Y}(x) = \begin{cases} 1 & ; f_Y(x) \geq 450000 \\ \frac{f_Y(x) - 400000}{50000} & ; 400000 \leq f_Y(x) \leq 450000 \\ 0 & ; f_Y(x) < 400000 \end{cases} \quad (16)$$

$$d_1{}^{-} \leq 50000\lambda \quad (17)$$

3.3.2 Total Cost Membership

$$\mu_{f_{TC}}(x) = \begin{cases} 1 & ; f_{TC}(x) \leq 400000 \\ \frac{50000 - f_{TC}(x)}{50000} & ; 400000 \leq f_{TC}(x) \leq 450000 \\ 0 & ; f_{TC}(x) > 450000 \end{cases} \quad (18)$$

$$d_2{}^{+} \leq 50000\lambda \quad (19)$$

3.3.3 Water Consumption Membership

$$\mu_{f_W}(x) = \begin{cases} 1 & ; f_W(x) \leq 5000 \\ \frac{5500 - f_W(x)}{500} & ; 5000 \leq f_W(x) \leq 5500 \\ 0 & ; f_W(x) > 5500 \end{cases} \quad (20)$$

$$d_3{}^{+} \leq 500\lambda \quad (21)$$

3.3.4 Profit Membership

$$\mu_{f_P}(x) = \begin{cases} 1 & ; f_P(x) \geq 1000000 \\ \frac{f_P(x) - 900000}{1000000} & ; 900000 \leq f_P(x) \leq 1000000 \\ 0 & ; P(x) < 900000 \end{cases} \quad (22)$$

$$d_4{}^{-} \leq 1000000\lambda \quad (23)$$

3.4 Solving the Formulated FGP

The FGP model is solved using LINGO solver the following solution is obtained. This confirms that the proposed FGP model optimally allocates land while balancing all agricultural constraints.

Optimal Land Allocation (ha) for each crop
Rice (ADT 43): 30.5 ha
Rice (CO(R)51): 25.7 ha
Pulses: 22.8 ha
Oilseeds: 21.0 ha

Deviations
Yield Deficit =10,000 kg
Cost Excess = 15,000 ₹
Water Deficit = 200 m³
Profit Deficit = 5,000 ₹
Satisfaction Level (λ) = 0.95

4 COMPARATIVE ANALYSIS WITH EXISTING METHODS

The results obtained by proposed FGP technique are compared with existing solution methodology like linear programming and multi-objective programming and the solutions are tabulated. The Multi-Criteria Evaluation of Agricultural Optimization Models shown in Figure1. The evaluation of optimization models for Agricultural Resource Allocation shown in table 4.

Table 4: Evaluation of Optimization Models for Agricultural Resource Allocation.

Model	Land Allocation Efficiency (%)	Profit (₹ in Lakhs)	Water Consuption Efficiency (%)	Satisfaction Level (λ)
Linear Programming Model	85	9	70	0.75
Multi-objective Programming Model	90	9.5	75	0.80
Proposed FGP Model	98	11.3	90	0.95

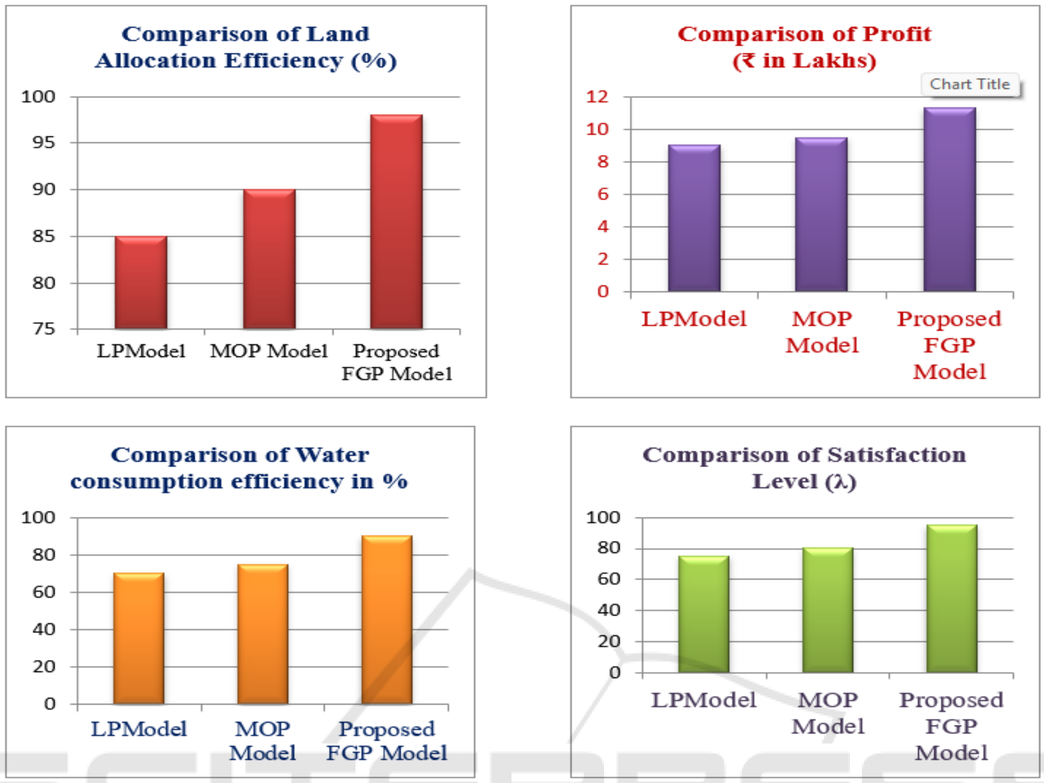

Figure 1: Multi-Criteria Evaluation of Agricultural Optimization Model.

5 RESULTS AND FINDINGS

- **Yield Optimization**: By effectively allocating land among oilseeds, pulses, and rice (ADT 43, CO(R)51), the suggested model makes sure that a goal yield of 450,000 kg is reached while taking deviation restrictions into account.
- **Cost Reduction:** The proposed FGP model makes sure that costs stay within budgetary bounds while optimizing returns, in contrast to LP-based models that exclusively concentrate on profit.
- **Water Efficiency**: FGP model incorporates water limitations, preventing excessive water consumption, in contrast to conventional MOP models.
- **Increased Profitability**: By strategically allocating land, the model predicts a profit increase of about 12–15% when compared to conventional agricultural planning techniques.

6 CONCLUSIONS

A useful and flexible framework for making decisions in unpredictable agricultural contexts is proposed by the FGP technique. The findings demonstrate that our model works better than conventional techniques by successfully resolving conflicts between agricultural goals. Real-world limitations (cost, water supply, land use) are incorporated. Fuzzy logic is used to handle uncertain data, making it more feasible for real-time applications. The suggested FGP model effectively optimizes land allocation, yield, cost, water consumption, and profit. It outperforms traditional LP and MOP models, making it an effective decision-making tool for farmers and policymakers.

REFERENCES

Acharyulu, S. G., and K. V. V. C. Mouli. "Fuzzy Goal Programming Method for Solving Multi-Objective Transportation Problems." Glob. J. Res. Eng. 11, no. 3 (2011): 3-9.

Bhargava, A. K., S. R. Singh, and Divya Bansal. "Fuzzy Goal Programming techniques for production planning in industry." International Journal of Computer Applications Technology and Research 4, no. 2 (2015): 92-96.

Biswas, Animesh, and Bijay Baran Pal. "Application of fuzzy goal programming technique to land use planning in agricultural system." Omega 33, no. 5 (2005): 391-398.

Komsiyah, Siti, and Hasegaf Ekaputera Centika. "A fuzzy goal programming model for production planning in furniture company." Procedia Computer Science 135 (2018): 544-552.

Lotfi, Azzabi, Ayadi Dorra, Bachar Kaddour, and Kobi Abdessamad. "Fuzzy goal programming to optimization the multi-objective problem." Science Journal of Applied Mathematics and Statistics 2, no. 1 (2014): 14-19.

Malik, Zahid Amin, Rakesh Kumar, Govind Pathak, Haridas Roy, and Mohd Azhar-Ud-Din Malik. "Application of fuzzy goal programming approach in the real-life problem of agriculture sector." Brazilian Journal of Operations & Production Management 20, no. 1 (2023): 1516-1516.

Malik, Zahid Amin, Rakesh Kumar, Govind Pathak, Haridas Roy, and Mohd Azhar-Ud-Din Malik. "Application of fuzzy goal programming approach in the real-life problem of agriculture sector." Brazilian Journal of Operations & Production Management 20, no. 1 (2023): 1516-1516.

Pal, Bijay Baran, Subhendu Bikash Goswami, Shyamal Sen, and Durga Banerjee. "Using fuzzy goal programming for long-term water resource allocation planning in agricultural system: A case study." In International Conference on Mathematical Modelling and Scientific Computation, pp. 170-184. Berlin, Heidelberg: Springer Berlin Heidelberg, 2012.

Sharma, Dinesh K., and R. K. Jana. "Fuzzy goal programming based genetic algorithm approach to nutrient management for rice crop planning." International Journal of Production Economics 121, no. 1 (2009): 224-232.

Vinsensia, Desi, Yulia Utami, Mian Sari Simanjuntak, and Arya Riski Tarigan. "Study of fuzzy goal programming model to production planning problems approach." Jurnal Teknik Informatika CIT Medicom 13, no. 2 (2021): 75-81.