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Research Paper

Solving stochastic agricultural production planning problems by using fuzzy goal programming

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ABSTRACT

The paper highlights the increasing concern among farmers in the agriculture sector, mirroring trends observed in other industries. The focus of the paper is on utilizing fuzzy goal programming approaches for vegetable crop planning, particularly when faced with insecurity. To address the issue related to insecurity, such as fluctuating agriculture prices and production planning, the suggested approach employs fuzzy multi-objective linear programming. By utilizing this approach, the aim is to optimize land use in vegetable crop planning to ensure guaranteed returns for farmers, while considering the uncertainties involved. The decision maker process is guided by two key factors: the best return and the weighted return. These factors are crucial for the decision-maker in determining the optimal strategy for crop planning, which maximizes profitability while accounting for the uncertainties associated with agriculture production. These uncertainties plays crucial role and exacerbate the problem faces by farmers. Hence the primary objective of this study is to assess and anticipate future agricultural planning, focusing on output levels (crop production) and profitability. By incorporating fuzzy goal programming and considering multiple objectives, proposed approach aims to provide a robust framework for agricultural planning.it aims to address the commercial concerns of farmers, account for uncertainties agriculture production, and strive for optimal profitability. Overall, this study aims to support farmers in making informed decisions regarding vegetable crop planning.

Key words: Fuzzy goal programming, fuzzy linear membership function, multi-objective linear programming problem, optimal solution

The majority of population of agricultural country like India, directly or indirectly depends on farming. The suicide rate of India farmers has increased by 18% in 2020[1] .The increased suicide rate of Indian farmers has many reasons as per the Social activists and scholars like failure of monsoon, Farming Loan burdens, policies of present government, public mental health, personal and family problems, lack of proper planning of agricultural land and many more. Agriculture production planning problems are essential from both socioeconomic viewpoints. They entail a complicated interplay between economics and nature. Worldwide population growth, especially in south East Asian nations like China, India, Pakistan, and Bangladesh. In order to increase productivity and fulfill the rising demands of the pollution, these nations need to expand the area under cultivation. India at present is the third world country and dropping land due to increase in population and industrialization. As a result the proper utilization of resources increases crop production in per unit area. Planning of crops is the most important factor of farming planning. The way that land is allotted and how crops are planted differs depending on how the farmer views his farm and its land. Different operation research techniques have been used in agriculture related problems in order to maximize profit, minimize the cost. Due to agricultural uncertainty that hinders the development of efficient and sustainable agricultural production. Furthermore, the agricultural management system also addresses the problems of land allocation for various crops, productivity minimization, maximize profits, and cost minimization of production. These problems in the agriculture industry were initially treated as single objective linear programming problems by addressing each target separately. But in order to effectively plan for and manage agriculture, a variety of objectives must be linked to changing real-world problems. Since the maximization of crop output cannot ensure the maximization of profit, various alternative strategies are required to resolve these difficult decision-making problems. In agriculture, the profit or loss also depends on the varying supply, demand, and price of a particular product while minimizing costs of cultivation required for that crop. Thus, turning toward maximizing profits. An approach for modeling optimization problems with uncertainty is stochastic programming. Problems in the real world nearly always contain some unknown parameters, in contrast to deterministic optimization problems, which are formulated with known parameters. A technique for solving such problems is known as resilient optimization when the parameters are only known within specific limitations. Finding a solution that is both optimal in a certain sense and practical for all of these facts is the objective here. Similar in design, stochastic programming models benefit from the fact that the probability distributions driving the data are known or may be inferred. The objective is to identify a policy that maximizes the expectation of a certain function of the decisions and random variables while being practical for all (or nearly all) conceivable data occurrences. More generally, these models are created, solved analytically or numerically, and then examined in order to give a decision-maker useful data.

Stochastic programming and fuzzy programming are two important methodologies in agriculture and allied sciences that help address uncertainties and make informed decisions. Stochastic programming deals with decision-making under uncertainty. In agriculture, there are various sources of uncertainty, such as weather conditions, market prices, disease outbreaks, and yield variability. Stochastic programming allows farmers and decision-makers to incorporate these uncertainties into their models and make optimal decisions. Stochastic programming helps in managing risk by considering different possible scenarios and their probabilities. It allows farmers to evaluate the impact of uncertain factors on their production plans and optimize decisions accordingly. It also programming plays a crucial role in optimizing supply chain decisions in agriculture, including inventory management, transportation planning, and distribution. It considers uncertainties in demand, transportation costs, and market conditions, enabling more efficient and responsive supply chain operations.

Fuzzy Programming: Fuzzy programming deals with decision-making in situations where the boundaries between different categories or states are not well-defined. It allows for reasoning and decision-making in the presence of imprecise or ambiguous information. In agriculture, there are often situations where data is incomplete or imprecise. Fuzzy programming helps in handling such uncertainties and making decisions based on qualitative or subjective information. For example, determining optimal irrigation schedules based on vague knowledge of soil moisture levels. It can assist in optimizing resource allocation decisions in agriculture, considering factors like water usage, fertilizer application, and land distribution. It accommodates fuzzy constraints and objectives, allowing for more flexible and realistic decision-making. It enables decision-makers to consider multiple objectives and trade-offs between them, incorporating subjective preferences and uncertainties. This is particularly useful in selecting crop varieties, evaluating technology adoption, or assessing sustainability measures.

MATERIALS AND METHODS

Zadeh established the first mathematical definition of fuzziness. A number of attempts were made by Orlovsky to investigate whether fuzzy set theory may serve as a useful instrument for sufficient mathematical study of difficulties encountered in the actual world. Numerous writers tackle various kinds of fuzzy linear programming issues using various methods. Zimmermann and Ross, fuzzy approaches have been used to nearly all types of decision-making problems. Senthilkumar and Rajendran use fuzzy variables to solve the FLPP in parametric form. Among the techniques used to address MOLP issues are the vector maximum method, goal programming, and interactive methods. Zimmermann presented a novel approach to the issue formulation for finding a compromise solution to the MOLP problem. Lone *et.al*. In this study, they show how a farmer with finite resources—such as labour, storage space, and land can be represented as a linear programming problem with a linear objective function and three constraints. The goal is to maximize overall profit while also knowing the value of a farmer's resource availability. This was done to investigate a MOLPP compromise solution. By using various types of membership functions, Buckley, Luhandjula, and Chanas further introduced the approaches for generating compromise solutions and Pal *et.al*; uses AI-based Dynamic Programming Approach in Agriculture for Solving Intuitionistic Fuzzy Assignment Problems . According to various researchers, including Slowinski, Sinha et al., Sher and Amir, Sumpsi et al., Sarker et al., Pal and Moitra, uncertainty and ambiguity in agricultural production play a significant role in decision making. According to Maqbool, Sharma, Lone, and R took into account MOTP with intuitive fuzzy numbers and solved the problem in both ways. Lone et al; showed optimal allocation in agriculture through assignment. Mellaku *et.al*., showed improved efficiency of agricultural production and contribute to achieving the goal of eradicating mathematical model-based decision making to promote sustainable performance of agriculture in developing countries. As a result, both the exponential and linear membership functions will continue to yield the best compromise solution. The present facts analysis was conducted using two steps used LINGO to solve it. Lone *et.al*. extended work by considered as an Intuitionistic triangular fuzzy number. The proposed accuracy function is used to defuzzifying the assignment costs which are converted into crisp values. In order to address such issues, Researchers are interested in studying stochastic linear programming issues because of a concept Kruse and Meyer put forth about agricultural crop planning with stochastic values. Lone et al. they present a fuzzy linear mathematical programming approach in this study for the best distribution of arable land. The approach used in fuzzy mathematical programming provides a more practical and adaptable answer to the challenge of cultivating agricultural land. Utilizing a study using a possibility measure by Itoh and Ishii, Lodwick *et.al*. compared three approaches to the crop planning problem: fuzzy, stochastic, and deterministic approaches. With the assumption that profit coefficients are discrete random variables, Itoh *et.al*. addressed a problem of crop planning under uncertainty and offered a model to determine the maximum and lowest value of gains for the decision maker. An annual agricultural plan for various crops was put up by Sharma et al. in order to examine fuzzy goal programming for the problem of allocating agricultural land. The majority of this essay considers the crop planning multi-objective linear programming problem using profit as a discrete random variable. The problem has been translated into a deterministic model to assist the decision-maker, and a model crop planning with the highest profit has been created using fuzzy programming. Moges *et.al*. discussed the intuitionistic fuzzy multi-objective linear fractional optimization problem and its application in agriculture land allocation problem. Due to uncontrollable factors, all uncertain parameters in IFMOLFO problems are set as triangular intuitionistic fuzzy numbers and the crisp MOLFO problem is obtained utilizing the accuracy ranking functions method. Malik Z.A *et.al*. demonstrate the applicability of the fuzzy goal programming to frame the decision support system for the decision-makers to deal with the real-life problem of the agriculture sector namely the apple cultivation planning problem and to obtain an optimum solution.

RESULTS AND DISCUSSION

Model formulation: In this example, there are n different types of crops, and the profit coefficients are $c_{i1}, c_{i2}, \ldots \ldots c_{in}$, in, for each crop type, per unit area, with a corresponding probability p_i, with the decision variable x_j, let w_j stand for the crop j cultivation area and the labour hours needed to grow crop j at the unit area, respectively. Let L and W represent the land and labour restrictions, respectively, given that a farmer's available time and land must both be less than or equal to these limits (L and W). We find the conclusion variable x_j, consequently as to manage the profit (P) In light of these restrictions and discrete, fuzzy, and unpredictable profit coefficients, so as to maximize the profit (P).

Maximize T

Such that

$$
\begin{aligned}
& x_1 + x_2 + \cdots \quad + x_n \le L \\
& w_1 x_1 + w_2 x_2 + \cdots \quad + w_n x_n \le W \\
& c_{11} x_1 + c_{12} x_2 + \cdots \quad \ldots . + c_{1n} x_n \ge P \\
& c_{21} x_1 + c_{22} x_2 + \cdots \quad \ldots . + c_{2n} x_n \ge P \quad \ldots \ldots \ldots \ldots \ldots \ldots . . (1) \\
& \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\
& \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\
& c_{m1} x_1 + c_{m2} x_2 + \cdots \quad \ldots . + c_{mn} x_n \ge P \\
& x_1, x_2 \ldots \ldots . \ldots \ldots . x_n, P \ge 0
\end{aligned}
$$

Consider the following linear programming model

$$
\begin{aligned}
& \text{Maximize } Z_k = C_k X, \quad k = 1,2,3, \ldots \ldots . K \ldots \ldots \ldots \ldots \ldots \ldots . . (2) \\
& AX \le B \quad \text{and} \quad X \ge 0
\end{aligned}
$$

Where C_k is the component vector of profit/cost of the kth, objective function and B is the vector of total resource available. $A = [a_{ij}]$, Matrix order $m \times n$ of coefficients with decision variable X.

Computational Algorithm: Step 1. Solve the crisp linear programming problem one by one and taking one objective function with constraints at a time.

Step 2. After the optimal solution of crisp LPP and calculate other objective functions.

Step 3.From step 2, we Construct a payoff table and obtain the lower and upper bounds U_k and L_k for each objective function.

Step 4. Construct a linear membership function between the lower and upper bound

$$\mu_k(X) = \begin{cases} 1, & Z_k(X) = U_k \\ Z_k(X) - L_k/d_k, & L_k \le Z_k(X) \le U_k, \text{ where, } d_k = \frac{U_k - L_k}{2} \\ 0, & Z_k(X) \le L_k \end{cases} \ldots\ldots\ldots\ldots\ldots\ldots(3)$$

Step 5.Convert multi-objective LP into LPP

Maximize δ

Such that $x_1 + x_2 + \cdots \ldots \ldots \ldots + x_n \le L$

$w_1 x_1 + w_2 x_2 + \cdots \ldots \ldots \ldots + w_n x_n \le W$

$\mu_k(X) = Z_k(X) - L_k/d_k \ge \delta, x \in X$, where $d_k = \frac{U_k - L_k}{2}$ .... (4)

i.e. $Z_k(X) - \delta\left(\frac{U_k - L_k}{2}\right) \ge L_k$

i.e. $c_{k1}x_1 + c_{k2}x_2 + \cdots \ldots + c_{kn}x_n - \delta\left(\frac{U_k - L_k}{2}\right) \ge L_k$, for all k= 1,2,………m

Problem (1) reduces to Maximize δ

Such that

$$x_1 + x_2 + \cdots + x_n \le L$$

$$w_1 x_1 + w_2 x_2 + \cdots + w_n x_n \le W$$

$$c_{11}x_1 + c_{12}x_2 + \cdots + c_{1n}x_n - \delta\left(\frac{U_1 - L_1}{2}\right) \ge L_1$$

$$c_{21}x_1 + c_{22}x_2 + \ldots + c_{2n}x_n - \delta\left(\frac{U_2 - L_2}{2}\right) \ge L_2$$

$$c_{m1}x_1 + c_{m2}x_2 + \ldots + c_{mn}x_n - \delta\left(\frac{U_m - L_m}{2}\right) \ge L_m \ldots\ldots\ldots\ldots\ldots (5)$$

Can be solved by using LINDO statistical software

Numerical Illustration: On a season, a farmer grows the following four vegetables: carrot, radish, cabbage, and cauliflower in plots of x_1, x_2, x_3 and x_4 , respectively. He can use 260 hours of labour and a total of 10 acres of land. The work time for the crops and profit coefficients (in units of 10,000 Japanese Yen) are displayed in Table 1.

Random Variables	Carrot c_{i1}	Radish c_{i2}	Cabbage c_{i3}	Cauliflower c_{i4}	Probability %
c_1	29.8	10.4	13.8	19.8	10
c_2	23.9	21.4	49.2	32.8	50
c_3	37.0	16.0	3.6	9.7	10
c_4	19.3	26.6	48.4	75.6	30
Work time	6.9	71	2	33	

Maximize $Z_1 = 29.8x_1 + 10.4x_2 + 13.8\,x_3 + 19.8x_4$ ……… (6)

Maximize $Z_2 = 23.9x_1 + 21.4x_2 + 49.2\,x_3 + 32.8x_4$ ………. (7)

Maximize $Z_3 = 37x_1 + 16x_2 + 3.6x_3 + 9.7x_4$ ……….. ……. (8)

Maximize $Z_4 = 19.3x_1 + 26.6x_2 + 48.4x_3 + 75.6$ ………….. (9)

Subject to constraints

$x_1 + x_2 + x_3 + x_4 \le 10$…………….. ………………………… (10)
$6.9x_1 + 71x_2 + 2x_3 + 33x_4 \le 260$……………………………. (11)

We proceed as

Maximize $Z_1 = 29.8x_1 + 10.4x_2 + 13.8\,x_3 + 19.8x_4$
Such that $x_1 + x_2 + x_3 + x_4 + \alpha_1 = 10$
$6.9x_1 + 71x_2 + 2x_3 + 33x_4 + \alpha_2 = 260$, Where x_1, x_2, x_3, x_4 and α_1, α_2 are greater are equal to zero.

The optimal solution of LPP is

$x_1 = 10, x_2 = 0, x_3 = 0, x_4 = 0$, $\quad Z_1(X_1) = 298$

Similarly $Z_2(X_1) = 239$, $Z_3(X_1)$ 370, $Z_4(X_1) = 193$

Repeat the method to obtain the other objective functions Z_1, Z_2, Z_3 and Z_4 . Thus payoff table becomes, Table 2.

	Z_1	Z_2	Z_3	Z_4
X_1	298	239	370	193
X_2	138	492	138	484
X_3	298	239	370	193
X_4	184.4	365.06	83.21	694.85

From the above table the maximum and minimum values of the respective columns are

$U_I = 298,\ L_1 = 138,\ \ d_1 = 80,$

$U_2 = 492,\ L_2 = 239,\ \ d_2 = 126.5,$

$U_3 = 370,\ L_3 = 36,\ \ d_3 = 167$ and $U_4 = 694.85,\ L_4 = 193,\ \ d_4 = 250.92$

(4) Reduces to LPP as,
Maximize δ
Such that $x_1 + x_2 + x_3 + x_4 \le 10$

$6.9x_1 + 71x_2 + 2x_3 + 33x_4 \le 260$

$29.8x_1 + 10.4x_2 + 13.8\,x_3 + 19.8x_4 - 80\delta \ \ge\ 138$

$23.9x_1 + 21.4x_2 + 49.2\,x_3 + 32.8x_4 - 126.5\delta \ge 239$

$37x_1 + 16x_2 + 3.6x_3 + 9.7x_4 - 167\delta \ge 138$

$19.3x_1 + 26.6x_2 + 48.4x_3 + 75.6x_4 - 250.92\delta \ge 193$

LINGO solver gives the solution below

$x_1 = 4.14,\ x_2 = 0,\ x_3 = 3.80,\ x_4 = 2.051,$
$\delta = 0.9044$

In different probabilistic cases the value of profit are calculated as given below in table 3.

Probability occurrences	Profit	Weighted profit
P_1: profit coefficient 10%	207.37	20.73
P_2: profit coefficient 50%	348.58	174.28
P_3: profit coefficient 10%	181	18.1
P_4: profit coefficient 30%	410.53	123.159
Total weighted profit		**= 336.269**

CONCLUSION

In the current study, we design and utilize a stochastic programming problem-solving technique using multi-objective linear programming problems in a fuzzy goal programming context. Additionally free of parameters, this approach has the advantage of producing a singular optimum solution with higher weighted profit. Thus, a better crop model for maximizing profit may be proposed. For high economic expectations, farmers, especially those in India, need proper land utilization and cropping patterns. Therefore mentioned model shows the best expected returns for vegetables in high probability cases, and our weighted turnover is significantly upper than that of any alternative method. Thus, one of the interesting aspects of this study is the need that farmers produce their vegetable crops so that they can be harvested and sold during the entire growing season while providing the best-weighted-return in consideration of market price fluctuations as a guarantee of profit

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