Optimal land distribution for ambiguous profit vegetable crops using multi-objective fuzzy linear programming

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ABSTRACT

Decisions in agriculture had been driven by methodical planning to increase yields to cater to the needs of overwhelming populations while also allowing farmers to prosper. Allocating land to various crops by making use of limited resources is becoming a crucial challenge for achieving higher profits. To make cropping pattern decisions, farmers traditionally rely on experience, instinct, and comparisons with their neighbors. Since profit varies depending on many factors, intuition and experience usually cannot guarantee optimal (maximum) profits. A number of research studies on linear programming (LP) have shown optimum cropping patterns when crop prices (profits) are fixed. Vegetable crops, also known as cash crops, are subject to a high degree of price volatility owing to the fact that their production is costly and they carry a significant risk of not being profitable, despite the fact that they provide higher earnings than food crops. The net returns of crops in agriculture are greatly impacted by price uncertainty. With the use of the optimization tool TORA, a step-by-step process is shown in this paper to solve the model and manage the volatility in vegetable crop profitability using fuzzy multi-objective linear programming (FMOLP).

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1. INTRODUCTION

There is a substantial relationship between the quantity of yield generated by agricultural farms and the demand for that product, which in turn influences the market pricing. A conventional technique is often followed by farmers when it comes to cropping patterns or the allocation of land to different crops. This distribution of land is determined by the resources that are available. It has been noted that the net return per acre for vegetable yields, often known as cash crops, is higher than the net return per acre for food crops throughout the course of the last decade. The maximizing of profits will thus be the primary aim of every farmer, regardless of the kind of vegetable crop that is being cultivated. By utilizing the operations research approach, specifically with linear programming problem (LPP), integer programming problem (IPP), assignment problem (AP), and transportation problem (TP), agricultural management systems are able to address the issues of allocating land for various crops, maximizing the production of crops, maximizing profits, and minimizing production costs. These issues are addressed in order to maximize profits and minimize production costs. These issues in the agricultural sector were first represented as a single-objective linear programming problem, which meant that they were approached one goal at a time. However, different goals need to be addressed concurrently while adhering to the same set of restrictions. This is because the situation of real-time issues that include several facets is always changing. Due to the fact that the maximizing of crop production cannot ensure the maximization of profit, the scenario necessitates the development of new approaches that are capable of addressing the advanced issue of decision making. In the agricultural industry, a crop's profitability is contingent upon the optimization of cultivation costs while also taking into account variations in crop demand, supply, and price. Optimizing profit becomes a multi-objective decision-making challenge as a result.

An economic model's ability to withstand price fluctuations in the market is what determines its success. A decent model must thus handle imperfect information and account for complicated and unpredictable settings. For instance, in the field of financial engineering, the prices of stocks are considered to be a random variable, and attempts are made to develop optimum plans that ensure a return. In a similar vein, the management of agribusiness plans at the level of farmers is very necessary to obtain assured returns despite variations in price. Food grain prices are often stable and provide a reliable return on investment. This is due to government support prices in many countries, such as India. In contrast, vegetable prices are more unpredictable and the cost of growing them is also quite expensive. In actuality, vegetable cropping involves managing a number of expenses, including capital investments in fertilizers, pesticides, insecticides, labor costs, and the cost of transportation. Occasionally, the unpredicted production of the same produces from nearby regions will also affect market rates because there is a lack of storage facilities. When taking into consideration the volatility of vegetable prices, adequate land planning can be undertaken in order to achieve optimal returns. Surprisingly, vegetable prices might change on a daily basis even throughout the same season. The numerical example used in this research is based on the likelihood of occurrence (probability) of crisp profit coefficients over an observable period.

2. LITERATURE REVIEW

Soil quality, crop rotation, climate conditions, disease management, market demand, and irrigations. are the factors to be considered when planning vegetable farming. Since LPP is perhaps the most significant and well-studied optimization issue, it is being employed for a wide range of manufacturing, distribution, marketing, and policy decision-making concerns. Numerous strategies have been established in management science to describe the challenges of multi-objective decision-making. The output function is the primary purpose of agricultural land; yet, as technology advances, the risk associated with land output is rising, particularly in places that produce a lot of grain and in urban suburbs. The development of an economic, social, and ecological environment is essential for coordinating the development of agricultural land-use patterns, and managers should be able to get trustworthy information to support their decision-making through specific approaches. To increase production and efficiency, optimal land allocation for vegetables requires careful planning and consideration of several criteria. Market prices are often impacted by several variables including consumer and farmer sentiments. Financial planning, by its very nature, is extremely conflictual, including a multitude of objectives with intricate financial relationships. Because of this, the financial industry is relying more and more on mathematical models to extract the most value from complexity. Additionally, agriculture now holds a large market share in the world, and several corporate entities finance farmers to ensure the smooth operation of their supply chain. Therefore, at the farmer level, optimal land usage and agricultural patterns are required. To ensure maximum profitability despite fluctuating prices, the farmer must cultivate and sell the vegetable crops over the full season, aiming for the highest possible weighted return.To address optimal farm planning, [1] devised the LP approach. The idea of fuzzy in decision making was initially introduced by Zadeh [2]. Fuzzy linear programming issues have been formulated and resolved using fuzzy set theory [3]. A parametric approach can be found in [4]. Sumpsi *et al.* [5] Employed fuzzy goal programming methodologies to address a farm planning issue. A fresh approach was provided for dealing with fuzzy variable issues in linear programming by Maleki *et al.* [6]. In their study of crop planning under vagueness. Itoh *et al.* [7] assumed that profit coefficients are discrete random variables. Ganesan and Veeramani [8], proposed a study about fuzzy linear programming using fuzzy variables and trapezoidal membership function representing different membership functions for multi-objective FLPP respectively. Weintraub and Romero [9] Emphasized the present issues and research priorities for the field of agriculture and forestry as well as the application of operations research models to evaluate historical performance in these areas. Tankol *et al.* [10] focused on environmental consequences, risk and uncertainty concerns for numerous criteria and planning challenges at the farm and regional sector level, as well as the creation of animal diets and feeding materials. Ross [11] suggested to solve linear optimization problems to find optimal solution for several objective functions. Senthilkumar and Rajendran [12] has developed the technique to solve FLPP consisting of fuzzy variables by using parametric form. Garg and Singh [13] Presented a method for solving MOLP by building up the membership function using the Max-Min strategy and claimed to provide better results than Itoh *et al.* [14] presented different membership functions for multi objective FLPP. Lone *et al.* [15] gave an approach for finding optimum allocation for FLPP by using the trapezoidal membership function. A yearly agricultural plan for several crops was suggested by Sharma *et al.* [16] after they investigated the FGP for the agricultural land allocation problem. Bharati and Singh [17] proposed computational algorithm for the resolution of multi-objective goal programming in interval valued fuzzy programming method. Ren *et al.* [18] proposed multi-objective stochastic fuzzy programming methods that can be used to find the optimal allocation of agricultural water. An algorithm based on the superiority and inferiority measures technique (SIMM) is provided to address fuzzy multi-objective linear fractional programming (FMOLFP) issues by [19]. Mitlif and Hussein [20] optimized the goal function by using the ranking function and fuzzy fractional programming in decision-making. Land allocation for optimum production planning through multi-objective LPP is suggested by Basumatary and Mitra [21]. Wang [22] described a mathematical model of fuzzy LPP under the restrictions of elastic constraints. Hakmanage *et al.* [23] proposed multi-crop cultivation programming approach by fuzzy goal programming. For the purpose of ranking triangular fuzzy numbers, a unique ranking function technique of ordinary fuzzy numbers is used in [24]. Khan and Aftab [25] also used fuzzy programming to explain multi-objective goal programming to improve agriculture crop production. Fakhrahmad *et al.* [26] addressed the current technique for predicting neighborhood satisfaction under ambiguous conditions. Mahmoodirad [27] introduced an innovative method for resolving linear programming issues using intuitionistic fuzzy numbers. Mahmud *et al.* [28] created a modeling system that uses machine learning to forecast activity concentration.

The objective of this study is to produce at least the best weighted return while taking into account the unstable price of vegetable crops and the uncertainty of earnings owing to several factors. It is, therefore, possible to include uncertainty in the planning model using the proposed fuzzy set based quantitative technique. A numerical illustration aids in the researchers' clear understanding of the model's solvability.

3. METHOD

Let us examine the situation where there are "n" producible crops and the corresponding profits for these crops are $k_{i1}, k_{i2}, k_{i3}, \dots, k_{in}$ per unit area and the associated probability p_i. The variables x_j, t_j, and w_j represent the crop j cultivation area, labor hours worked, and water units required to cultivate crop j at the unit area, respectively. A farm's land is restricted and must be less than or equal to "A" acres; this is known as a "land constraint"$x_1 + x_2 + x_3 + \cdots + x_n$. Because there is a cap on the total number of labor hours that may be worked, the sum of the following: $t_1x_1 + t_2\,x_2 + t_3x_3 + \cdots + t_nx_n$ must be less than or equal to a fixed "T." This is known as a "labor constraint." Water may also be considered a limitation when dealing with "W" units. The equation: $w_1x_1 + w_2\,x_2 + w_3x_3 + \cdots + w_nx_n$ can be considered a "water constraint" as the total need needs to be modified within the limit. Given the above limitations and the presence of discrete crisp and fuzzy random profit coefficients, our objective is to determine the choice variables x_j that will result in the maximum profit (P).

Maximize P Subject to

$$\begin{aligned}
&x_1 + x_2 + x_3 + \cdots.. + x_n \le \text{A} && \text{(Land constraint)}\\
&t_1x_1 + t_2\,x_2 + t_3x_3 + \cdots.. + t_nx_n \le \text{T} && \text{(Labour constraint)}\\
&w_1x_1 + w_2\,x_2 + w_3x_3 + \cdots.. + w_nx_n \le \text{W} && \text{(Water constraint)}\\
&k_{11}x_1 + k_{12}\,x_2 + k_{13}x_3 + \cdots.. + k_{1n}x_n \ge P\\
&k_{21}x_1 + k_{22}\,x_2 + k_{23}x_3 + \cdots.. + k_{2n}x_n \ge P\\
&k_{31}x_1 + k_{32}\,x_2 + k_{33}x_3 + \cdots.. + k_{3n}x_n \ge P\\
&k_{m1}x_1 + k_{m2}\,x_2 + k_{m3}x_3 + \cdots.. + k_{mn}x_n \ge P
\end{aligned} \tag{1}$$

3.1. Fuzzy programming and max-min approach

In a fuzzy context, a decision is generally seen as a membership function-based fuzzy objective function. Constraints are treated in a similar fashion. When there are several objectives, a process for choosing activities arises that simultaneously fulfills all of the restrictions and objective functions. This procedure may be thought of as a combination of fuzzy objective functions and fuzzy constraints. The decision is further optimized to a degree of satisfaction using the membership function of the solution set. Using Zimmermann's (1978) max-min fuzzy programming technique, the current study on optimization under vagueness in agricultural production management has been examined in the case where profit coefficients are discrete, crisp random variables. He asserts that if the objective function is (2).

$$\textbf{Max/Min}\ \ Z_n\,(k_r, x) = C_nx\,, r = 1,2,3, \dots, k \text{ Subject to} \\ P(A, X) = Ax \le b \ \text{ and } \ x \ge 0 \tag{2}$$

Where $k_r = (k_{r1}, k_{r2}, \dots \dots k_{rn})$ is the profit/cost coefficients vector of the kth objective function, $b = [b_1, b_2, b_3, \dots\dots b_n]^{\mathrm{T}}$ is the vector of total available resources $x = [x_1, x_2, x_3, \dots\dots x_m]^{\mathrm{T}}$ is decision variable vector and $\mathrm{A} = [a_{ij}]_{m\times n}$ is coefficient matrix. He suggested the max-min operator to explain the

MOLP problem and considered the equation as find x, such that $z_n(x) \geq z^0_k$ ∀k, x ∈ X where z^0_k ∀k is related objectives and maximizing each of the objective functions is the aim. Here, the fuzzy constraints are the objective functions in (2). (If the fuzzy constraints' tolerances are provided, one may determine their membership function $\mu_k(x)$, $\forall k$ and then the membership function of a feasible solution set defines it,

$$\mu_D(x) = \min\{(\mu_1(x), \mu_2(x), \mu_3(x) \ldots \mu_r(x)\} \tag{3}$$

now, when a decision maker reaches a conclusion with a maximum μD, the problem will be transformed into Max $\mu_D(x)$,

Subject to

Max [$\min_k \mu_r(x)$] such that $x \in X$, *let* $\alpha = \min_k \mu_r(x)$ be the overall satisfactory level of compromise.

The subsequent model is derived as Max α such that $\alpha \leq \mu_r(x)$, ∀r, $x \in X$

For the purpose of estimating the membership functions of the objective functions, the payoff table of the positive ideal solution (PIS) is constructed using this method. It is assumed that the membership functions belong to the category of non-decreasing linear or hyperbolic functions, among other possibilities.

3.2. Computational approach for solving a fuzzy multi-objective linear programming (MOLP) problem

Here is a computational technique employing fuzzy multi-objective linear programming for a case where profit coefficients are discrete, crisp variables.

1) Solve the same set of restrictions as stated in (3.1.1), and solve each goal function independently.
2) Determine the corresponding value of each objective function for each solution by using the result that was determined in step 1.
3) Create a table of Positive Ideal Solutions (PIS) after obtaining the lower and upper limits, z' and z'', for each objective function from step 2.
4) Consider a linear and non-decreasing membership function between z'_n *and* z''_n

$$\mu_n(x) = \begin{cases} 1 & if\ \ z_n(x) = z'_n \\ \frac{z_n(x) - z'_n}{z''_n - z'_n} & if\ \ z'_n \leq z_n(x) \leq z_n'' \\ 0 & if\ \ z_n(x) < z'_n \end{cases}$$

5) Convert multi-objective linear programming to LPP as

Max α

Subjected to

$$\begin{aligned} &x_1 + x_2 + x_3 + \cdots .. + x_n \leq A && \text{(Land constraint)} \\ &t_1x_1 + t_2x_2 + t_3x_3 + \cdots .. + t_nx_n \leq T && \text{(Labour constraint)} \\ &w_1x_1 + w_2x_2 + w_3x_3 + \cdots .. + w_nx_n \leq W && \text{(Water constraint)} \\ &\mu_n(x) = \frac{z_n(x) - z_n'}{z^*_n - z'} \geq \alpha \quad \forall x \in X \end{aligned} \tag{4}$$

where $Z_n(x) = k_{r1}x_1 + k_{r2}x_2 + k_{r3}x_3 + \cdots .. + k_{rn}x_n$, this equation can be rewritten as

Max α

Subjected to

$$\begin{aligned} &x_1 + x_2 + x_3 + \cdots .. + x_n \leq A && \text{(Land constraint)} \\ &t_1x_1 + t_2x_2 + t_3x_3 + \cdots .. + t_nx_n \leq T && \text{(Labour constraint} \\ &w_1x_1 + w_2x_2 + w_3x_3 + \cdots .. + w_nx_n \leq W && \text{(Water constraint)} \\ &k_{11}x_1 + k_{12}x_2 + k_{13}x_3 + \cdots .. + k_{1n}x_n - \alpha\,(z''_1 - z'_1) = z'_1 \\ &k_{21}x_1 + k_{22}x_2 + k_{23}x_3 + \cdots .. + k_{2n}x_n - \alpha\,(z''_2 - z'_2) = z'_2 \\ &k_{31}x_1 + k_{32}x_2 + k_{33}x_3 + \cdots .. + k_{3n}x_n - \alpha\,(z''_3 - z'_3) = z'_3 \\ &k_{m1}x_1 + k_{m2}x_2 + k_{m3}x_3 + \cdots .. + k_{mn}x_n - \alpha\,(z''_n - z'_n) = z'_n \end{aligned} \tag{5}$$

6) Solve the equation with the help of TORA software.
7) Finally, the assured anticipated yield may be computed as $\sum_{i=1}^{n} z_i(x)p_i$ where $z_i(x)$ is the ith objective function's value at the decision-variable values found by solving the equation.

4. NUMERICAL ILLUSTRATION

4.1. Numerical illustration-problem description

A farmer intended to cultivate a variety of vegetable crops viz. potato, tomato, brinjal and onion in a particular season on his 25 acres of arable land. Based on his own experience, he estimated that there are 450 hours of labor available with him and 50 acres of water accessible. The Table 1 gives the profit coefficients (in lakh rupees), the amount of water needed, and the amount of labor hours necessary for each crop on an acre of land. To ensure net returns from profit coefficient volatility, how many acres must he take into account for each crop?

Table 1. Profit, labor and water constraints building data for the entire duration of crop

	Brinjal	Potato	Onion	Tomato	Probability
Profit coefficient (in 0000's) 1st scenario	0.74	0.67	1.44	1.98	40%
Profit coefficient (in 0000's)2nd scenario	1.16	0.86	1.63	2.52	25%
Profit coefficient (in 0000,s) 3rd scenario	1.37	1.11	2.14	1.42	20%
Profit coefficient (in 0000's) 4th scenario	1.72	1.30	2.62	1.68	15%
Required labor hours (per acre)	27	18	19	20	
Required water per acre	1.8	1.3	1.7	1.84	

Here, we use the working method from section 3.3 to demonstrate how to solve the problem. Let x_1,x_2, x_3 and x_4 represent the number of acres to be taken into consideration for tomatoes, potatoes, onion and brinjal, respectively. The problem to be solved transforms into

$$\begin{aligned} &\text{Maximize } Z_1 = 0.74\,x_1 + 0.67\,x_2 + 1.44\,x_3 + 1.98x_4 \\ &\text{Maximize } Z_2 = 1.16\,x_1 + 0.86\,x_2 + 1.63\,x_3 + 2.52\,x_4 \\ &\text{Maximize } Z_3 = 1.37\,x_1 + 1.11\,x_2 + 2.14\,x_3 + 1.42\,x_4 \\ &\text{Maximize } Z_4 = 1.72\,x_1 + 1.30\,x_2 + 2.62\,x_3 + 1.68x_4 \end{aligned} \tag{6}$$

Subject to constraints

$$\begin{aligned} &x_1 + x_2 + x_3 + x_4 \le 25 && \text{(land restriction)} \\ &27x_1 + 18\,x_2 + 19x_3 + 20x_4 \le 450 && \text{(labor restriction)} \\ &1.8\,x_1 + 1.3\,x_2 + 1.7\,x_3 + 1.84\,x_4 \le 50 && \text{(water restriction)} \end{aligned} \tag{7}$$

Using the optimization program TORA, the optimal solution is givento this crisp LP Problem for the specified objective functions with respect to the constraints. Table 2 provides a summary of the four optimal results.

Table 2. Solution at each objective function

	Max Z_1	Max Z_2	Max Z_3	Max Z_4
x_1	0	0	0	0
x_2	0	0	0	0
x_3	0	0	23.68	23.68
x_4	22.5	22.5	0	0

The solutions for each objective function that has been solved with respect to constraints using (4.1.2) may be arranged to get step 3 in section 3.3. These solutions are described as positive ideal solution (PIS). These solutions are shown in Table 3.

Table 3. Positive ideal solution

	Max Z_1	Max Z_2	Max Z_3	Max Z_4	Max	Min	Max-Min
Z_1	44.55	44.55	34.10	34.10	44.55	34.10	10.45
Z_2	56.7	56.7	38.6	38.6	56.7	38.6	18.1
Z_3	31.95	31.95	50.68	50.68	50.68	31.95	18.73
Z_4	37.8	37.8	62.04	62.04	62.04	37.8	24.24
	x_1	x_2	x_3	x_4			

Now, given LPP can be reformulated as per our discussed solving procedure
Maximize ∝
Subject to constraints

$$\begin{aligned}
&x_1 + x_2 + x_3 + x_4 \leq 25\\
&27x_1 + 18\,x_2 + 19x_3 + 20x_4 \leq 450\\
&1.8\,x_1 + 1.3\,x_2 + 1.7\,x_3 + 1.84\,x_4 \leq 50\\
&0.74\,x_1 + 0.67\,x_2 + 1.44\,x_3 + 1.98x_4 - 10.45 \propto \geq 34.10\\
&1.16\,x_1 + 0.86\,x_2 + 1.63\,x_3 + 2.52\,x_4 - 18.10\alpha \gg 38.60\\
&1.37\,x_1 + 1.11\,x_2 + 2.14\,x_3 + 1.42\,x_4 - 18.73\,\alpha \gg 31.95\\
&1.72\,x_1 + 1.30\,x_2 + 2.62\,x_3 + 1.68x_4 - 24.24\alpha \geq 37.8
\end{aligned} \tag{8}$$

Solving the above constraints with the help of the optimization software TORA, we find the solution

$x_1 = 0$, $x_2 = 0$, $x_3 = 11.84$, $x_4 = 11.25$, $\alpha = 0.5$

After that, we may see the optimal response that TORA has provided. The computation of the optimal return are shown in Table 4. This table also provide weighted average after taking respective probabilities into consideration.

Table 4. Return calculation and weighted average

Decision variables	Constraints	Return calculation	Probability
$x_1 = 0$	Constraint 1 = 23.09	Z_1=39.32	40%
$x_2 = 0$	Constraint 2 = 441.96	Z_2=47.65	25%
$x_3 = 11.84$	Constraint 3 = 41.39	Z_3=41.31	20%
$x_4 = 11.25$	Constraint 4 = 34.10	Z_4=49.92	15%
$\alpha = 0.5$	Constraint 5 = 38.60		
	Constraint 6 = 31.95		
	Constraint 7 = 37.8		
		Weighted average	43.39

4.2. Result and discussion

Crop output maximization does not guarantee profit maximization. Optimal outcomes require the creation of novel strategies that can effectively tackle the complex problem of decision making. Considering the given problem having different probabilities for profit coefficients, we applied the Max-min approach for solving the fuzzy LPP. Different optimal outcomes are obtained corresponding to different probabilities, so weighted average has been taken into consideration. Table 1 demonstrates the data of constraints. Using TORA, solution of each objective function and PIS are obtained in Tables 2 and 3 respectively. The optimum solution that satisfies four objective functions (4.1.1) simultaneously is $x_1 = 0$, $x_2 = 0$, $x_3 = 11.84$ and $x_4 = 11.25$ (shown in Table 4) which means that the farmer has to cultivate onion and tomato at 11.84 and 11.25 acres of land respectively in order to get guaranteed average net earnings of Rs. 4.339 lakhs (weighted average) in spite of inconsistent prices. The fourth set of profit coefficients, which occurs only 15% of the time, determines the maximum profit.

The presented study has both strengths and limitation. The use of this approach may provide direct guidance to farmers in their decision-making processes. The analysis accounts for the range in possible outcomes by using a weighted average and taking into account various probabilities for profit coefficients. This approach may be adapted to accommodate a larger number of constraints; however, we only explored three constraints here. The probability distributions for profit coefficients are assumed by the model to be constant across time which works as limitation for study.

Based on various profit coefficient probabilities, the study yields several ideal results. The research finds an optimum solution that concurrently fulfils four objective functions by taking weighted average of these results. Max-min approach may be practical, balanced and adaptable for more complex scenarios of crop allocation. As a future prospective, it can be used efficiently in optimized resource management, crop yield prediction, pest and disease management, and adaptive irrigation system. Policymakers may use fuzzy max-min methodologies to develop policies that exhibit more resilience to uncertainties in agriculture, including market volatility, environmental shifts, and technology progress.

5. CONCLUSION

In the contemporary agricultural production system, the evaluation of compromise options is often used while making choices pertaining to particular objectives, rather than only prioritizing the maximum-attainable alternative. In simulating the agricultural cropping pattern, the current study took into account a few contributing aspects. The research shows how, while taking into account the risks and uncertainties related to price fluctuation in vegetable crops, FMOLP may be used to identify the best planting patterns that optimize farmers' income. Fuzzy logic is used in this work to handle the inherent uncertainty and price variations of vegetable crops, which are notoriously volatile owing to market risks and production costs. FMOLP enables a methodical and data-oriented approach to decision-making in agriculture, reducing the dependence on intuition and experience alone.

Therefore, the quantitative techniques based on fuzzy sets that have been created may include uncertainty in the planning model. A numerical illustration aids in the researchers' clear understanding of the model's solvability. The fuzzy max-min technique in agriculture is a very promising field that has several potential applications. It is motivated by the need for more accurate and adaptable decision-making in the presence of uncertainty.

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