LAND ALLOCATION PLANNING IN AGRICULTURAL SYSTEMS UNDER UNCERTAINTY: A CHANCE-CONSTRAINED APPROACH IN INEXACT DECISION-MAKING ENVIRONMENTS

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ABSTRACT

This paper explores the application of fuzzy goal programming (FGP) for modeling and solving land allocation problems with chance constraints, aimed at optimizing the production of seasonal crops within agricultural systems in uncertain environments. The decision-making environment in agricultural systems is often characterized by imprecision, particularly due to unpredictable rainfall patterns and limited availability of irrigation water, which are influenced by socio-economic factors. These uncertainties pose significant challenges in real-world agricultural scenarios.

The proposed model incorporates fuzzy descriptions for the utilization of cultivable land, farming resources, and the achievement of production goals for seasonal crops. Water supply, as a critical resource, and socio-economic constraints are represented probabilistically within this uncertain decision-making framework. The model addresses land-use planning for the cultivation of five major crops—Paddy, Wheat, Mustard, Potato, and Pulses—across three crop cycles: Pre-Kharif, Kharif, and Rabi, throughout the planning year for the Bardhaman district of West Bengal, India.

The solution process focuses on maximizing the membership value (unity) of the fuzzy goals, reflecting the aspirations of the decision maker (DM) as closely as possible, based on their needs and objectives. The potential of this approach is demonstrated through a case study of Bardhaman district, West Bengal, India, illustrating how FGP can be used to address agricultural planning challenges under uncertain conditions.

Keywords: Agricultural Planning, Chance Constrained Programming, Fuzzy Programming, Fuzzy Goal Programming, Goal Programming.

1. INTRODUCTION

The history of agriculture shows significant advancements in techniques and technology from the 12th to the 13th century, with crop yields peaking in the 13th century and remaining relatively stable until the 18th century. Following population growth and the Cultural Revolution, agricultural practices, including cropping systems and water supply, improved significantly before the mid-20th century. The Green Revolution in the 1960s led to the development of planning models for water supply and farming systems to meet societal needs. Water resources, however, are limited, with only 2.5% of the planet's water suitable for drinking and irrigation, and 98.6% of this water being locked in glaciers, snow, groundwater, and soil moisture. India receives only 0.7% of global water precipitation (4,000 km^3), and its rainfall is uneven and unpredictable, presenting challenges for water resource management.

West Bengal, with 7.5% of India's water resources and home to 8% of the national population, faces significant water stress due to its high population density (904 people per square kilometer, as of 2011) and the extensive irrigation needs of its agricultural economy. The annual per capita freshwater availability in 1961 was 5,177 cubic meters, but it had declined to 1,869 cubic meters by 2001 and is projected to fall further to 1,341 cubic meters by 2025. Misuse and over-exploitation of water resources contribute to the current crisis. In agricultural production, water is the primary resource, and its availability is highly uncertain due to varying rainfall across seasons. Additionally, irrigation water supply is influenced by socio-economic and environmental factors, with industrial emissions, water pollution, and climate change posing increasing threats.

Water scarcity, compounded by pollution, has become a significant challenge for agriculture, with farmers facing reduced access to fresh water. Fertilizer use is also crucial for crop production, as fertilizers supply essential macro and micro-nutrients for plant growth. However, over-application of fertilizers, especially in West Bengal, is a common issue, leading to environmental concerns. Sustainable agriculture seeks to optimize resource management by minimizing the use of external inputs such as fertilizers and pesticides, to reduce costs, avoid pollution, and increase farm profitability. Yet, overuse of fertilizers has led to secondary nutrient deficiencies, which can limit crop yields if not addressed.

Agricultural planning, particularly in multi-crop systems, requires optimal land allocation, resource management, and water control. However, due to the imprecise nature of many objectives in farm planning—such as crop yield targets and resource allocations—simultaneous optimization is often not possible. In such cases, fuzzy goal programming (FGP) can be effectively used as a goal-satisficing approach to manage the complexities of farm management. Therefore, decision makers face the challenge of balancing water resources and fertilizer inputs to ensure the sustainable growth and survival of agricultural systems.

The mathematical programming models to agricultural production planning have been widely used since Heady [1] in 1954 demonstrated the use of linear programming (LP) for land allocation to cropping plan in agricultural system. From the mid-'60s to '80s of the last century, different Linear Programing (LP) models studied [2, 3] for farm planning has been surveyed by Glen in [4] in 1987. Since most of the farm planning problems are multiobjective in nature, the goal programming (GP) methodology in [5] as a prominent tool for multiobjective decision analysis has been efficiently used to land-use planning problems [6] in the past.

Although, GP has been widely accepted as a promising tool for multiobjective decision making (MODM), the main weakness of the conventional GP methodology is that the aspiration levels of the goals need be stated precisely. To overcome the above difficulty of imprecise in nature of them, fuzzy programming (FP) approach in [7] to farm planning problems has been deeply studied [8] in the past. The FGP approach [9] as an extension of conventional GP to agricultural production planning problems has also been studied by Pal et al. [6,10] in the past.

Now, in most of the real-world decision situations, the DMs are often faced with the problem of inexact data due to inherent uncertain in nature of the resource parameters involved with the problems. To deal with the probabilistically uncertain data, the field of stochastic programming (SP) has been studied [11] extensively and applied to various real-life problems [12, 13] in the past.

The use of chance constrained programming (CCP) to fuzzy MODM problems has also been studied by Pal et al. [14] in the recent past. However, consideration of both the aspects of FP and SP for modeling and solving real-life decision problems has been realized in the recent years from the view point of occurrence of both the fuzzy and probabilistic data in the decision making environment. Although, fuzzy stochastic programming (FSP) approaches to chance constrained MODM problems have been investigated [15] by active researchers in the field, the extensive study in this area is at an early stage.

Now, in the agricultural production planning context, it is worthy to mention that the sustainable supply of water depends solely on the amount of rainfall in all the seasons throughout a year. As such, water supply to meet various needs is very much stochastic in nature.

Although, several modeling aspects of water supply system have been investigated [12] in the past, consideration of probabilistic parameters to the agricultural systems in fuzzy decision environment is yet to be circulated in the literature. In this article, utilization of total cultivable land, different farming resources, achievement of the aspiration levels of production of seasonal crops are fuzzily described. The water supply as a productive resource and certain socio-economic constraints are described probabilistically in the decision making environment.

In the solution process, achievement of the highest membership value (unity) of the membership goals defined for the fuzzy goals of the problem to the extent possible on the basis of the needs and desires of the decision maker (DM) is taken into account in the decision making horizon.

The potential use of the approach is demonstrated by a case example of the Bardhaman District, West Bengal (W. B.), INDIA. *Now, the general chance constrained FGP formulation is presented in the Section*

2. PROBLEM FORMULATION

The general form of a fuzzy MODM problem with chance constrained can be stated as:

Find X $(x_1,x_2,\ldots,x_n)$ so as to

satisfy $Z_k(X)\begin{pmatrix}\gtrsim\\ \lesssim\end{pmatrix} g_k$, k = 1, 2,….,K. (1) (1)

subject to $X \in S\{X \in R^n \mid \Pr[H(X) \geq b] \geq p,\ X \geq 0,\ H, b \in R^m\}$, (2)

where X is the vector of decision variables in the bounded feasible region S (≠Φ), and where & and .indicate the fuzziness of ≥ and ≤ restrictions, respectively, in the sense of Zimmermann [7], and where g_k be the imprecise aspiration level of the k-th objective. Pr stands for probabilistically defined (linear / nonlinear) constraints set H(X), b is a resource vector, and p (0< p <1) is the vector of satisficing probability levels of the defined constraints.

Now, to formulate the FGP model of the problem, the fuzzy goals in (1) are first characterized by their membership functions in [7] to measure the degree of achievement of the goals. Then, they are transformed into membership goals [16] by assigning the highest membership value (unity) as the aspiration level for goal achievement and introducing under- and over- deviational variables to each of them. Again, the probabilistic constraints are converted into their deterministic equivalent to employ the proposed approach in the process of solving the problem.

2.1 CONSTRUCTION OF MEMBERSHIP GOALS OF FUZZY GOALS

The membership goal expression of the membership function $\mu_k(X)$ defined for the fuzzy goal $Z_k(\mathbf{X})\ \&\ g_k$ appears as [16]:

$$\mu_k(X): \frac{Z_k(X) - g_{lk}}{g_k - g_{lk}} + d_k^- - d_k^+ = 1,\ k \in K_1 \quad (3)$$

where, g_{lk} and $(g_k - g_{lk})$ represent the lower tolerance limit and tolerance range , respectively, for achievement of the associated k-th fuzzy goal. Also, $d_k^- \geq 0$ and $d_k^+ \geq 0$ are the under- and over- deviational variables, respectively, of the k-th membership goal $\mu_k(X)$.

Similarly, the membership goal expression for the fuzzy goal $Z_k(\mathbf{X})\ .\ g_k$ takes the form:

$$\mu_k(X): \frac{g_{uk} - Z_k(X)}{g_{uk} - g_k} + d_k^- - d_k^+ = 1,\ k \in K_2 \quad (4)$$

where, g_{uk} and $(g_{uk} - g_k)$ represent the upper tolerance limit and tolerance range, respectively, for achievement of the associated k-th fuzzy goal, and where $k_1 \cup k_2 = \{1,2,\ldots,K\}$ with $k_1 \cap k_2 =$ Φ.

2.2 DETERMINISTIC EQUIVALENT OF CHANCE CONSTRAINTS

The deterministic equivalent of a chance constraint depends on randomness and probability distribution of the parameters involved with the constraints. In the present decision situation, the resource vector b in (2) is taken as normally distributed random parameter.

Then, the deterministic equivalent of the i-th constraint takes the form [15]:

$$H_i(X) \geq E(b_i) + F_i^{-1}(p_i)\sqrt{\{\text{var}(b_i)\}},\ i=1,2,\ldots,m \quad (5)$$

where, $E(b_i)$ and $\text{var}(b_i)$ represent mean and variance of b_i and $F^{-1}(.)$ represents the inverse of the probability distribution function F(.) of standard normal variate.

Now, the general FGP model of the problem is presented in the following Section 2.3.

2.3 FGP MODEL FORMULATION

In a fuzzy decision making situation, the aim of the decision maker (DM) is to achieve the highest membership value of each of the defined membership goals to the extent possible by minimizing the under deviational variables of each of them, and that depends on the needs and desires of the DM.

In a fuzzy decision making situation, the aim of the DM is to achieve the highest membership value of each of the defined membership goals to the extent possible by minimizing the under deviational variables of each of them, and that depends on the needs and desires of the DM.

The FGP model formulation under a pre-emptive priority structure can be presented as [10]:

Find $X(x_1,x_2,\ldots,x_n)$ so as to

Minimize $Z = [P_1(d^-), P_2(d^-), \ldots, P_r(d^-), \ldots, P_R(d^-)]$

and satisfy the membership goals in (3) and (4) ,subject to the system constraints set in (5); where Z represents the vector of R priority achievement function. $P_r(d^-)$ is a linear function of the weighted under-deviational variables, where $P_r(d^-)$ is of the form

$$P_r\,(d^-) = \sum_{k=1}^{K} w_{rk}^- d_{rk}^-\,, \qquad k = 1, 2, ..., K\,;\,(R \le K),$$

where d_{rk}^- is renamed for d_k^- to represent it at the r-th priority level, w_{rk}^- (>0) is the numerical weight associated with d_{rk}^- and it designates the weight of importance of achieving the aspired level of the k-th goal relative to other which are grouped at the r-th priority level and where w_{rk} values are determined as [16] :

$$w_{rk}^- = \begin{cases} \frac{1}{(g_k - g_{kl})_r}, & \text{for the defined } \mu_k(\mathbf{X}) \text{ in (3)} \\ \frac{1}{(g_{ku} - g_k)_r}, & \text{for the defined } \mu_k(\mathbf{X}) \text{ in (4)} \end{cases}$$

where $(g_k - g_{kl})_r$ and $(g_{ku} - g_k)_r$ are used to present $g_k - g_{kl}$ and $g_{ku} - g_k$ respectively, at the r-th priority level.

Now, the FGP model formulation of the proposed problem is presented in the Section 3.

3. FGP MODEL FORMULATION OF THE PROBLEM

The decision variables and different types of parameters involved with the problem are defined first in the following Section 3.1.

3.1 DEFINITION OF DECISION VARIABLES AND PARAMETERS

(a) DECISION VARIABLE:

l_{cs} = Allocation of land for cultivating the crop c during the season s, c = 1,2, ..., C; s = 1, 2, ..., S.

(b) PRODUCTIVE RESOURCE PARAMETERS:

- Fuzzy resources:

LA_s = Total farming land (hectares (ha)) currently in use for cultivating the crops in the season s.
MH_s = Estimated total machine hours (in hrs.) required during the season s.
MD_s = Estimated total man-days (in days) required during the season s.
F_f = Estimated total amount of the fertilizer f (f = 1,2,…,F) (in quintals (qtls.)) required during the planning year.
RS = Estimated total amount of cash (in Rupees (in Rupees)) required per annum for supply of the productive resources.

- Probabilistic resource:

WS_s = Total supply of water (in inch / ha) required during the season s.

(c) FUZZY ASPIRATION LEVELS:

P_c = Annual production level (in qtls.) of the crop c.
MP = Estimated total market value (in Rupees) of all the crops yield during the planning year.

(d) PROBABILISTIC ASPIRATION LEVELS:

R_{ij} = Ratio of annual production of the i-th and j-th crop (i, j = 1, 2, ...,C; $i \neq j$).
r_{ij} = Ratio of annual profits obtained from the i-th and the j-th crops (i, j=1,2,...,C; $i \neq j$).

(e) CRISP COEFFICIENTS:

MH_{cs} = Average machine hours (in hrs.) required for tillage per ha of land for cultivating the crop c during the season s.
MD_{cs} = Man days (in days) required per ha of land for cultivating the crop c during the season s.
F_{fcs} = Amount of the fertilizer f required per ha of land for cultivating the crop c during the season s.
P_{cs} = Estimated production of the crop c per ha of land cultivated during the season s.
A_{cs} = Average cost for purchasing seeds and different farm assisting materials per ha of land cultivated for the crop c during the season s.
MP_{cs} = Market price (Rupees / qtl.) at the time of harvest of the crop c cultivated during the season s.

(f) RANDOM COEFFICIENTS:

W_{cs} = Estimated amount of water consumption (in inch) per ha of land for cultivating the crop c during the season s.

3.2 DESCRIPTION OF FUZZY GOALS AND CHANCE CONSTRAINTS

(a) LAND UTILIZATION GOAL:

The land utilization goal for cultivating the seasonal crops appears as:

$$\sum_{c=1}^{C} l_{cs} \lesssim LA_s, \quad s = 1, 2, \ldots, S.$$

(b) PRODUCTIVE RESOURCE GOALS:

• Machine-hour goal: An estimated number of machine hours is to be provided for cultivating the land in different seasons of the plan period.

The fuzzy goals take the form:

$$\sum_{c=1}^{C} MH_{cs}.l_{cs} \gtrsim MH_S, \quad s = 1, 2,..., S.$$

• Man-power requirement goals: A number of labors are to be employed through out the planning period to avoid the trouble with hiring of extra labors at the peak times.

The fuzzy goals take the form:

$$\sum_{c=1}^{C} MD_{cs}.l_{cs} \gtrsim MD_s. \quad s = 1, 2,..., S.$$

• Fertilizer requirement goals: To maintain the fertility of the soil, different types of fertilizer are to be used in different seasons in the plan period.

The fuzzy goals take the form:

$$\sum_{c=1}^{C} F_{fcs}.l_{cs} \gtrsim F_f, \quad f = 1, 2, ..., F; \; s = 1, 2,..., S.$$

(c) CASH EXPENDITURE GOAL:

An estimated amount of money (in Rs.) is involved for the purpose of purchasing the seeds, fertilizers and other productive resources.

The fuzzy goals take the form:

$$\sum_{s=1}^{S} \sum_{c=1}^{C} A_{cs}.l_{cs} \gtrsim RS$$

(d) PRODUCTION ACHIEVEMENT GOALS:

To meet the demand of agricultural products in society, a minimum achievement level of production of each type of the crops is needed.

The fuzzy goals appear as:

$$\sum_{s=1}^{S} P_{cs}.l_{cs} \gtrsim P_c, \quad c = 1, 2,..., C.$$

(e) PROFIT GOAL:

A certain level of profit from the farm is highly expected by the farm decision maker.

The fuzzy profit goal appears as: $\sum_{s=1}^{S} \sum_{c=1}^{C} (MP_{cs} \,.\, P_{cs} - A_{cs}).l_{cs} \gtrsim MP$

3.3 DESCRIPTION OF CHANCE CONSTRAINTS

The different chance constraints of the problem are presented in the following Sections.

(a) WATER-SUPPLY CONSTRAINTS:

An estimated amount of water need be supplied to the soil for sustainable growth of the crop c cultivated during the season s. But, water-supply resources solely depends on rainfall and so probabilistic in nature.

The water-supply constraints appear as:

$$\Pr[\sum_{c=1}^{C} W_{cs} l_{cs} \geq WS_s] \geq p_s, \quad s = 1,2,\ldots,S.$$

where p_s ($0 < p_s < 1$) denotes the satisficing level of probability for the supply of water.

(b) PRODUCTION-RATIO CONSTRAINTS:

To meet the demand of the primary food products in society, allocation of land for the crops production in different seasons should be made in such a way that certain ratios of total production of major crops can be maintained.

The production-ratio constraints appear as:

$$\Pr\left[(\sum_{s=1}^{S} P_{is}.l_{is})/(\sum_{s=1}^{S} P_{js}.l_{js}) \geq R_{ij} \right] \geq p_{ij}, \quad i, j = 1, 2, ..., C, \text{ and } i \neq j.$$

where p_{ij} ($0< p_{ij} <1$) denotes the satisficing level of probability for the ratios of i-th and j-th crops.

(c) PROFIT-RATIO CONSTRAINTS:

Here, similar to the case in production-ratio constraints, the profit-ratio constraints are random in nature. The profit-ratio constraints take the form:

$$\Pr\left[(\sum_{s=1}^{S} (MP_{is}.P_{is} - A_{cs}) l_{is})/(\sum_{s=1}^{S} (MP_{js}.P_{js} - A_{cs}) l_{js}) \geq r_{ij} \right] \geq q_{ij}, \quad i, j = 1, 2, ..., C, \text{ and } i \neq j.$$

where, q_{ij} ($0< q_{ij} <1$) denotes the satisficing level of probability for the i-th and j-th profit-ratio.

4. AN ILLUSTRATIVE EXAMPLE: A CASE STUDY

The land-use planning problem for production of the principal crops of the District Bardhaman of West Bengal (W.B.) in India is considered to illustrate the proposed FGP model. Now, the three seasonal crop- cycles: Pre-kharif, Kharif and Rabi successively appear in W.B. during a planning year, and they designate the time periods for crop production during summer, rainy and winter seasons, respectively. The data were collected from different sources recorded District Statistical Hand Book, 2015 [17]; Economic Review; Basak, 2017 [18].

The decision variables and different types of data involved with the problem are summarized in the following Tables 1–4.

Table 1. Summary of the seasonal crops and decision variables

Season (s)	Pre-kharif (1)			Kharif(2)	Rabi (3)				
Crop (c)	Jute (1)	Sugarcane (2)	Aus-paddy (3)	Aman-paddy (4)	Boro-paddy (5)	Wheat (6)	Mustard (7)	Potato (8)	Pulses (9)
Variable (l_{cs})	l_{11}	l_{21}	l_{31}	l_{42}	l_{53}	l_{63}	l_{73}	l_{83}	l_{93}

Table 2: Data description of the aspired goal levels and tolerance limits

Goal	Aspiration Level	Tolerance Limit	
		Lower	Upper
1. Land utilization ('000 hectares) :			
(i) Pre-kharif season	272.14	----	309.33
(ii) Kharif season	272.14	----	309.33
(iii) Rabi season	272.14	----	309.33
2. a) Machine-hours (in hrs.) :			
(i) Pre-kharif season	14522.30	13070.07	----
(ii) Kharif season	7253.57	6528.22	----
(iii) Rabi season	35373.01	31835.71	----
b) Man-days (days) :			----
(i) Pre-kharif season	14274.1	12846.69	----
(ii) Kharif season	6513.1	5861.79	----
(iii) Rabi season	11312.2	10180.98	----
c) Fertilizer requirement (metric ton) :			
(i) Nitrogen	51.5	46.36	----
(ii) Phosphate	19.7	17.73	----
(iii) Potash	19.7	17.73	----
3. Production ('000 metric ton) :			
(a) Jute	339.660	325.152	----
(b) Sugarcane	78.798	70.919	----
(c) Rice	829.00	800	----
(d) Wheat	126.28	111.78	----
(e) Mustard	94.71	86.10	----
(f) Potato	526.18	478.34	----
(g) Rabi pulse	38.6	28.3	----

Goal	Aspiration Level	Tolerance Limit	
		Lower	Upper
4. Cash expenditure (Rupees Lac.)	82636.4175	-----	90900.0592
5. Profit (Rupees Lac.)	81470.8825	73323.794	----

Table 3. Data description of productive resource utilization, cash expenditure and market price.

Crops	MH_s	MD_s	F_f			PA	CE	MP
			N	P	K			
Jute	66.72	90	40	20	20	2603	17297.00	1050
Sugarcane	166.76	123	200	100	100	70364	30887.50	1200
Aus	138.99	60	40	20	20	2256.039	14331.80	1350
Aman	66.72	60	40	20	20	2153.989	12849.20	1600
Boro	266.87	60	100	50	50	3482.690	23721.60	1200
Wheat	66.72	39	100	50	50	2187.633	11119.50	1100
Mustard	33.36	30	80	40	40	869.182	8401.40	1700
Potato	111.19	70	150	75	75	21087.719	37312.10	500
Pulses	49.06	15	20	50	20	725.641	4942.00	2200

Note: MH_s = machine hours (in hrs/ha), MD_s = man-days (days/ha), F_f = fertilizer (kg/ha): N=Nitrogen, P = Phosphate, K = Potash; PA = production achievement (kg/ha), CE = cash expenditure (Rs / ha), MP = market price (Rs / qtl).

Table 4. Data description of water-supply, water-utilization, production-ratio and profit-ratio.

WU (i) ↓	Year			
	2003-2004	2004-2005	2005-2006	2006-2007
1	20	20	20	20
2	60	60	60	60
3	34	34	34	34
4	50	50	50	50
5	70	70	70	70
6	15	15	15	15
7	10	10	10	10
8	18	18	18	18
9	10	10	10	10
WS(PKS,KS,RS)	(116.93, 159.85, 264.62)	(119.42, 147.76, 335.92)	(100.44, 147.77, 243.49)	(100.96, 133.19, 224.10)
PDR(Rice and Wheat)	6.22	7.39	6	6.6
PR(Jute and Aus-paddy)	1.17	2.27	5.5	2

Note: WU(i)= Water-utilization (inch/ha) for the i-th crop (i=1,2,...,9), WS(.)= Water-supply (inch), PKS= Pre-kharif season, KS= Kharif season, RS= Rabi season, PDR= Production-ratio, PR= Profit-ratio.

Now, using the data Tables 1-3, the membership functions of the defined fuzzy goals can be constructed by using the expressions in (3) and (4).

The fuzzy goals appear as follows:

LAND UTILIZATION GOALS

The membership goals for land utilization in the three consecutive seasons appear as

$$\mu_1 : 8.32 - 0.027\,(l_{11} + l_{21} + l_{31}) + d_1^- - d_1^+ = 1 \qquad \text{(Pre-kharif)}$$

$$\mu_2 : 8.32 - 0.027\,(l_{21} + l_{42}) + d_2^- - d_2^+ = 1 \qquad \text{(Kharif)}$$

$$\mu_3 : 8.32 - 0.027\,(l_{21} + l_{53} + l_{63} + l_{73} + l_{83} + l_{93}) + d_3^- - d_3^+ = 1 \qquad \text{(Rabi)} \quad (6)$$

PRODUCTIVE RESOURCE GOALS

MACHINE-HOUR GOAL

$$\mu_4 : 0.0459\,l_{11} + 0.0383 l_{21} + 0.0957 l_{31} - 9 + d_4^- - d_4^+ = 1 \qquad \text{(Prekharif)}$$

$$\mu_5 : 0.0919 l_{21} + 0.0766\,l_{42} - 8.999 + d_5^- - d_5^+ = 1 \qquad \text{(Kharif)}$$

$$\mu_6 : 0.0157\, l_{21} + 0.0754\, l_{53} + 0.0189\, l_{63} + 0.0094\, l_{73} + 0.0314\, l_{83} + 0.0139\, l_{93} - 9.012 + d_6^- - d_6^+ = 1 \quad \text{(Rabi)} \quad (7)$$

MAN-POWER GOALS

$$\mu_7 : 0.0630\, l_{11} + 0.0287 l_{21} + 0.0420 l_{31} - 9.03 + d_7^- - d_7^+ = 1 \quad \text{(Prekharif)}$$

$$\mu_8 : 0.0629 l_{21} + 0.0921 l_{42} - 8.98 + d_8^- - d_8^+ = 1 \quad \text{(Kharif)}$$

$$\mu_9 : 0.0.0362\, l_{21} + 0.0530\, l_{53} + 0.0345\, l_{63} + 0.0265\, l_{73} + 0.0619\, l_{83} + 0.0133\, l_{93} - 9 + d_9^- - d_9^+ = 1$$

(Rabi) (8)

FERTILIZER REQUIREMENT GOALS

$$\mu_{10} : 0.0097\, l_{11} + 0.0388 l_{21} + 0.0116 l_{31} + 0.0116 l_{42} + 0.0252 l_{53} + 0.0233 l_{63} + 0.0194 l_{73} + 0.0388 l_{83} + 0.0039 l_{93} - 9.001 + d_{10}^- - d_{10}^+ = 1 \quad \text{(N)}$$

$$\mu_{11} : 0.0127 l_{11} + 0.0508 l_{21} + 0.0152 l_{31} + 0.0152 l_{42} + 0.0329 l_{53} + 0.00202 l_{63} + 0.0254 l_{73} + 0.0761 l_{83} + 0.0203 l_{93} - 8.89 + d_{11}^- - d_{11}^+ = 1 \quad \text{(P)}$$

$$\mu_{12} : 0.0253 l_{11} + 0.0501 l_{21} + 0.0152 l_{31} + 0.0152 l_{42} + 0.0329 l_{53} + 0.0304 l_{63} + 0.0254 l_{73} + 0.0761 l_{83} + 0.0203 l_{93} - 9 + d_{12}^- - d_{12}^+ = 1 \quad \text{(K)} \quad (9)$$

CASH EXPENDITURE GOAL

$$\mu_{13} : 11 - (0.0209 l_{11} + 0.0374 l_{21} + 0.0173 l_{31} + 0.0016 l_{42} + 0.0287 l_{53} + 0.0134 l_{63} + 0.0102 l_{73} + 0.0452 l_{83} + 0.0059 l_{93}) + d_{13}^- - d_{13}^+ = 1$$

(10)

PRODUCTION ACHIEVEMENT GOALS

$$\mu_{14} : 0.0778 l_{31} + 0.0742 l_{42} + 0.01201 l_{53} - 27.5862 + d_{14}^- - d_{14}^+ = 1 \quad \text{(Rice)}$$

$$\mu_{15} : 0.200 l_{11} - 22.4119 + d_{15}^- - d_{15}^+ = 1 \quad \text{(Jute)}$$

$$\mu_{16} : 0.1509 l_{63} - 7.7089 + d_{16}^- - d_{16}^+ = 1 \quad \text{(Wheat)}$$

$$\mu_{17} : 3.93 l_{21} - 5.9 + d_{17}^- - d_{17}^+ = 1 \quad \text{(Sugercane)} \qquad \mu_{18} : 0.1009 l_{73} - 10 + d_{18}^- - d_{18}^+ = 1 \quad \text{(Mustard)}$$

$$\mu_{19} : 0.4408 l_{83} - 9.9987 + d_{19}^- - d_{19}^+ = 1 \quad \text{(Poteto)}$$

$$\mu_{20} : 0.0704 l_{93} - 2.7476 d_{20}^- - d_{20}^+ = 1 \quad \text{(Pulses)} \quad (11)$$

PROFIT ACHIEVEMENT GOAL

$$\mu_{21} : 0.0123 l_{11} + 0.0916\, l_{21} + 0.0198 l_{31} + 0.0265 l_{42} + 0.0222 l_{53} + 0.0159\, l_{63} + 0.0078 l_{73} + 0.08364 l_{83} + 0.0135\, l_{93} - 8.9999 + d_{21}^- - d_{21}^+ = 1$$

(12)

Now, using the data in the Table 4 and following the procedure, the deterministic equivalent of the defined chance constraints can be obtained by using the expression (5).

WATER-SUPPLY CONSTRAINTS

$$20 l_{11} + 60 l_{21} + 34 l_{31} \geq 4576.99, \qquad 50 l_{42} \geq 6318.53$$

$$70 l_{53} + 15 l_{63} + 10 l_{73} + 18 l_{83} + 10 l_{93} \geq 12891.72, \quad (13)$$

where the satisfaction of probability levels are taken 0.70, 0.80, 0.90, respectively.

PRODUCTION-RATIO CONSTRAINT

The ratio of the two crops rice and wheat are considered here as the major agricultural products.

The production ratio constraint appears as:

$$(2.256 l_{31} + 2.154 l_{42} + 3.483 l_{53}) / (2.188 l_{63}) \geq 7.851, \quad (14)$$

where the satisfaction of the probability level is considered 0.90.

PROFIT-RATIO CONSTRAINT

The profit ratio for Jute and Aus-paddy in the pre-kharif season is taken into account here.

The profit-ratio constraint takes the form:

$$(100.32 l_{11}) / (969{,}45 l_{21} + 161.25 l_{31}) \geq 3.448, \quad (15)$$

where the probability of satisfaction of the profit ratio constraint is taken as 0.70.

Now, the executable FGP model under the four assigned priorities appears as:

Find $\{l_{cs} \mid c = 1,2,\ldots,9;\, s = 1,2,3\}$ so as to:

MinimizeZ= $[P_1(0.014\, d_{14}^- + 0.06\, d_{15}^- + 0.088\, d_{16}^- + 0.048\, d_{17}^- + 0.14\, d_{18}^- + 0.028\, d_{19}^- + 0.26\, d_{20}^-)$,

$P_2(0.027\, d_1^- + 0.027\, d_2^- + 0.027\, d_3^-)$, $P_3(0.012\, d_4^- + 0.025\, d_5^- + 0.014\, d_6^- + 0.2\, d_7^- + 0.09\, d_8^- + 0.06\, d_9^- + 3.7\, d_{10}^- + 1.2\, d_{11}^- + 0.65\, d_{12}^-)$, $P_4(0.00012\, d_{13}^- + 0.0001\, d_{21}^-)]$ (16)

and satisfy the membership goals in (6)-(12), subject to the systen constraints in (13) – (14).
The model solution for goal achievement is presented in the Table 5.

Table 5. Land allocation and crops - production under the proposed model.

Crop(c)	Jute	Sugarcane	Rice	Wheat	Mustard	Potato	Pulses
Land allocation	117.06	1.76	398.24	57.71	109.02	24.95	53.23
Production	304.68	123.54	824.51	126.26	94.76	126.26	38.63

The existing and allocation and production plan is presented in the Table 6.

Table 6. Existing land allocation and crops - production of the year 2006-07.

Crop(c)	Jute	Sugarcane	Rice	Wheat	Mustard	Potato	Pulses
Land allocation	130.5	1.1	250.3	46.9	79.6	5.7	39.0
Production	339.66	77.4	677.7	102.6	69.1	120.2	28.3

A comparison shows that a better cropping plan is obtained here from the view point of achieving the goal levels of crops-production on the basis of the needs and desires of the DM in the decision making environment.

5. CONCLUSION

In the framework of proposed approach, the other different parameters (fuzzy / probabilistic) can easily be incorporated without involving any computational difficulty. In future studies, the proposed approach can be extended to cropping plan problems having the fuzzy satisficing probability levels of the chance constraints in the decision situation. Finally, it is hoped that the solution concept presented here can contribute to future studies in farming and other stochastic MODM problems in the current uncertain decision making arena.

CONFLICT OF INTERESTS

None.

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